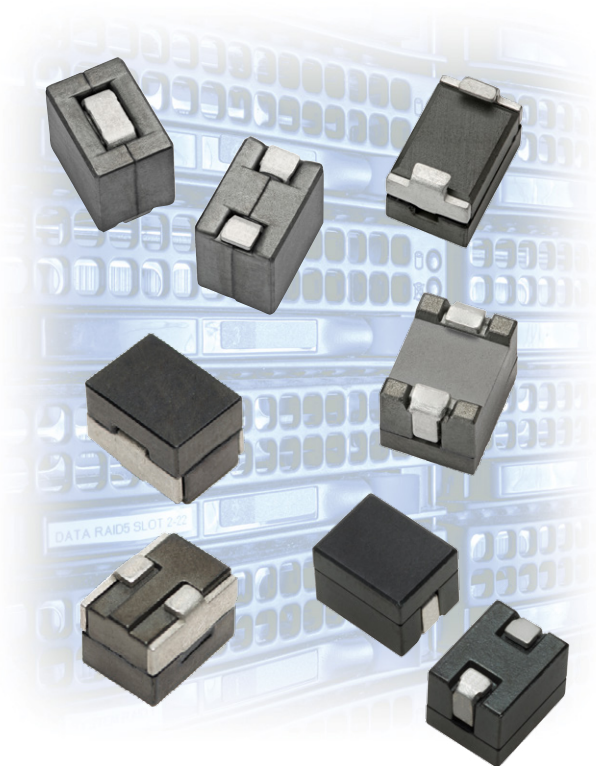


High Current Inductors for Server Power Applications



Overview

With the growing demand for servers to address ever-increasing data processing requirements, reduced energy consumption provides a major driving force to the key performance issues confronting server power supply designers. Energy efficiency is extremely important but by no means the only design consideration that needs to be addressed to select the right high current inductor for a particular application.

This white paper discusses the key performance targets of high current inductors for use in Multi-phase and Vcore regulators, Voltage Regulator Modules (VRMs), Point-of-Load, and memory power applications. It also highlights the key electrical and mechanical parameters that engineers should be addressing to select the optimum product. Finally, the paper summarizes the Eaton high current product line capabilities and provide access to additional specifications and sample information.

Today's Server Power Supply Challenges

With efficiency requirements dictated by regulations from governments around the world as well as the need to reduce the carbon footprint of their products, server power supply designers are under extreme pressure to maximize the highest efficiency possible. Improving efficiency and reducing power losses in server power systems are also required for strictly competitive reasons.

The high current inductor is among the components that can deliver improved efficiency once the design is optimized. In addition to the higher current, higher operating temperature and higher frequency requirements needed to obtain higher efficiency other important selection criteria for power inductors include:

- Smaller size - reduces circuit layout area
- Tighter tolerances - assures consistent circuit performance
- Very low DC Resistance (DCR) - increases power efficiency
- Multi-phase Integration - reduces PCB footprint and component count

Background and Definition of Terms

Eaton's Electronics Division is a leading supplier of high current and other inductors for DC-DC power conversion and switch-mode power supply applications requiring high frequency operation. Eaton designs and develops inductor products to achieve high efficiency using high frequency ferrite material to satisfy light load and full load efficiency requirements for VR12.5 and VR13 applications. Eaton's products designed specifically for these applications are widely used in several IC reference designs.

Key parameters for assessing an inductor's performance include:

- DC resistance (DCR)
- Open circuit inductance (OCL)
- Full load inductance (FLL)
- Peak saturation current (I_{sat}) vs. temperature
- Heat effect current (I_{rms})
- Magnetic saturation flux density, in Gauss (B_{sat})
- K-factor used to determine B_p -p (in Gauss) for core loss
- AC resistance (ACR).

It should be clear from the foregoing, that optimizing the selection of high-current inductors requires evaluation of a wide assortment of physical and electrical variables. While all customers desire higher efficiency and lower losses, all customer applications are not the same. Thermal management, space constraints and other aspects make the optimal choice of a power inductor a nontrivial task. At the root of this process for Eaton's inductor designers is the selection of the core material.

Core Selection and Product Tradeoffs

For high current, the two most common inductor core materials are ferrite and powder. Selection of the best core material occurs based on inductance, tolerance of the inductance, current rating, saturation current, shielded or non-shielded, DCR, Q at certain frequencies, self-resonant frequency, operating temperature, mounting type and package dimensions required for the application. It should be noted that both electrical and physical attributes are important in this selection process.

Understanding application trade-offs is key to device selection and hence material selection for inductor designers. Powder core devices exhibit better temperature stability and B_{sat} . So, in some cases for higher power density, a powder core may be preferred but this choice sacrifices efficiency. Ferrite is the most efficient material used in high power inductors. High efficiency inductors are made by developing inductor core materials that produce high saturation flux density with low core loss for operation from 300 kHz to 1.0 MHz and higher. However, higher current operation requires higher saturation flux density (B_{sat}) materials. Higher ripple current and frequencies result in higher core losses. Eaton's inductor designers understand these materials and performance trade-offs well to maximize overall device performance.

Ferrite advantages in Server Power applications, compared with powder core, are: 1) Higher operating frequency (3MHz now, up to 10MHz coming); 2) Much lower core loss for a given frequency and AC flux density resulting in higher efficiency; and 3) Higher initial permeability (μ_i), up to 3300 (10-20 times powder material), to achieve higher OCL.

An important comparison that system designers find on a specific data sheet is the change in core loss versus increasing B_p -p. In Figure 1, core losses increase with increasing B_p -p and with increasing frequencies. As demonstrated in this example, as an inductor's total losses increase the devices temperature will also increase. Increasing temperature also increases the DCR value.

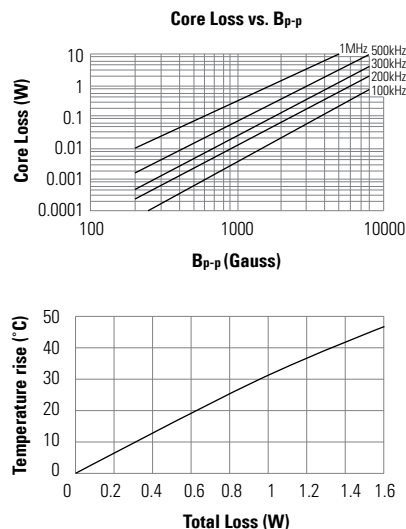


Figure 1. a) Core loss vs B_p -p with increasing frequencies.
b) Temperature vs. total loss.

Choosing the Eaton Solution

Eaton's magnetics product line offers a wide selection of inductors with different inductance and current values and advanced packaging to meet today's demand for high current power supplies for the server and memory industry. The success of these products is based on the continuous investment and resulting outstanding capabilities of design, manufacturing and test facilities within Eaton's global group. The facilities have a combination of certifications and recognitions which include:

- ISO9001 (Quality System): A quality management system focused on meeting customer expectations and delivering customer satisfaction with the purpose of giving attention to the customer.
- TS16949 (Quality System): A quality management system focused on meeting the specific and rigorous requirements of the automotive industry
- ISO17025 (Testing Facility): It is the single most important standard for calibration and testing laboratories around the world. Laboratories that are accredited to this international standard have demonstrated that they are technically competent and able to produce precise and accurate test and/or calibration data.

In addition to those products that have established Eaton's product line as an industry leader, our research and development efforts with leading IC manufacturers and OEM system companies have created new and exciting solutions to address industry trends and the need for ever-increasing efficiency.

Reducing PCB Footprint

The electronics industry's need for high efficiency and high power density in a smaller area is driving inductor suppliers to reduce the high current inductor's form factor overall size. To meet this need, factors that impact the inductor's design include:

- Higher switching frequency
- Better core material
- Higher operating frequency
- Higher Bsat
- Lower core loss
- Wider operating temperature range

Eaton addresses the latest design criteria with several new inductors to allow designers achieve an optimum solution.

Addressing Tighter Tolerances

Although the inductor is rarely used in a current sense application, tight DCR tolerance remains a desired product feature. Tighter DCR and OCL tolerances provide designers with important benefits in assuring circuit stability and consistent performance from lot-to-lot in volume manufacturing. Achieving this level of precision is the result of the combination of several factors:

- Consistent manufacturing processes
- Quality raw material for both core and winding
- Optimum design for manufacturing
- Precise testing system

All of these aspects are addressed in Eaton's industry-leading approach to high-power inductor design and manufacturing.

A Process of Collaboration

For Eaton, an application-specific approach allows the selection of the right inductor for each application. This can involve modifying an existing design to fit a customer's needs. While this is not uncommon in the inductor business, the differentiation occurs with the experience and expertise of the inductor supplier.

For new product design, or a simple derivative of an existing product, with the customer's input regarding the application specifics (including AC current, DC current, operating frequency, operating temperature and more) and an interactive dialog, our design experts select the appropriate product or core material to meet the application operating requirements. The interactive process with proposed prototypes and testing in the customer's circuit and modification, if necessary, occurs until the highest efficiency/optimized solution is achieved.

Knowing whether the core material and other design factors will properly address a specific application is part of the expertise derived from Eaton's long history and breadth of products for high-frequency power supply applications.

Modeling

Simulation is one of the many tools employed by our design experts. As shown in Figure 2, the modeling of the gap or bulk materials identifies innovative approaches for advanced inductor designs to solve the industry's need for higher efficiency.

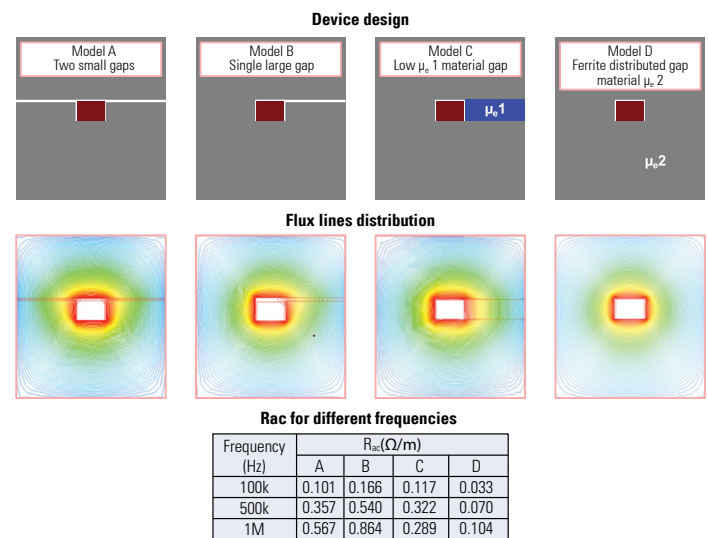


Figure 2. Modeling is one of Eaton's Electronics Division tools for providing higher efficiency inductors.

Extensive Testing Capabilities

Mechanical and thermal shock, vibration, and solder reflow testing are among the in-house capabilities that Eaton has specifically for developing and qualifying new inductors and new inductor technologies. This test capability is possibly the most extensive in the inductor industry, with the highest ISO (ISO17025) qualifications.

Products to Meet Customer Requirements

One of Eaton's most successful products is the Ferrite-based Flat-Pac series. Eaton has developed several Flat-Pac (FP) inductors to address today's server and memory power supply requirements. The FP product line uses ferrite cores and offers a large selection of space-saving package types with different inductance and current values to meet OEM high power requirements. This section identifies the newest products, shows the packaging and device capabilities and discusses their role in helping customers optimize the selection of the right product.

FP Dual Inductor

This dual-mode inductor offers manufacturers space saving and reduced manufacturing costs. Several form factors are provided in surface mount, both vertical and horizontal orientation, and in through-hole. The dual design benefits include PCB area space saving and reduction in manufacturing cost by reducing pick-and-place time. See Figure 3 for the offering overview.

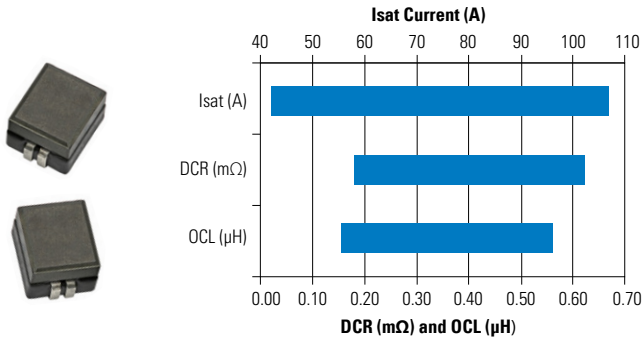


Figure 3. FP Dual inductor provides designers options.

FP Small Size

Reducing the size of the inductor (item 1, above) to extremely small (a few millimeters on each side) dimension is desired, even as the saturation current per phase is increasing. This requirement demands high flux density material with lower core loss at high frequencies.

To satisfy the industry's requirement for smaller size, Eaton has developed a ferrite-based series of 4 mm by 4-mm and 5 mm by 5-mm inductors with varying height. The small size allows designers to include more content/new features on the PCB and the inductor's low fringing flux enables a high-density layout. The height ranges from 3 mm to 6.6 mm. See Figure 4 for other product capabilities.

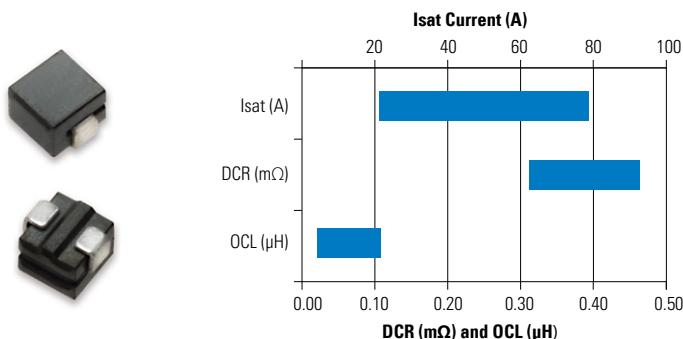


Figure 4. FP Small size occupies as little as 4 mm by 4 mm of PCB space.

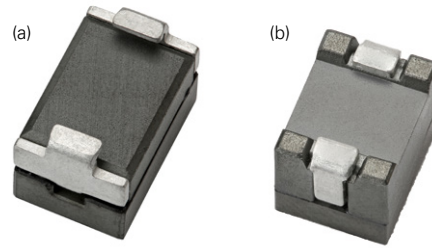


Figure 5. Two techniques to get more space under the inductor: (a) an elevated leadform and (b) a deeper mold channel.

FP Open Bottom Inductor

Folding the leads under the inductor (Figure 5 (a)) increases the gap from 0.2 to 0.3 mm. This initially allowed mounting the inductor over traces on the PCB. The industry followed Eaton's lead and adopted this design approach. The deep mold channel (Figure 5 (b)) is another innovative Eaton solution that achieves a gap of as much as 0.8 mm.

In addition to mounting the power stage under the inductor, which is increasingly popular with point of load (POL) applications, other options include a chip resistor or chip capacitor placed under the inductor.

The actual space required for the cutout depends on the customer application and Eaton has been able to modify this design for this purpose. Figure 6 shows the capabilities of the industry's newest package.

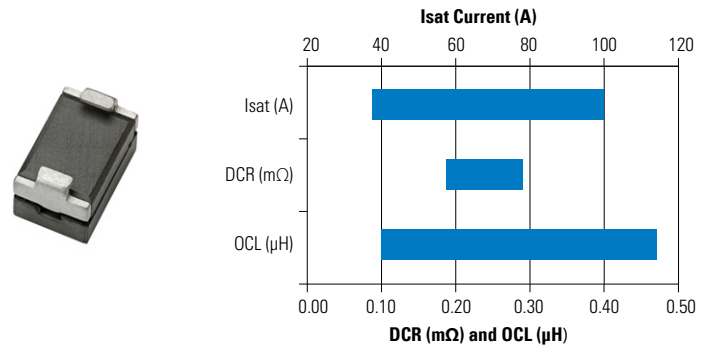


Figure 6. The innovative FP Bottom gap design allows running copper traces or mounting a variety of components under the inductor to save PCB space.

FP Vertical

Increasing functionality typically requires increased power. Increasing the number of phases is one approach to obtain more power. However, to fit in the same space, the inductor width has to be between 6 to 7mm. Shown in Figure 7, Eaton's solution is a narrow-width inductor with increased height - the FP Vertical package. In initial products, the inductance ranges from 120 nH to 320 nH, current ranges from 34A to 77A at 100°C and the height goes up to 14 mm. These vertically orientated FP inductor designs provide the incremental power required with a form factor that reduces PCB area.

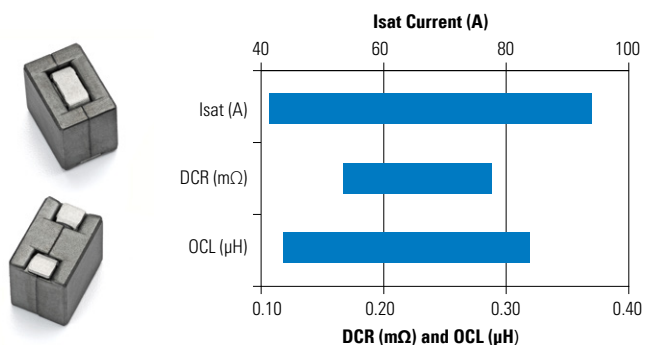


Figure 7. FP Vertical packaging addresses the industry's need for more power while reducing the PCB space consumed.

FP Low DCR

Eaton's low DCR products address the need for improved efficiency. These new inductor designs have a DCR as low as 0.125mΩ. With an understanding of customer performance requirements, these low DCR inductors provide another option to increase system efficiency in a small package.

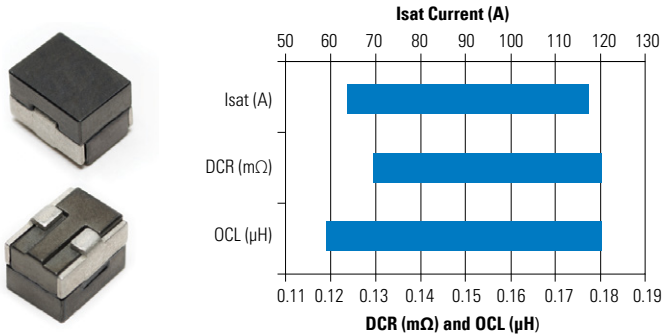


Figure 8. FP Low DCR design provides another solution for higher efficiency.

FP Ultra low DCR

Eaton's new ultra low DCR Flat Pac products have been introduced recently to improve the overall efficiency of the power stage. The low DCR is achieved by adding extra copper on the side of the inductor's leads as illustrated in Figure 9. In current offerings, the inductance ranges from 50 nH to 330 nH and current ranges from 152 to 20 Amps. The DCR of this product line can reach as low as 0.05 mΩ. This is the lowest DCR in this class of inductor and lowest in the industry.

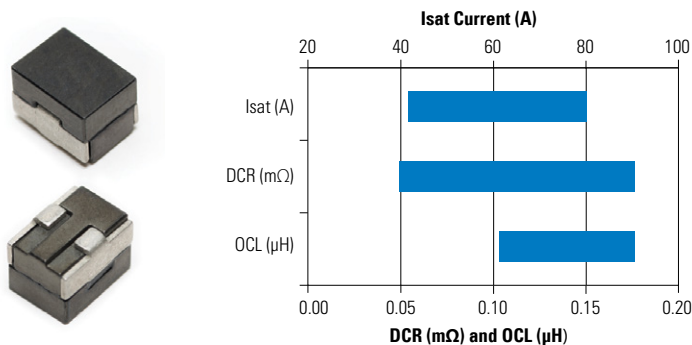


Figure 9. FP Ultra low DCR products provide the industry's lowest DCR values.

The Roadmap to Greater Efficiency

To address the increasing need for greater system efficiency, higher power density and other current trends, Eaton's inductor experts have developed and released the aforementioned new products. These new products are being rapidly adopted and becoming the next generation of standard products in the marketplace.

Additional products that designers can expect to see in the near future include: swing choke, hybrid ferrite with composite magnetic materials, ultra-low DCR inductors, and more. While each addresses a different design issue and many are covered by patents, these inductors all target greater system efficiency in high-current power applications.

Optimizing Your Inductor Selection

A major task for a system design engineer is system design validation. Device selection is an important part of this step and sometimes system engineers will compare inductors from different manufacturers to determine which part to choose. Although comparison testing is good engineering practice, it can lead to misleading results. This is because each product family is designed and optimized for a targeted application, i.e. operating frequency range, ripple current, and/or DC current.

Each product family incorporates voice of the customer requirements such as inductance versus DC current at different temperatures, core loss at application conditions, DC resistance requirements, temperature rise versus total loss and estimated total loss at application conditions. Typically there are performance trade-offs amongst these requirements resulting in different products utilizing different materials and/or processes, each optimized for its application. Therefore, comparing 150 μH parts of similar size from two different manufacturers, for example, may not result in the correct conclusion. At Eaton, we strongly recommend discussing your application with our Field Application Engineers and Internal Application and Design teams to ensure you are selecting the best product for your application.

Satisfying the server power requirements for increased efficiency, higher power and reduced footprint and other critical design parameters requires exceptional design and manufacturing expertise for power inductor suppliers. In addition to the obvious design criteria of AC current, DC current, frequency and temperature that drive core material and other inductor design aspects, there are subtle applications issues that must be addressed. Many times system designers are not fully aware of these issues and are not asked the right questions.

Based on the numerous times that Eaton has worked with unusual design requirements, the iterative, interactive process used by Eaton's inductor experts brings out these design aspects to ensure the proper, optimized application-specific inductor solution.

Please contact Eaton with your design requirements.

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