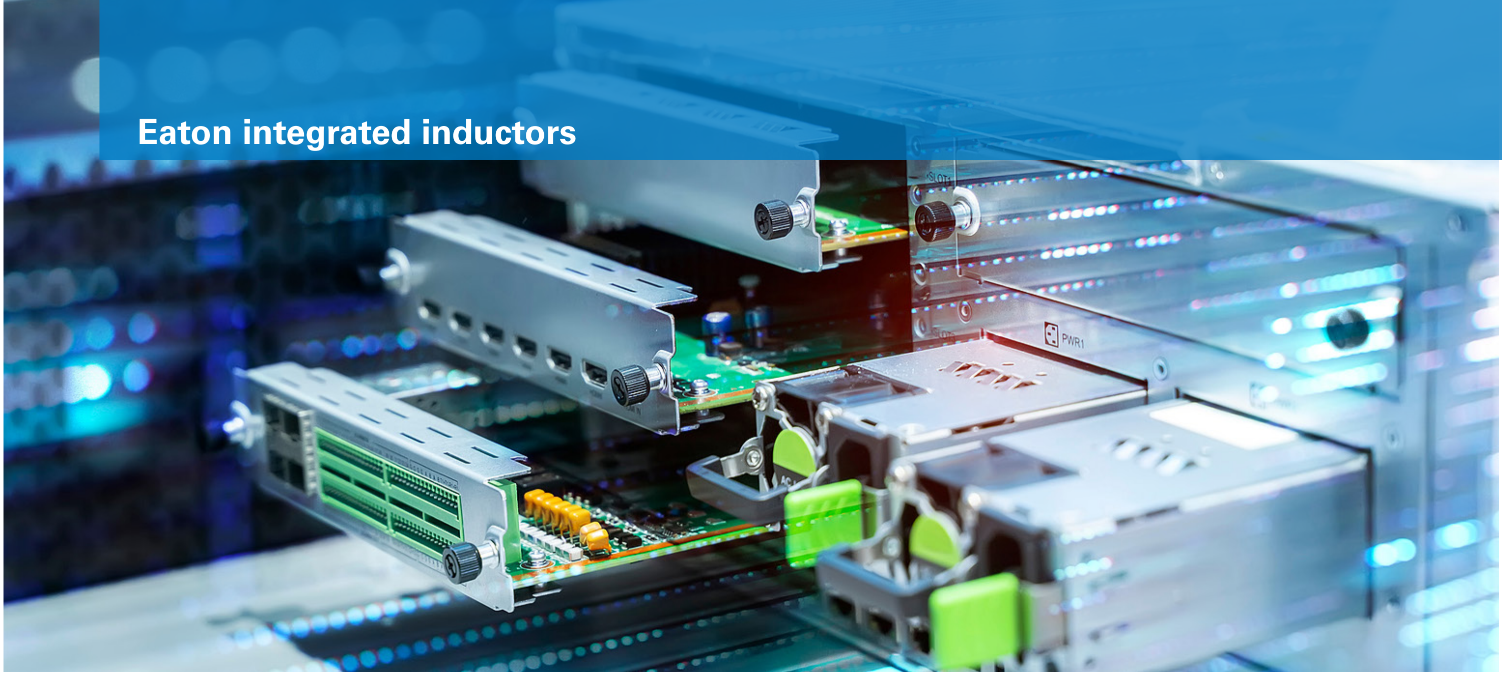
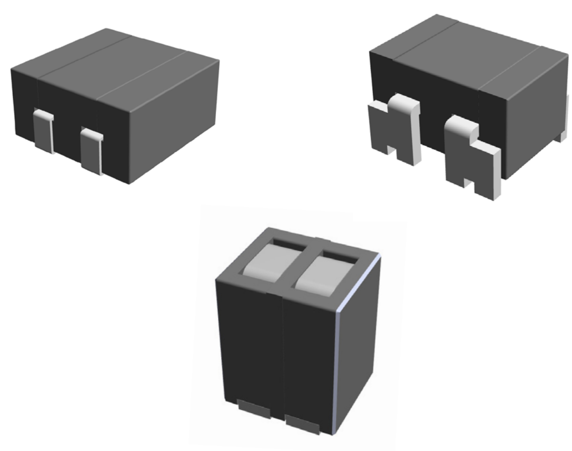
Eaton integrated inductors



Integrated inductors empower multi-phase buck converters for computing



Introduction

The latest telecommunications and computing (datacenter, cloud, etc.) applications are requiring ever more powerful and high performance power supplies. In the case of medium and low power supplies (below 40 amps), a single-phase power supply architecture is adequate. However, with the latest processors, field programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), and cloud computing systems, higher levels of power and greater performance are in demand.

In order to achieve these new thresholds of power, multiphase power supply architectures are the natural choice, but require much more complex design strategies. Importantly, the increased complexity falls largely on the magnetic components of the power supplies. Fortunately, innovations with integrated inductors, both coupled and non-coupled, have arisen that address these challenges and enable a new standard in high performance power supplies for modern use cases.

Multiphase versus single-phase power architecture

Achieving optimal efficiency in a power supply design is among the top criteria for information infrastructure power systems. Efficiency is so important as the operational costs of these systems is largely electrical energy, and additional power loss adds to the cost of services. Keeping the cost of services as low as possible improves a system’s competitiveness in an increasingly challenging marketplace. Moreover, greater levels of efficiency reduces the excess thermal energy produced from power loss within components, which allows for smaller, lower cost, less complex, and more reliable thermal management systems to be used.

This is the major argument for multiphase power supplies over single-phase power supplies. This is a result of the necessity to increase either voltage or current to deliver greater power to a single phase power supply. Increasing the voltage of a power supply line reduces the current needed to meet a given power requirement with practical limitations to how high a voltage can be delivered without specialized high voltage cabling and design. Relying on a higher current power line means that there will be greater resistive power losses from the supply line to the power supply device, as well as greater losses within the internal interconnect and components of the power supply device. These losses reduce the overall power supply efficiency compared to multiple lower current power supplies with multiphase power line input.

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The tradeoff with using a multiphase power supply architecture is the increased complexity of the device, in essence having a separate power supply for each power line phase and the necessary circuitry to combine the power supply outputs. However, multiphase power supplies can be designed to be much more efficient than single-phase power supplies at higher power levels, and the architecture also allows for more operational flexibility. Such flexibility could also include turning off some of the phases when they aren't needed to deliver the required power, and redundancy if failures occur in certain portions of the power supply system.

Additionally, multiphase power supplies typically present reduced input and output capacitance compared to single phase power supplies. These power supplies also tend to exhibit a better response to transient loads. Thermal energy is also better distributed in multiphase power supplies, which reduces the component and board temperatures. This could allow for more component and design options that lower cost and lead to smaller form factor solutions.

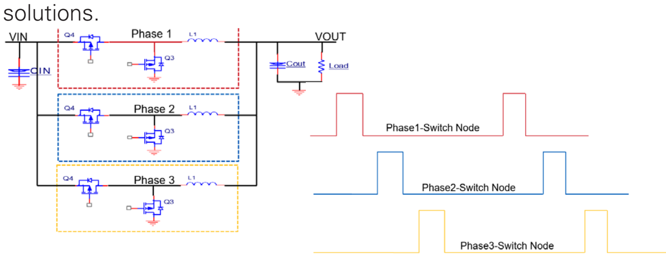

Figure 1: A multiphase buck converter can more efficiently handle higher power than a single-phase buck converter of equivalent power output specification.

Integrated inductors

Power supply form factor is a growing concern for many modern electronic systems, especially for telecommunications and computing, which are shrinking in size while simultaneously expected to deliver better performance than previous solutions. These physical constraints require innovations that reduce the overall size and footprint of power supply components, including magnetic components that are usually some of the largest components in a power supply design. Following modern trends, recent advances have resulted in high performance, integrated inductors. These integrated inductors have been realized in compact packages with several inductors in either coupled or non-coupled configurations. The result is inductors that enable power supply designs that are even more efficient and can deliver higher power densities.

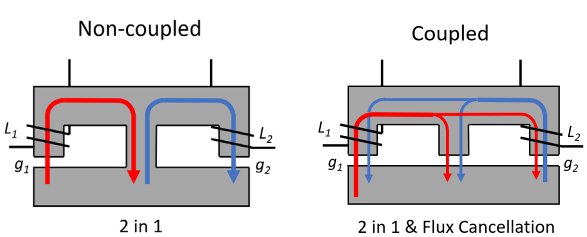

Figure 2: Discrete inductors require additional spacing between components compared to integrated inductors which also use common ferrites for greater space savings.

Non-coupled integrated inductors

Non-coupled integrated inductors are much like discrete inductors in how they behave, but are much more compact. With non-coupled integrated inductors the spacing between two discrete inductors is eliminated in such a way that both inductors still operate independently. This means that the normal distance needed to mitigate coupling between two discrete inductors isn't necessary for non-coupled integrated inductors, neither is the necessary minimum spacing for PCB manufacturing and pick-and-place machines. More compact inductor spacing allows for much higher power density, which means either a smaller power supply section or higher power capability in the same footprint.

Unlike discrete inductors, non-coupled integrated inductors do share a common center post. This allows for the DC flux, flux density, from an impulse to be canceled, where discrete inductors would produce multiple responses to a shared impulse at their inputs. There are non-coupled integrated inductors currently that combine as many as 4 inductors in a single package.

Coupled integrated inductors

Coupled integrated inductors share all of the benefits of non-coupled integrated inductors, with added value derived from the enhanced current ripple cancellation. The ripple current cancellation with coupled inductors affects each element in a multiphase buck converter circuit: MOSFETS, PCB traces, and inductor windings. Greater peak-to-peak ripple current cancellation results in lower conduction and switching losses throughout the circuit, and in this way, directly impacts efficiency. Enhanced ripple current cancellation can be achieved with coupled inductors versus non-coupled inductors given the same value of inductance.

The direct benefits of this are that smaller inductor values of coupled inductors can be used to reach a maximum ripple current level compared to non-coupled inductors. Lower inductance values for the same peak-to-peak current ripple current also translates to better transient performance. With better transient performance smaller output capacitors may be used, or these may even be eliminated if the transient performance is enhanced adequately by using lower inductance value coupled inductors. In this case the "faster" slew rate of smaller inductance value coupled inductors may be addressed by ceramic capacitors, instead of larger and more expensive ESR and ESL capacitors commonly used due to the enhanced transient performance benefits.

Coupled integrated inductors can also intrinsically be made smaller than discrete non-coupled inductors, as the negative coupling exhibited by coupled inductors leads to canceling of the mutual fluxes when all phases share the current equally. This operation is typical to multiphase converter applications, especially those that operate as current-mode controllers. With only leakage flux stored in the coupled inductors, they can be fabricated in much smaller footprints than discrete inductors.

Practical applications of integrated inductors

Though coupled integrated inductors demonstrate additional valuable features compared to non-coupled integrated inductors, there are some applications that aren't able to take advantage of coupled inductors. Hence, integrated non-coupled inductors can be a key space saving and performance enhancing solution versus discrete non-coupled inductors.

Non-coupled inductors in integrated power modules (IPMs)

In many of the latest telecommunication and computing devices (e.g., graphics processing units (GPUs), central processing units (CPUs), FPGAs, and tensor processing units (TPUs)), power systems are being allocated less space while power supply performance requirements and complexities are increasing. As opposed to typical approaches relied upon in the past, board designers are beginning to use integrated power modules (IPMs) that are compact and provide the necessary supply rails for their designs with minimal need for nuanced power design.

A main driving factor on the size and performance of IPMs is the inductor technology, which has undergone many innovations to enable this new application. One such innovation is the use of 2-in-1 non-coupled integrated inductors to reduce the size and bill-of-materials (BOM) for complex and compact IPMs.

Another innovation is the use of bottom sunken integrated inductors in which the power stage may be placed underneath the inductor to further reduce the overall footprint of the IPM. With a typical inductor the power ICs and affiliated passive are placed next to the device. However, bottom sunken integrated inductors allow for many of the space consuming components of the power stage to be placed beneath the inductor, which has the added benefit of reducing the conduction loss as the conduction path from power ICs to the inductor is much shorter. There is also the potential benefit that some designs may experience less signal emissions as the high power and fast switching power signals traveling in the power stage may be somewhat contained or limited by the shorter traces and non-exposed traces typical to IPMs with power stages placed beneath a bottom sunken inductor.

Conclusion

Integrating inductors into smaller form factor packages with unique design benefits can overcome many of the modern power supply and integrated power module challenges seen in modern telecommunications and computing applications. In cases where coupled integrated inductors aren’t viable, non-coupled integrated inductors can provide the performance and compact footprint needed to realize competitive power system designs that need to be reliable, high performance, and fit in an ever shrinking footprint.

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