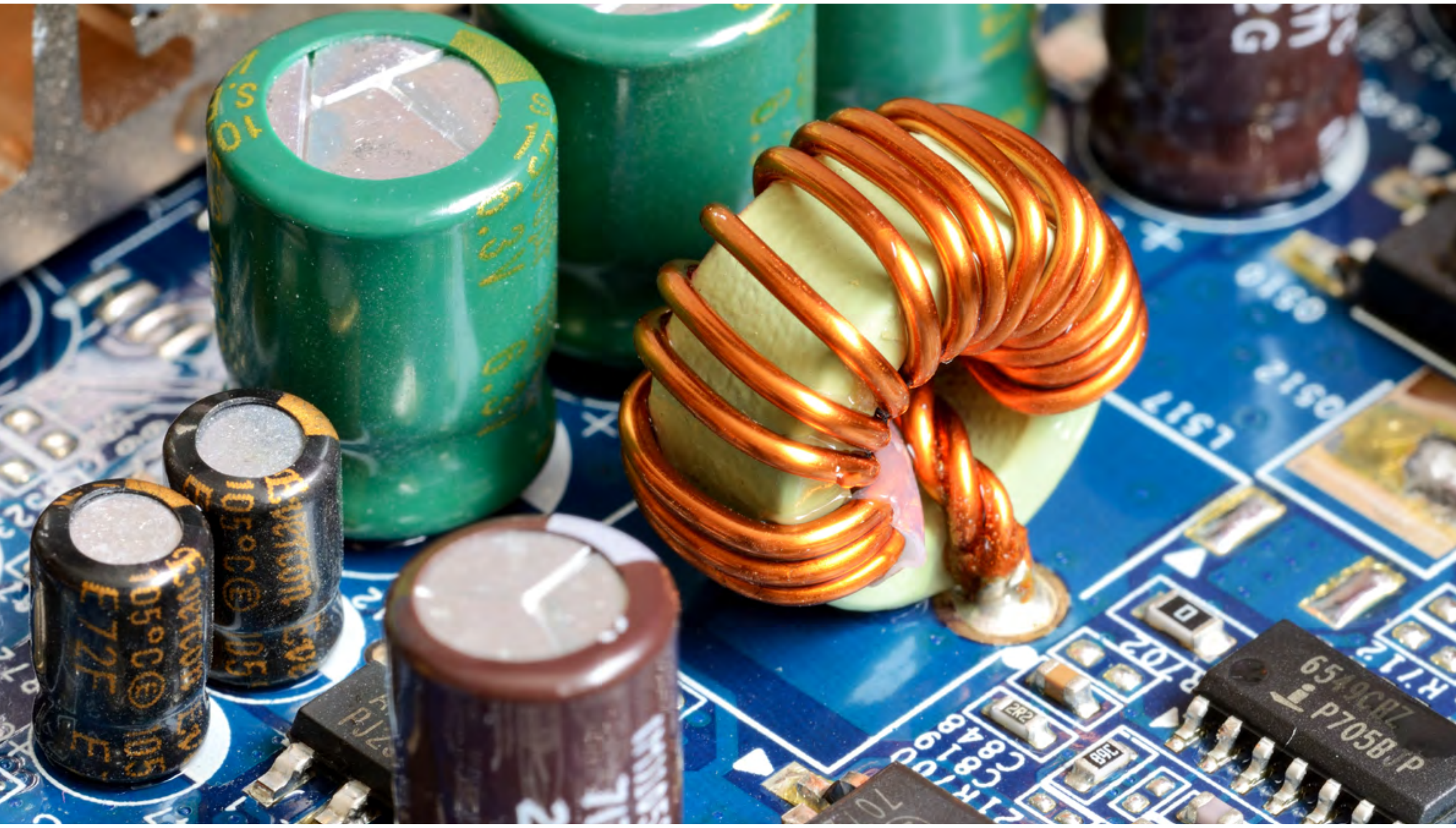

WHAT ARE THE DIFFERENT TYPES OF INDUCTORS?

Introduction

Inductors are present in almost every power electronics circuit for electrical energy conversion. They are dynamic energy storage devices and, as such, are employed to provide stored energy between different operating modes in a circuit. Additionally, they can also act as filters for switched current waveforms and can be used to provide transient current limiting in snubber switches.

In general, the main inductor parameters typically considered when selecting an inductor are:

- Rated inductance Lr
- Rated current Ir
- Rated frequency *f*r
- Typical DC resistance R_{typ}
- Rated voltage Vr
- Test voltage V_{test}
- Total losses
- Temperature rise ΔT
- Rated temperature Tr

Selecting the optimal high-frequency inductor requires one to focus on high amplitude currents and minimize the AC losses in order to reach a reasonable compromise. In addition to current and AC losses several factors to keep in mind as someone begins inductor selection process include:

- Switching frequency
- Output power requirements
- Temperature rise/Environment
- Inductor application and circuit topology
- Construction and physical sizes
- Mechanical mounting methods
- Core and winding materials
- Price

As a global leader in design and production of custom magnetics, Agile Magnetics Inc (a Standex Electronics company) can help you weigh the design considerations above. As a high-tech company, we have the tools to help design and verify with FEA that your design is the right size for your application.

What Are the Types of Inductors?

There are many different types of inductors available based on the specific materials and construction methods on the inductor. Each one has certain benefits and trade-offs that must be considered when tailoring to the specific application intended. Our engineers at Agile (a Standex Electronics Company) are highly experienced and willing to help you navigate the design and selection process when you are seeking custom inductors for your next project.

Material Type: Air Core Inductors

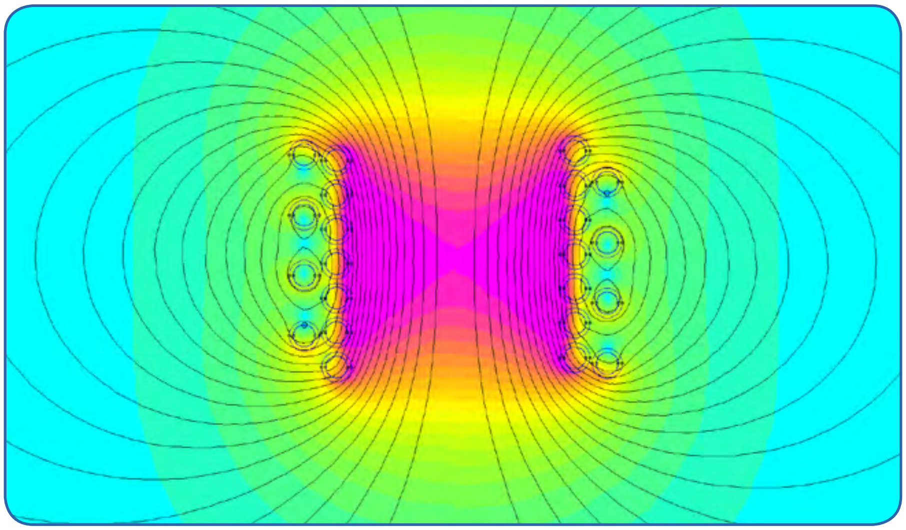

Figure 1. 2D distribution of air core inductor magnetic field

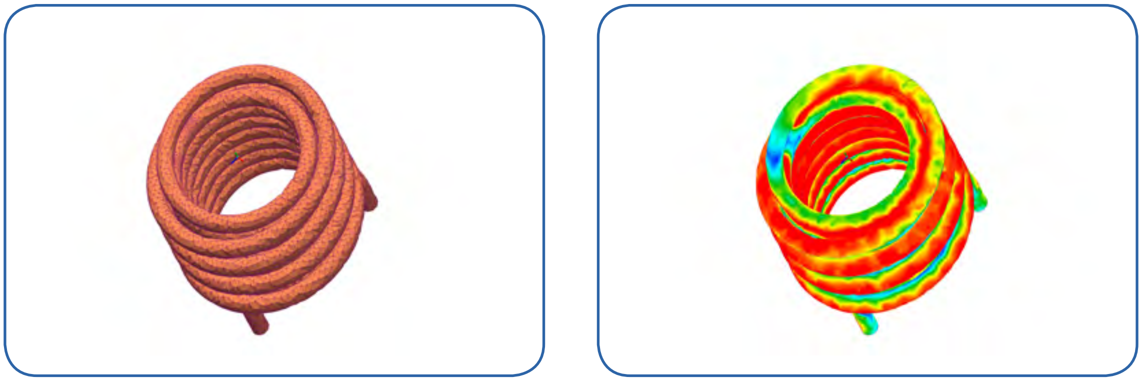

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Figure 2. High frequency 400kHz air core Litz-wire inductor:

a) FEA model; b) Distribution of current density

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As the name suggests, an "Air core" inductor leverages air as a medium to store the magnetic energy rather than utilizing a magnetic material such as ferrite. In some instances, inductors with an air core can be wound so the coil will be able to support itself; in others, a ceramic or insulated material may be employed to provide structure.

Because air core inductors lack a ferromagnetic core, numerous advantages for high frequency switching applications exist such as high linearity, no core saturation, and no iron losses. However, the absence of a ferromagnetic core limits the L-I product, making it more suitable for low power applications such as commodity electronic products, computer devices, communication equipment, and other consumer goods.

Material Type: Iron Core Inductors

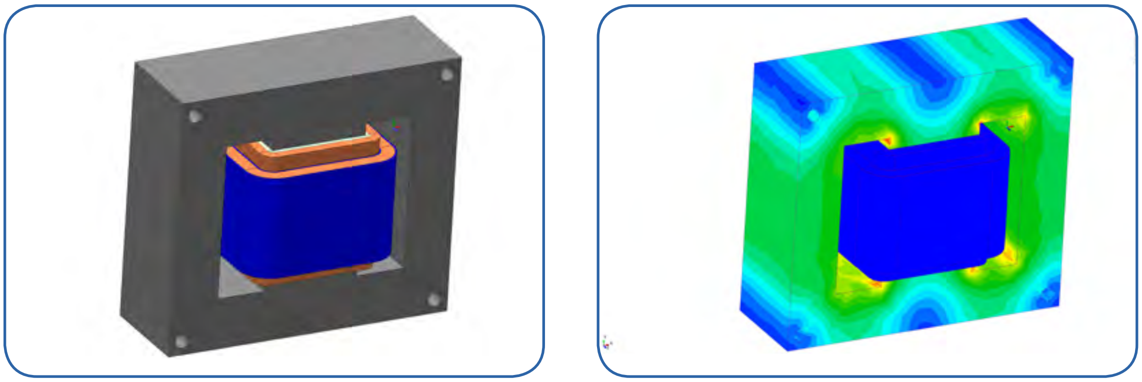

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Figure 3. Iron core inductor:

a) FEA model; b) Distribution of magnetic flux density

In order to realize higher inductance values, a different core must be used with different material properties. Iron core inductors are better at storing magnetic energy than air core inductors as the iron material helps amplify the inductor's magnetic field. This in turn allows an inductor with an iron core to store more magnetic energy compared to an inductor with an air core with the same number of turns.

Although an iron core does increase inductance magnitude, the iron material exhibits high core loss at high frequency. For this reason, iron core inductors are typically used in applications that require higher power levels but low frequencies such as audio equipment, power conditioning, and inverter systems.

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Material Type: Ferrite Core Inductors

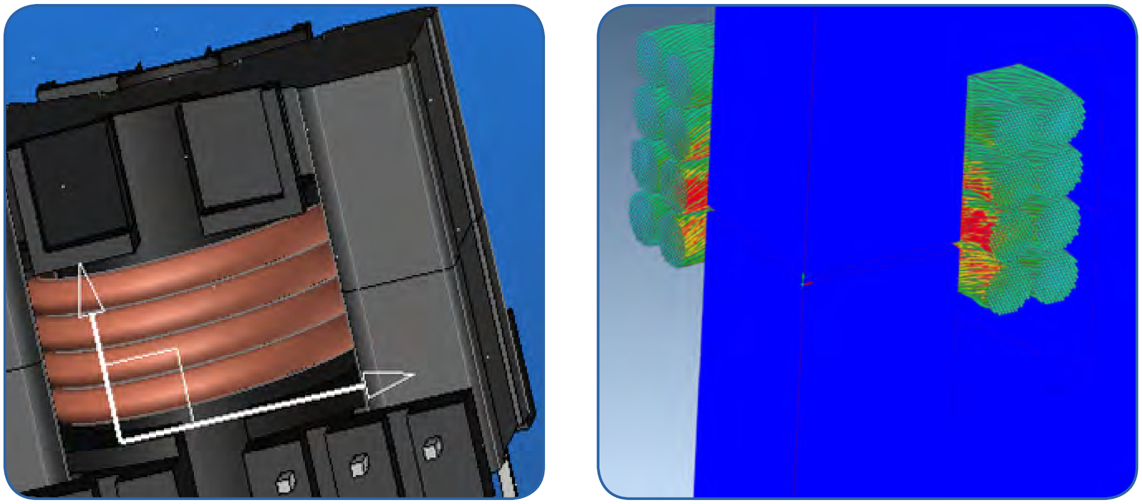

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Figure 4. High frequency inductor with Litz-wire coil wound on bobbin:

a) FEA model of winding with twisted strands; b) Distribution of current density

In an increasing number of applications, power electronic systems require ever greater power densities in smaller and smaller package sizes. In most cases, this goal is realized by optimizing the underlying power magnetics to operate at high frequencies, thus shrinking the size of the magnetic components. However, high frequency operation comes with its own unique tradeoffs, as higher frequencies often lead to increased eddy current losses due to skin and proximity effects.

Ferrites are an ideal core material for high frequency power inductors, as they help mitigate eddy current losses associated with other core materials such as iron. As long as the ferrite core is held below a certain temperature known as the Curie temperature, the core will exhibit good magnetic properties with a high intrinsic resistivity. This allows ferrite cores to be used without additional laminating material, as would be required for non-ferrite cores in high frequency applications.

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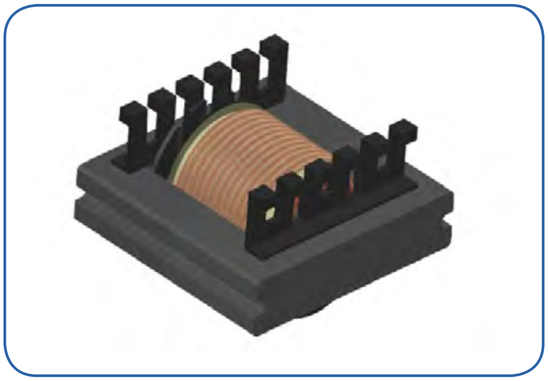
Construction Type: Bobbin-based Inductors



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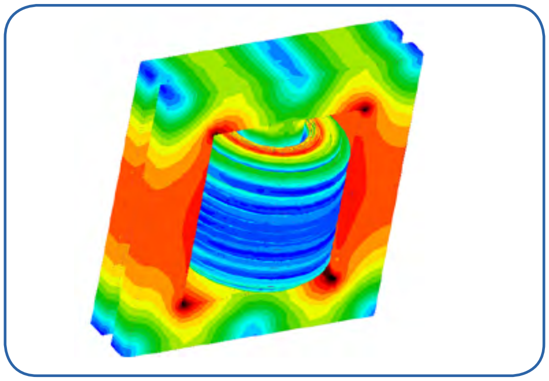

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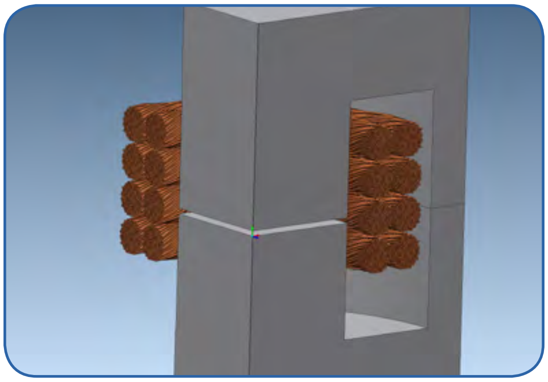
Figure 5. Bobbin based high frequency inductor:

a) 3D CAD model; b) Distribution of magnetic flux density

Bobbins are a construction technique that wind wire around a core. Bobbins can be used in a variety of inductors that have different materials, such as a laminated steel core or a tape wound cut core. Sometimes, there isn't a core, in which case it's an air core inductor.

Construction Type: Inductors with Litz-wire coils



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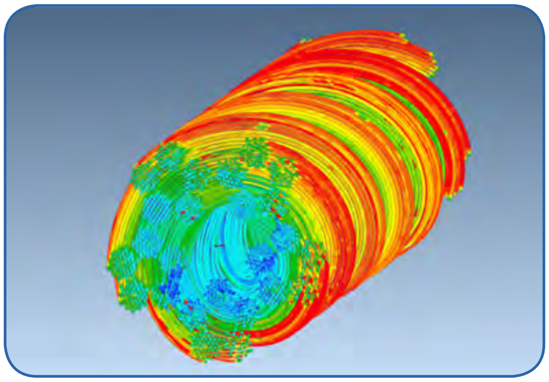

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Figure 6. High frequency power inductor with Litz-wire coil:

a) 3D FEA model with real twisted Litz-wire strands;

b) Current density distribution in Litz wite strands, caused by skin and proximity effects

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In high frequency applications, AC losses often become an issue that must be addressed for the component to perform as intended. To decrease AC losses, two types of conductor materials can be used: Litz-wire and copper foil. Both materials have associated complexities that require in-depth knowledge to help navigate. As a result, Agile has invested in design tools that are available to help optimize your design such as professional 2D/3D FEA software. Using our own proprietary methodology for Litz-wire modeling, we can predict AC losses with high accuracy.

Construction Type: Toroidal Core Inductors

a b

Figure 7. High frequency toroidal core inductor:

a) 3D FEA model; b) Temperature field distribution

Due to the symmetry of its magnetic circuit, toroidal core inductors offer a low leakage flux as its main advantage. As a consequence, this a closed-loop core has a higher magnetic field and thus higher inductance and Q factor than an inductor of the same value with a straight core and solenoid coils. Toroidal inductors can therefore carry more current and radiate less electromagnetic interference (EMI). Additionally, they are more compact than other shaped cores inductors because they are made of fewer materials, resulting in a significantly lighter weight design.

Toroidal inductors are used in medical equipment, telecommunication technique, industrial controls, ballasts, electronic clutches, electronic brakes, and in the aerospace & nuclear fields. Other applications include noise filtering for switching regulators, power supplies, power amplifiers, and triac control circuits.

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Construction Type: Gapped core inductors

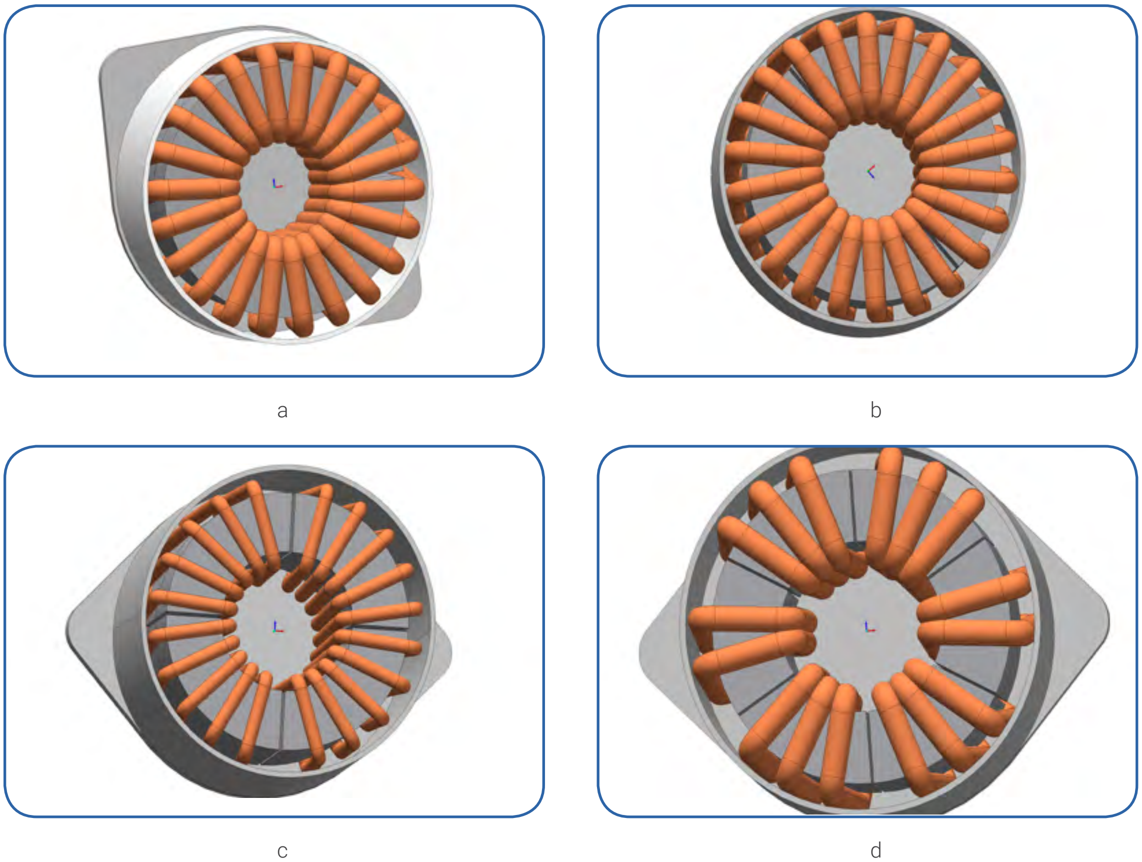

Figure 8. High frequency gapped core inductor with:

a) Single air gap; b, c, d) Distributed air gap

To prevent core saturation of power inductors, air gaps can be utilized on the core (Figure 8). Although this construction method allows for better core performance, it is important to keep in mind that the air gap creates a large leakage field near the gap. As a result, it is undesirable to place wire close to the core gap, because the high fringing flux density in this region can lead to excessive eddy current losses. Taking this into account, we at Agile Magnetics Inc. use FEA software for prediction of air gap losses and fully optimize the inductor winding design to decrease these losses.

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Construction Type: Cut core inductors

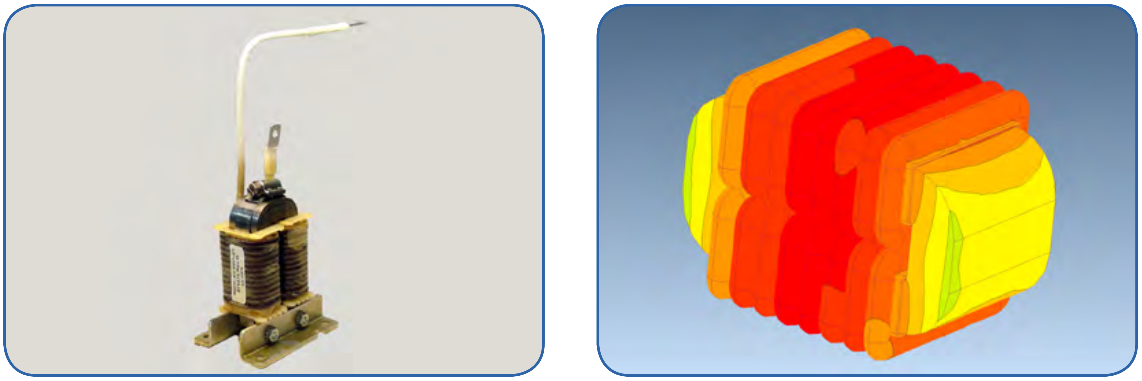

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Figure 9. High frequency cut core inductor:

a) 3D FEA model; b) Temperature field distribution

Advanced military technologies require equally advanced components. Magnetic components, such as high performance cut core inductors, are integral to the functionality of many of these technologies: they allow field radios to pick up signals clearly, GPS systems to track movement accurately, and missile defence systems to precisely target incoming projectiles.

Cut core inductors, as their name implies, feature a core that has been cut. These are made using thin tape wound advanced core material with properties such as very low core loss and high saturation flux density which are then cut to allow use of an air gap, and placement of an easily manufactured winding. Windings can be made for standard magnet wire, copper foil, or Litz-wire for high frequency applications.

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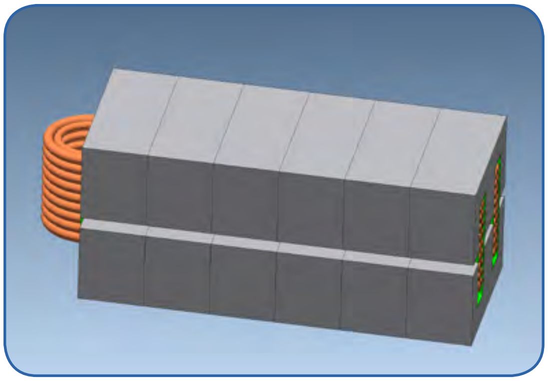
Construction Type: Multi-core Inductors



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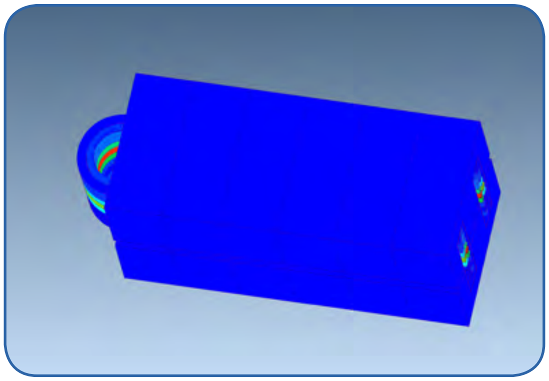

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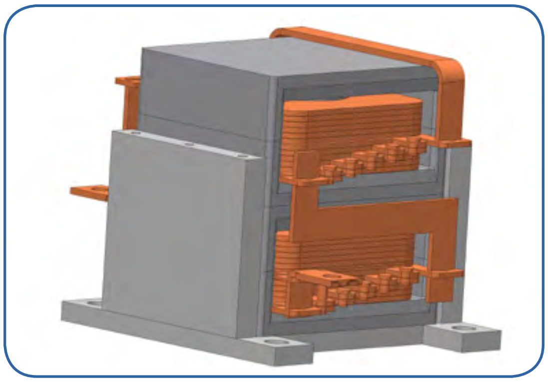
Figure 10. High frequency 100 kHz multi-core ferrite inductor:
a) 3D FEA model of half device; b) Current density distribution

Multi-core inductors are inductors constructed modularly from a number of individual cores. We are capable of designing and producing a multi-core inductor when customers haves a requirement for very high rated power, as can be seen on Figure 10 we used 12 E-shape ferrite cores.

Construction Type: Planar inductors



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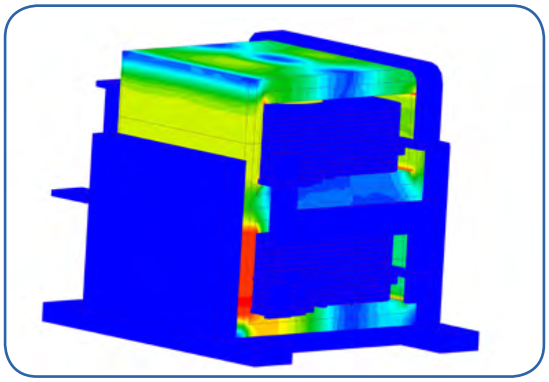

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Figure 11. Planar inductor:
a) 3D FEA model; b) Flux density distribution

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The drive towards higher power density with overall lower profile in switched-mode power supplies has led to the creation of planar inductors. In contrast to the helical windings of conventional magnetic devices, the windings of planar inductors are located on flat surfaces extending outward from the core centerleg. Magnetic cores used with planar devices have a different shape than conventional cores used with helical windings.

The main advantages of planar inductors are:

- Excellent repeatability as variation due to wire winding is eliminated
- High power density, due to efficient use of turns
- Ideally designed for conductive cooling
- Low leakage inductance
- Minimal AC winding resistance

As a global leader in planar magnetics design and production, Standex Electronics offer a wide range of planar inductors. To learn more please download our [SME Planar Magnetics Design Guide].

Agile Magnetics Inductors

Agile Magnetics Inc. produces some of the most efficient and affordable inductors in the industry. Our highly qualified engineers work to ensure that every custom design project we take on is manufactured in accordance with the exact specifications provided by our customers. Our ISO 9001:2015, UL, CUL, VDE, and CE certifications demonstrate our commitment to extreme quality.

Our friendly and knowledgeable staff are eager to speak with you about your goals and provide you with innovative solutions to meet your unique needs. Regardless of industry, application, or order size, we're excited to work with you and piece together a solution that will help you achieve your objectives. To learn more about inductor selection, download our high-performance inductor guide or contact us today.

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About Us

With more than 23 years in the magnetics business, Agile Magnetics, a Standex Electronics company, has set the standard for manufacturing custom-designed electromagnetics at the highest levels of quality and value. Our highly experienced team has led the industry in manufacturing quality high frequency power assemblies, custom coils, value-added assemblies and 50-60-400Hz products for the most demanding industries and applications. We are ISO 9001 compliant, and our products can be manufactured to UL, CUL, VDE and CE, with UL and CUL markings when required.

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