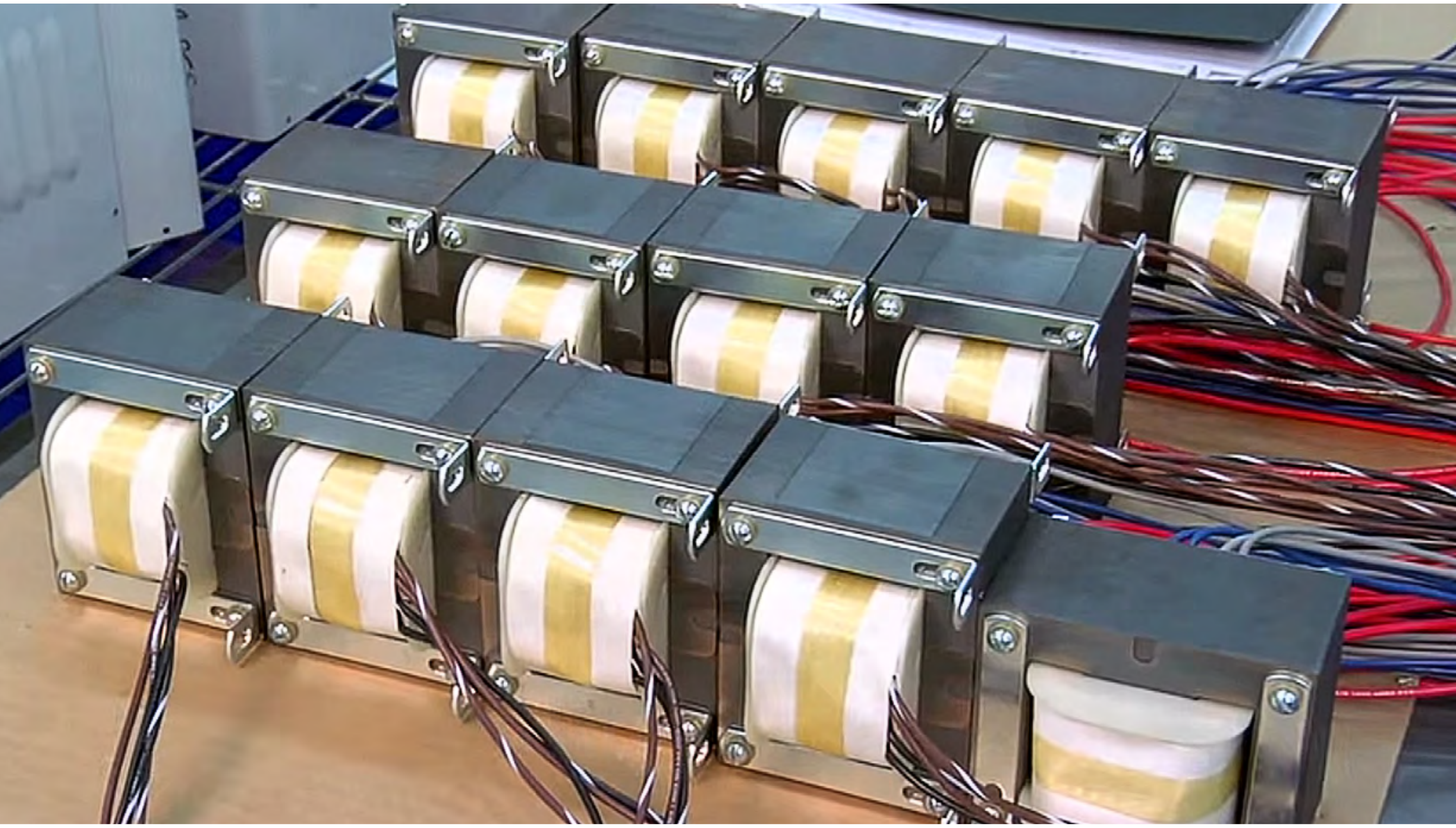

FEA BASED HIGH-FREQUENCY HIGH-POWER MAGNETIC COMPONENT DESIGN AND OPTIMIZATION

Introduction to FEA

When it comes to the design of high frequency magnetics, accuracy matters. Inaccurate calculations for a high frequency transformer or inductor may misrepresent issues such as winding impedance, leakage inductance, proximity and eddy current effects, or component hot spots. Such issues can significantly undermine a design's real-world performance and are often challenging to address once the design is frozen. In order to optimize your high frequency magnetic design, accurate and early modeling is imperative.

Unfortunately, modeling with accuracy is often resource intensive, requiring engineering time and talent to cultivate the experience necessary. As a result, most high frequency magnetics are designed without the benefit of an accurate model. Most commonly, rough theoretical calculations may be performed to help estimate component performance and avoid trouble areas. In an ideal scenario, these calculations suffice and performance can be proven out with prototypes in a few weeks. However, when issues arise, they can be difficult to address as high frequency designs are inherently complex and dynamic. Without the benefit of fully understanding the underlying interactions within the magnetics design, it could take significant time to identify and implement solutions.

Fortunately, Agile Magnetics is here to help. Agile, a Standex Electronics company, is the industry leader for designing and validating high frequency magnetic designs. Not only is Agile capable of developing a magnetics solution to meet your specific need, but we are also experienced in using FEA simulation to help you visualize and address the electromagnetic and thermal properties of the design. Depending on your project scope, Agile engineers can help provide a simple model to validate part performance, detailed models to fully optimize performance, sample prototypes to allow you to empirically validate the design, or any combination therein. By partnering with you on the front end to design and validate your solution, Agile seeks to speed your product development time by helping you avoid costly design iterations.

Benefits of FEA

Although a primary benefit of FEA is accuracy, there are several supporting benefits that make this achievable. In order to make an informed decision on how to validate your next magnetic design, it is important to understand all the advantages FEA offers. These advantages include modelling flexibility, speed, and depth of insight.

Flexibility

One of the main advantages of FEA is how flexible this tool can be to handle a variety of conditions. This flexibility is key to generating high fidelity results, because it allows the unique aspects of your magnetic design to be fully modelled. Without such an accommodating tool, design calculations would need to be approximated, leaving significant room for error. However, with a versatile FEA toolkit, a skilled engineer can easily accommodate:

- Complex component geometries
- Arbitrary directional loading of the component
- Non-uniform material properties (e.g. non-homogenous)
- Direction dependent material properties (e.g. anisotropic)
- Bespoke inputs representing your design conditions (component load, temperature, pressure, flux, etc.)
- Various thermal conditions (e.g. convection, conduction, radiation)
- Different levels of solution complexity, including linear, non-linear, transient and steady-state (Figure 1&2)

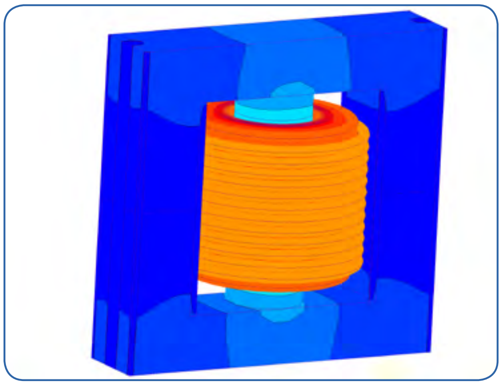

Figure 1 Distribution of temperature field for transformer model solved via steady-state analysis

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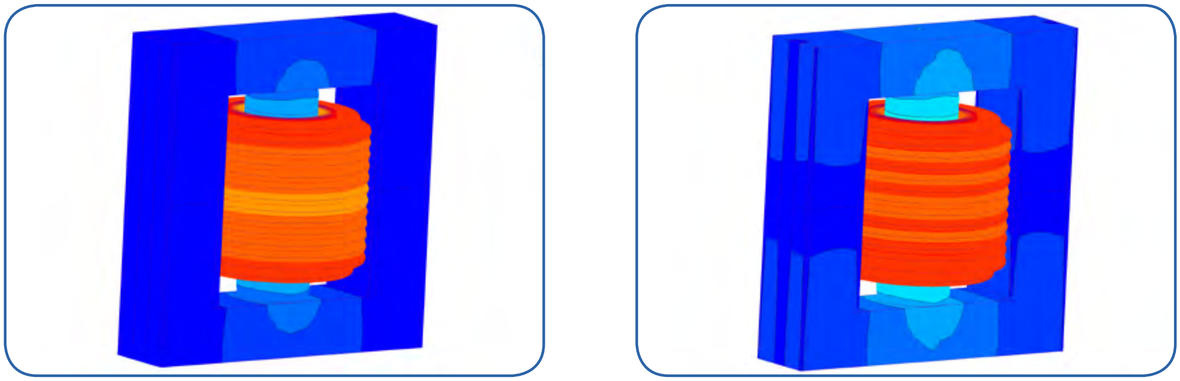

a) Time = 1800 sec

b) Time = 3600 sec

Figure 2 Distribution of temperature field for transformer model solved via transient analysis

Speed

Since high frequency magnetic designs are inherently complex, any model truly representing these designs will be similarly complex. Although the underlying physics remain straightforward, intricate models require simultaneous solution of many variables to yield worthwhile results. Fortunately, FEA provides a standard process for converting the governing differential equations into a system of matrix equations. By leveraging the FEA and a workstation with the appropriate computational power, a skilled engineer can rapidly and accurately model even the most challenging designs.

Insight

Ultimately, the goal of using FEA to design high frequency power magnetics is to better understand how the design will operate in the real world. To fully understand component behaviour requires accurate modelling of the design's electrical and thermal characteristics. Crucially, these models must be coupled as many magnetic materials have temperature dependent properties which often have a significant impact on electrical performance. Without accounting for this feedback loop, estimates on high frequency magnetic designs are unlikely to provide useful insight into how the design will perform.

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Examples of FEA Results

As simulation can be rapidly set up and run, our skilled engineering team can help you perform preliminary verification soon after we finalize your magnetic design. Depending on your validation schedule, our team can provide a simple report detailing design performance, prototype samples to allow you to verify the design via testing, or both. As simulation does not require material samples to be procured, it allows for early insight to ensure the design is operating within the envelope intended – critical on time sensitive projects.

The following simulation outputs are examples of how our team can help you visualize and verify your designs:

Electrical

- Flux distribution and saturation
- Magnetic flux density distribution
- Current density distribution (Figure 3)
- Loss distribution (AC&DC Winding Loss, Core Loss)
- Leakage fields distribution
- Inductances, Resistances, Capacitances
- Electromagnetic Forces for Power Magnetics

Thermal

- Temperature rise under nonlinear load conditions
- Temperature field distribution
- Component hot spots against material property limits
- Temperature field distribution
- Heat flow distribution
- Heat source distribution

Given the amount of insight that a FEA model can provide, we at Agile Magnetics frequently use simulation to supplement the traditional design process (Figure 4). As a result, our skilled engineers can help remove the guess work from the typical magnetic design process.

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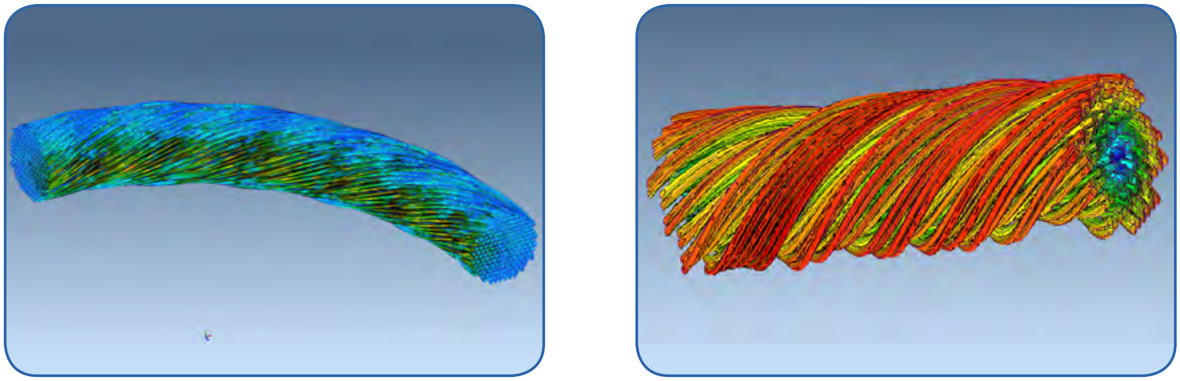
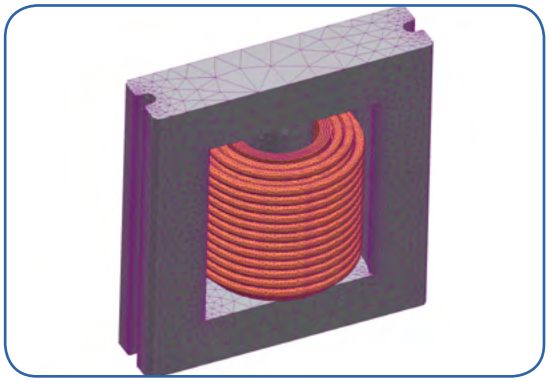
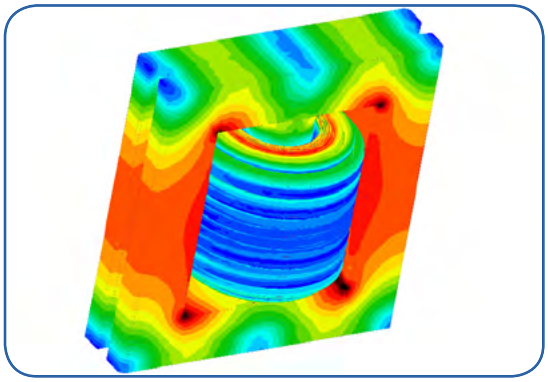


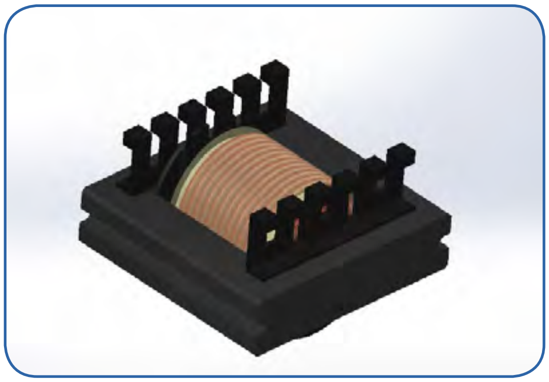
Figure 3 Current density distribution in different Litz wire types



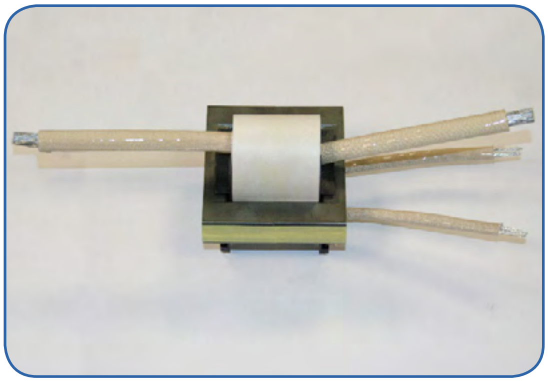
a) FEA baseline model



b) FEA Simulation, visualizing distribution of magnetic flux



c) CAD assembly model



d) Final product

Figure 4. Process of simulation-based design in Agile Magnetics

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FEA Optimization for Power Magnetics

Although FEA is well suited to help visualize how a given design will perform, the true power of FEA is to help optimize design parameters with several different options. As an example, winding losses in transformers and inductors increase dramatically with frequency due to eddy-current effects. To optimize the design, there is a need to accurately predict the winding losses over a wide frequency range and for various winding geometries in the design stage. As FEA allows for a virtual DOE against a variety of conditions, the most accurate calculations can be made using FEA simulation.

The following are some examples on how our engineering team at Agile can optimize your design to maximize its performance.

Optimization

- Visualize core losses across different waveforms
- Calculate correct insulation level to avoid high voltage failures
- Optimization of winding designs to ensure target efficiency met
- Determine stray losses in house and heat sinks
- Recommend design options to minimize material usage (Figure 5)
- Ensure design operates within material thermal “sweet spot”
- Optimize Litz strand size/cost (Figures 6 -7)
- Recommendations to minimize losses, and associated tradeoffs

Depending on your needs, our team can supply you with a simple document verifying key performance criteria or an in-depth report detailing assumptions, findings, and next step recommendations to fully optimize the design. When approaching your next power electronic project, consider partnering with Agile to design, validate, and manufacture the magnetics for your most critical applications.

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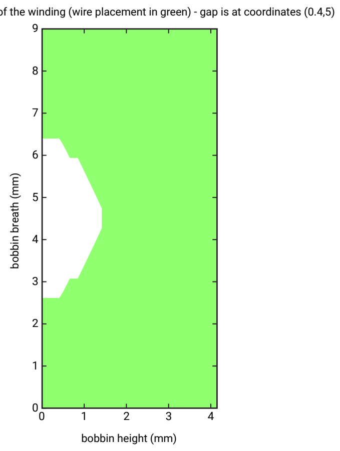
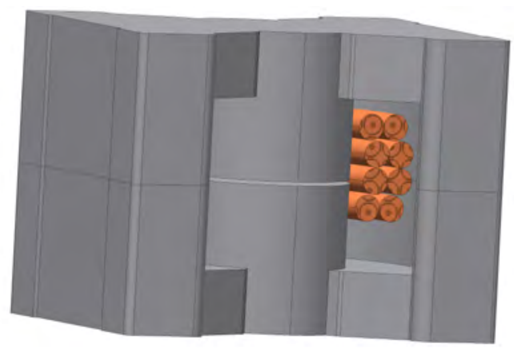


a) Result from using optimization software



b) 3D model of winding with optimized shape for FEA

Figure 5. Optimized coil shape on high frequency ferrite inductor

Design Number	AWG# (Primary)	AWG# (Secondary)	Relative Cost	AC Loss Watts	Strands Number (Primary)	Strands Number (Secondary)
Design 1	32	32	$.03	36.48	20	126
Design 2	34	34	$0.05	24.02	49	313
Design 3	36	36	$0.07	15.97	121	774
Design 4	38	38	$0.13	10.79	298	1,914
Design 5	40	40	$0.23	7.407	742	4,762
Design 6	42	42	$0.42	5.49	1,501	1,1837
Design 7	44	44	$0.66	4.88	2,354	2,0662
Design 8	46	46	$1.32	4.61	3,691	3,2401
Design 9	48	48	$3.65	4.45	5,788	5,0807

Figure 6: Litz Wire Optimization DOE

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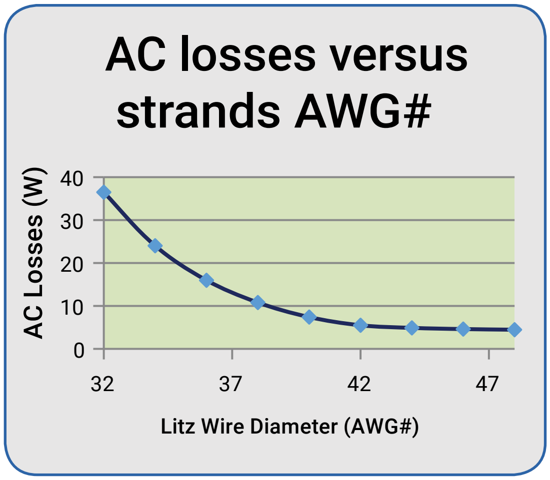
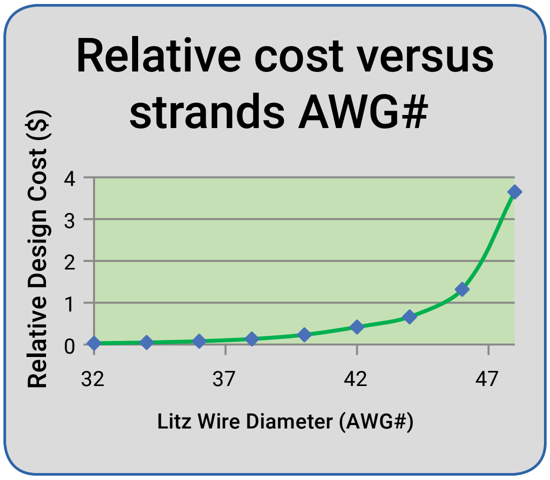


a) Litz Wire: Losses vs Strand size



b) Litz Wire: Cost vs Strand size

Figure 7: Litz Wire Optimization Curves

FEA Examples

Agile Magnetics and its parent company Standex Electronics are well versed in designing, validating, and manufacturing a wide variety of magnetics. To help showcase our expertise, the following pages summarize some of the unique design characteristics that we are capable of modeling. For more information on how Agile can help simulate your next design, contact us via our webpage.

FEA of high frequency wire wound transformers

In designs where higher power and frequency levels are required, AC losses are a major concern. In these types of magnetic designs, certain materials such as Litz wire or copper foil are utilized to help minimize AC losses. Although these materials are common in magnetic designs, the complex geometries involved make it rare to find an expert who understands how these materials operate under load. Due to Agile's experience with FEA, we have deep, physics-based insight into how these materials behave and can optimize the designs accordingly.

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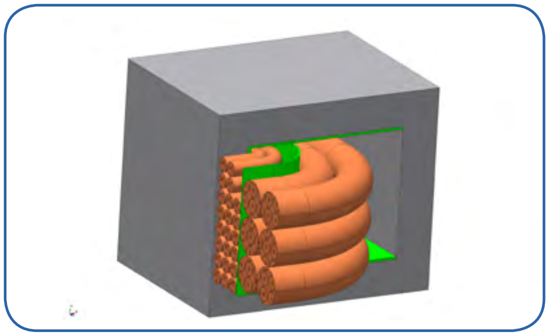
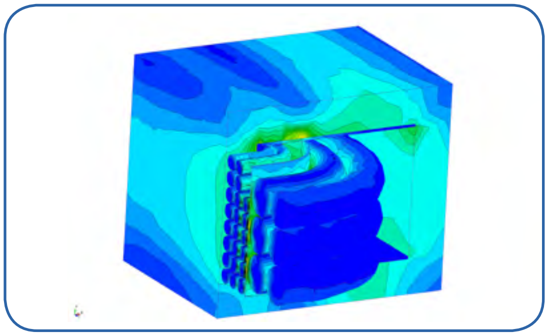
FEA Results for high frequency transformer with Litz wire windings

Power level	3.5 kW
Switching Frequency	40-60 kHz
Maximum power loss	<0.2%
Turns ratio	11:2



a) FEA model

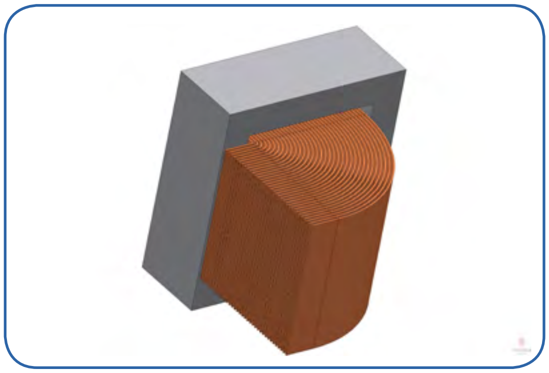


b) Distribution of magnetic flux density

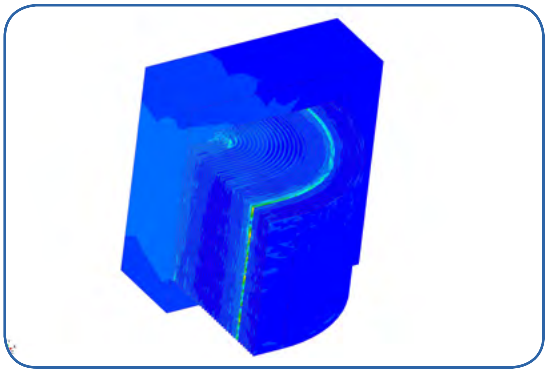
Figure 8. One quarter of HF transformer With Litz wire windings

Results of FEA for high frequency transformer with foil windings

Power level	42 kW
Switching Frequency	24 kHz
Maximum power loss	<4%
Turns ratio	1:1.11



a) FEA model



b) Distribution of magnetic flux density

Figure 9. One quarter of HF transformers with foil windings

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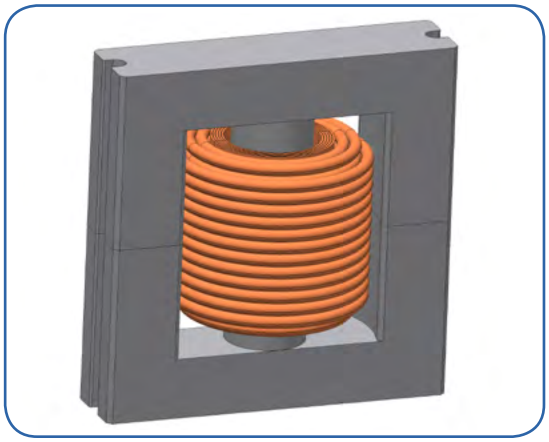
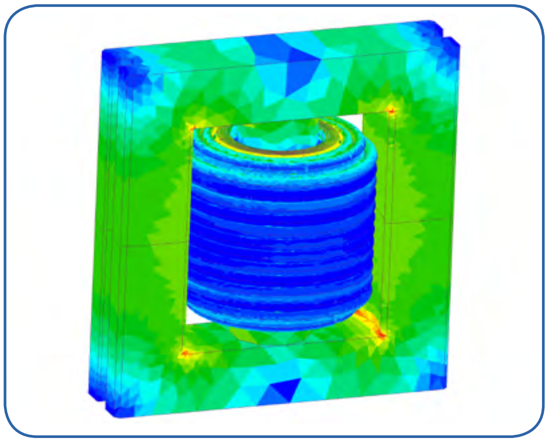
Results of FEA for HF transformer with foil and Litz windings

Power level	1.5 kW
Switching Frequency	200 kHz
Maximum power loss	<0.6%
Turns ratio	1:20



a) FEA model



b) Distribution of magnetic flux density

Figure 10. High frequency transformers with foil and Litz wire windings

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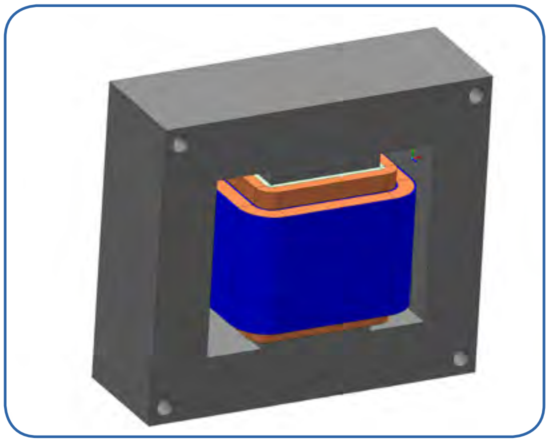
FEA of low frequency transformers

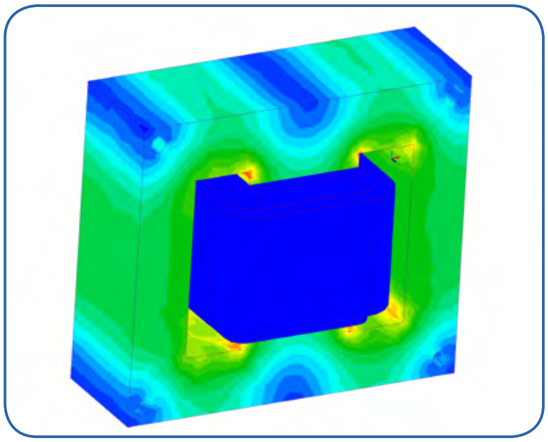
For small and medium power transformers with a low frequency, magnetic designs commonly use a laminated core and magnet wire windings. As this design is more straightforward, we can approximate the round magnetic wire as a block to rapidly model and optimize the design. Although the model geometry is approximated, the results are still highly accurate if the model boundary conditions are tightly controlled. In this way, we can generate results that are close representations of not only conventional winding and core losses but also any stray losses within mounting components.

Results of FEA for low frequency transformer

Power level	1.38 kW
Switching Frequency	50-100 Hz
Maximum power loss	<4%
Turns ratio	1:14



a) FEA model



b) Distribution of magnetic flux density

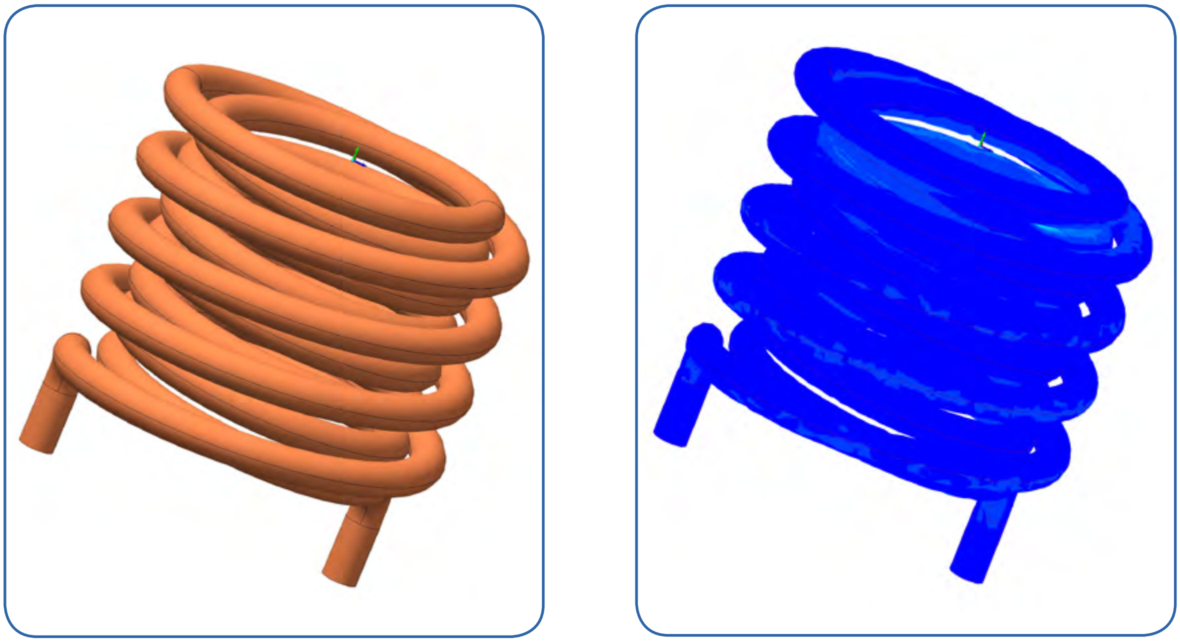
Figure 11. Low frequency transformer with coils from round magnetic wire:

FEA of high frequency air core inductors

Since our launch in 1992, our team at Agile Magnetics has been manufacturing a full array of air core inductors, and free-standing coils for clients around the world. We manufacture air core coils in a variety of dimensions using a range of inductance and wire gauges based on the specifications of our customers' applications. Now with the help of FEA we can simulate every air core inductor's geometry and calculate with high accuracy its inductance, AC resistance, and losses.

Results of FEA for Air Core Inductor

Power level	22.5 kW
Switching Frequency	400 kHz
Maximum power loss	<0.05%
Inductance	5 µH



a) FEA model

b) Distribution of magnetic flux density

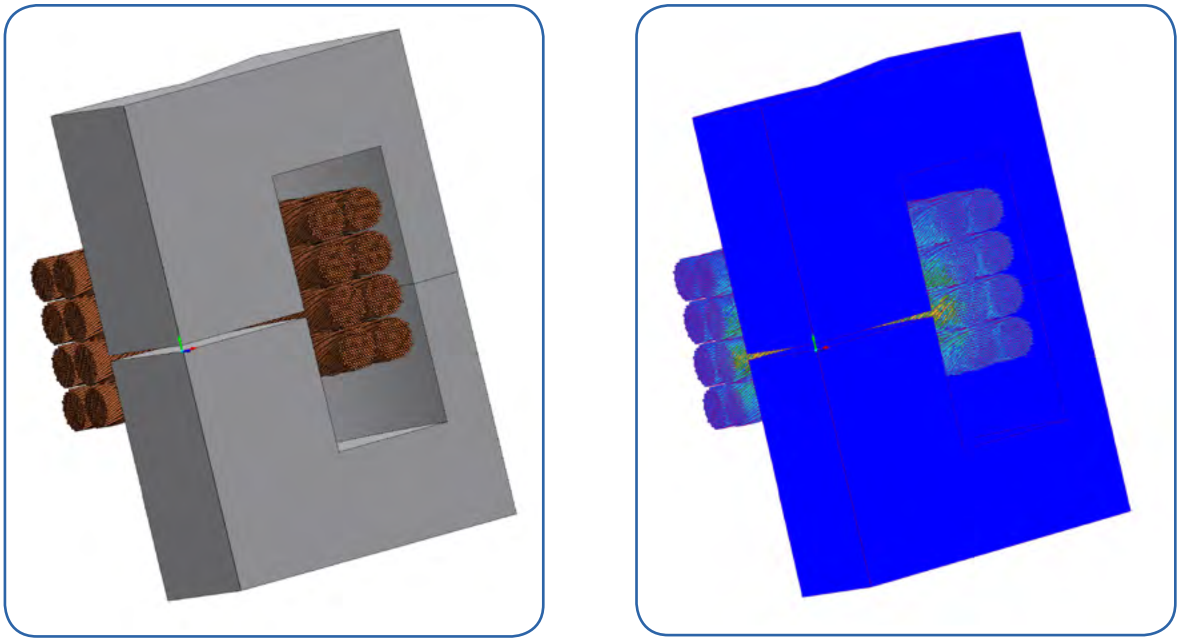
Figure 12. High frequency air core Litz wire inductor

FEA of ferrite core inductors

Use of ferrite cores allows for several advantages, including maximizing efficiency and minimizing core losses. At Agile, we offer a range of ferrite inductors to match the exact specifications of your application. During the custom inductor development process, our team can provide an FEA evaluation for each design factor including assessment of rated current, required inductance, and acceptable winding and core losses. Using FEA software we have the possibility to modify the core type, core material, and coil shape to help minimize AC, caused by leakage field near the air gap. This level of optimization is too complex to be completed by traditional analytic methods, but is a speciality that Agile is proud to offer to our customers.

Results of FEA for Ferrite Inductor

Power level	0.75 kW
Switching Frequency	200 kHz
Maximum power loss	<0.05%
Inductance	10 μH



a) FEA model

b) Distribution of current density

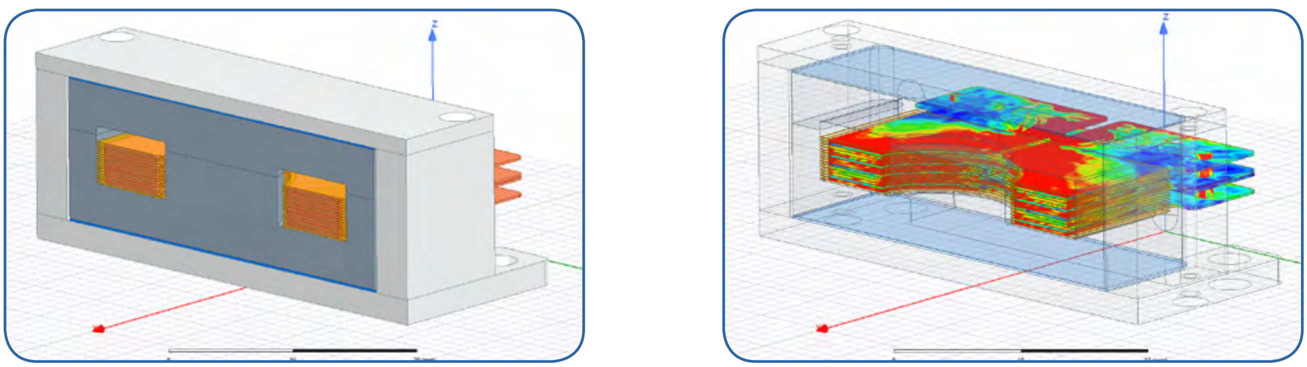
Figure 13. High frequency ferrite inductor with Litz wire

FEA of planar magnetics

Planar magnetics are constructed from closely stacked windings, making them ideal for applications that require a small electronic footprint with a high power density. As with any high power and high frequency magnetic design, AC losses are always a concern to address to maximize component efficiency. Additionally, the tight stacked nature of planar magnetics makes it critical to verify that any heat generated within the part can be controlled so the design operates within its ideal temperature window. In both cases, FEA is a tool that is well suited to help visualize and optimize the performance of the planar design, even before testing the first prototype samples.

Results of FEA for Planar Transformer

Power level	4kW
Switching Frequency	200kHz
Maximum power loss	<0.8%
Inductance	146.62 µH, 16.302 µH



a) FEA model

b) Distribution of current density

Figure 14. High Frequency Planar Transformer with Leadframes

References

1. Uzunov, Peter (2019, May). Personal interview.

About Us

Agile Magnetics Inc. has some of the deepest insight regarding magnetic design within 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 create a solution that will help you achieve your objectives. To learn more about simulation capabilities, contact us today.

Contact Us

Agile Magnetics

24 Chenell Drive, Concord, NH 03301
www.agilemagco.com
Toll Free: 800-805-8991