Electromagnetic modeling for inductors and transformers using ANSYS (HFSS)

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Objective:

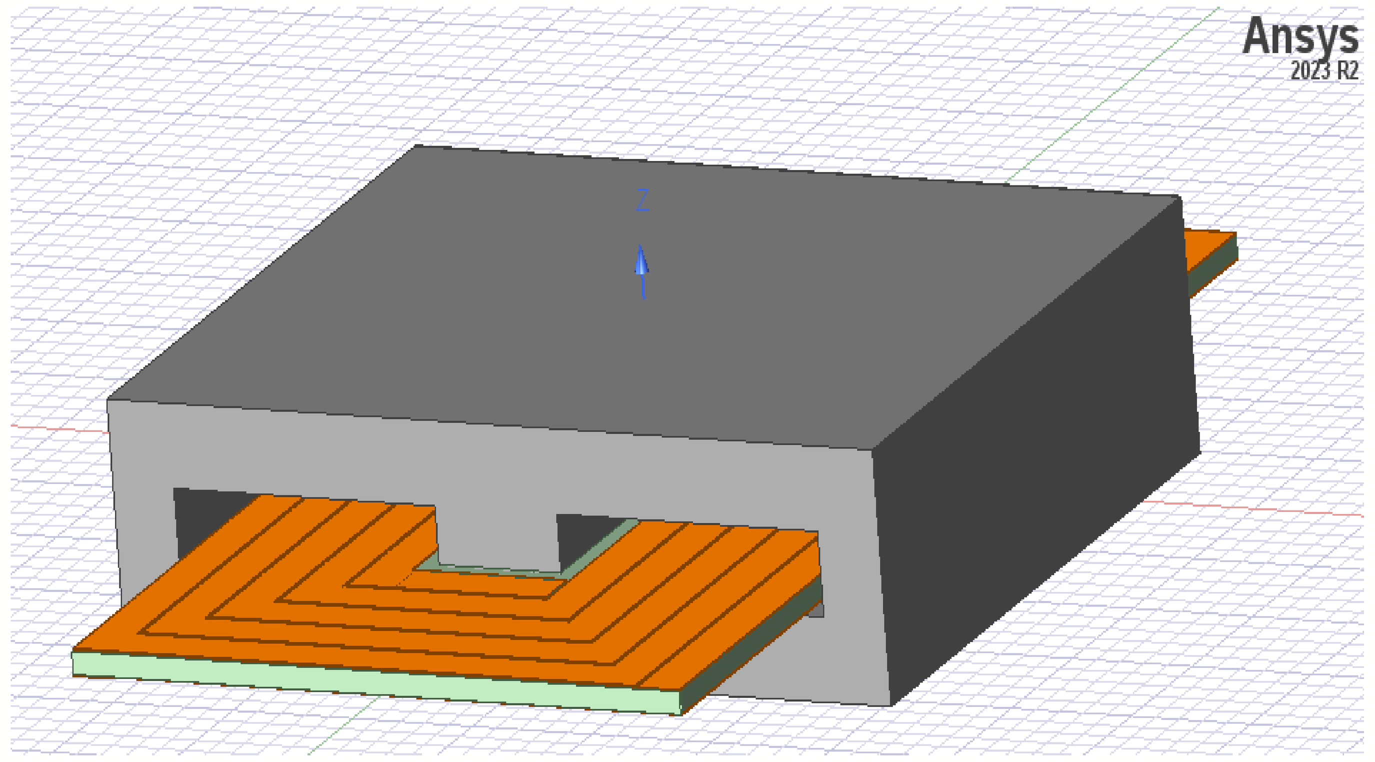
This project aims to develop precise models for inductors operating at high frequencies to improve their efficiency in energy conversion systems. The key research question focuses on understanding how parasitic effects—such as inter-winding capacitance and core losses—impact the electrical behavior and performance of magnetic components at MHz-range frequencies.

Background:

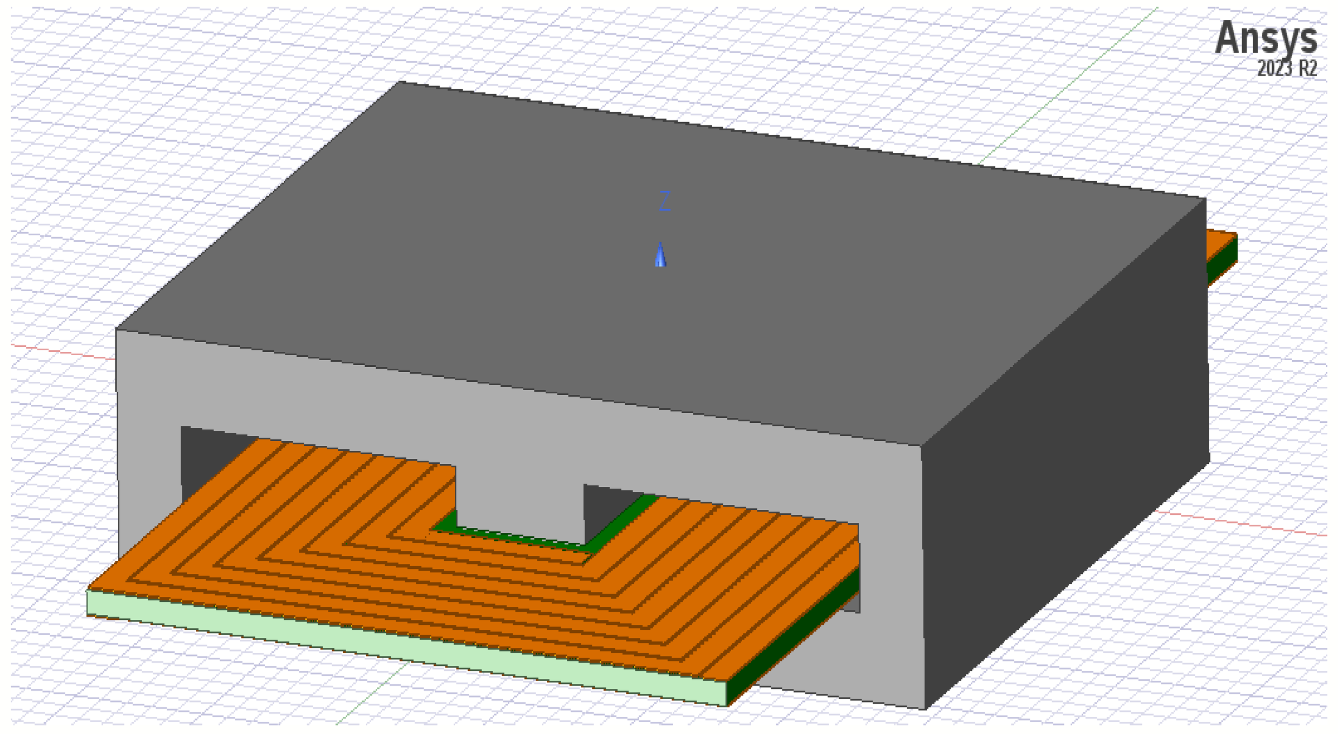
At high frequencies, magnetic components deviate from their ideal behavior due to parasitic elements and frequency-dependent material properties. Accurately modeling these effects is essential for optimizing designs used in modern power converters. Using ANSYS HFSS, impedance characteristics were simulated and extracted around the resonance frequency, then compared with experimental measurements to refine and validate the model.

Procedure:

- Simulations included multiple core materials and winding configurations to analyze their impact on parasitic behavior.
- Evaluated various ferrite cores and winding geometries (single-layer, multi-layer, and interleaved) to study performance across designs.
- Modeled different magnetic materials and winding layouts to assess frequency-dependent losses and coupling effects.



HFSS Model for Core 1 (2-layer inductor w/ 5 turns per layer

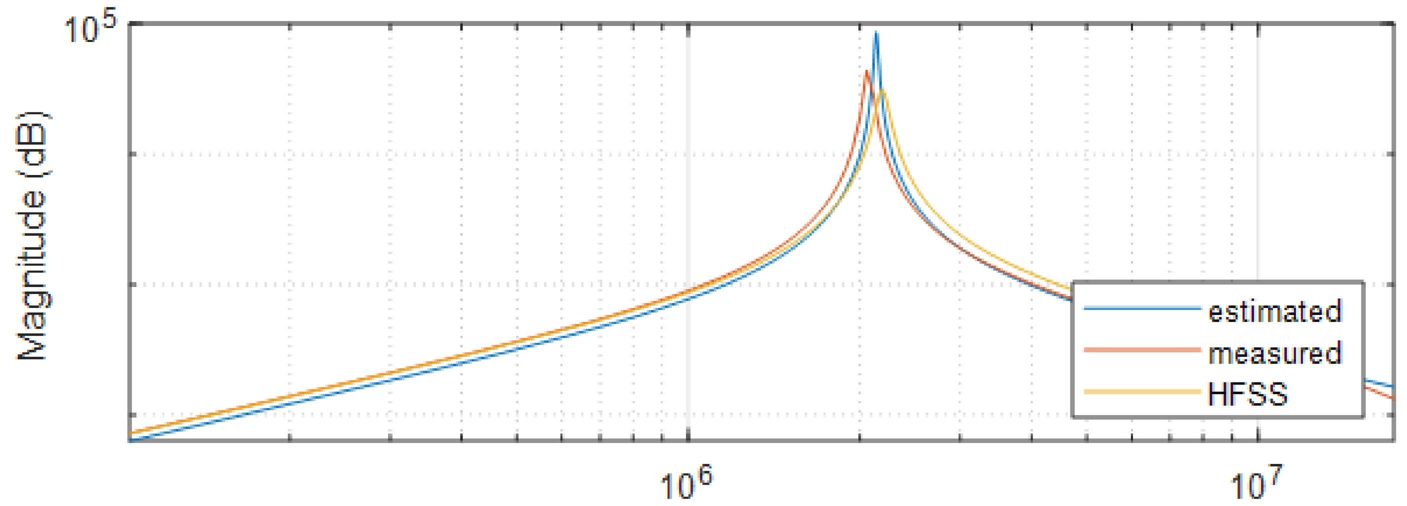


HFSS Model for core 2 (2-layer inductor w/ 7 turns per layer

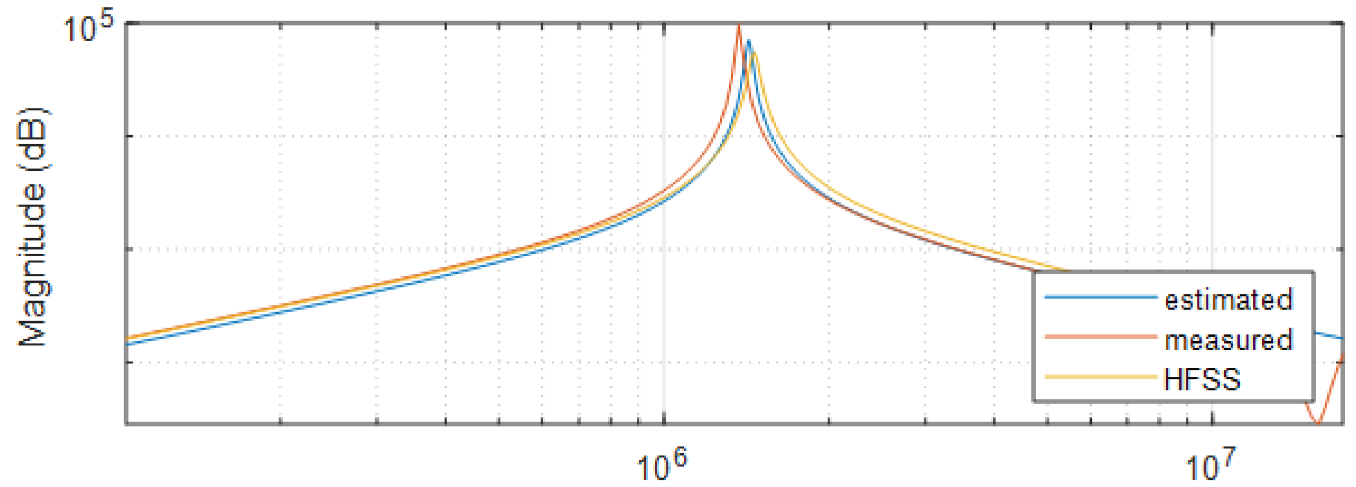
Results:

- Strong correlation was observed among HFSS simulations, MATLAB analytical models, and experimental measurements, especially around the resonance frequency.
- The developed model accurately captured the influence of inter-winding capacitance, leakage inductance, and core losses.
- Multiple core materials and winding configurations showed distinct impedance profiles, confirming material- and geometry-dependent effects.
- The validated model provides a reliable basis for predicting parasitic behavior in high-frequency magnetic components.
- Findings contribute toward improving efficiency and design optimization of transformers and inductors in MHz-range power converters.

Impedance curve for core 1



Impedance curve core 2



Conclusion:

- The study successfully developed and validated a **high-frequency model** for inductors and transformers that closely aligns with experimental and analytical results.
- The approach demonstrates the importance of **accurate parasitic modeling** for improving efficiency in modern power conversion systems.

Future Work:

- Extending the modeling approach to transformers to analyze coupling effects between primary and secondary windings.
- Exploring advanced transformer geometries and insulation structures relevant to MHz-range converters.
- Validating full transformer models experimentally to enable predictive, high-efficiency magnetic design for high-frequency power applications.

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