Extended Electromagnetic Modeling of Planar Inductors and Transformers

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Motivation:

To develop and validate a semi-analytical electromagnetic model for planar magnetic components – inductors and transformers – that accurately captures self resonance by accounting for inter-conductor capacitances.

Methods:

Verification followed the three-pronged framework shown in the figure below: analytical derivation, Finite Element Analysis (FEA) in ANSYS HFSS, and experimental impedance measurements using a precision impedance analyzer on fabricated PCB windings with varied core materials and geometries.

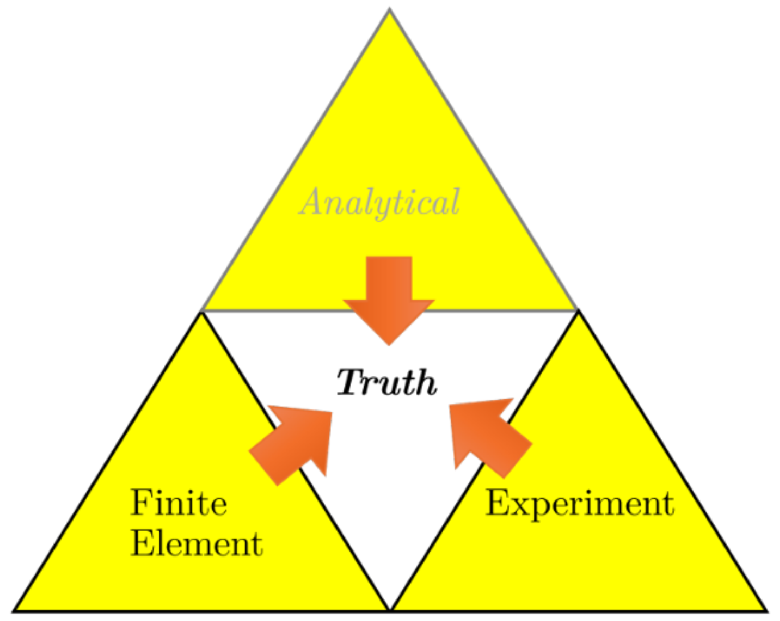

Figure 1: Contrasting finite element and analytical models with Experimental data brings us closer to the truth.

Obstacles Faced and Overcome:

- **Model assumption breakdown at higher turns-per-layer counts** — Initial formulation neglected capacitive fringing effects, producing discrepancies for smaller core geometries. Incorporating fringing capacitance improved agreement across all configurations tested.
- **Insufficient manufacturer permeability data** — Datasheet specifications were inadequate above a few MHz. Core permeability was experimentally extracted up to 110 MHz, enabling accurate high-frequency material modeling.
- **Cost and time constraints on physical PCB configurations** — Fabricating every winding variant was impractical within the project timeline. An ANSYS HFSS simulation workflow was independently developed to evaluate configurations beyond those physically available, avoiding unnecessary fabrication cost and lead time.

Findings and Progress:

- The extended model was verified across a wide and deliberately varied set of inductor and transformer configurations, chosen to provide an unbiased assessment of its strengths and limitations.
- The model performs best for larger core geometries, where fringing effects are proportionally smaller, and model assumptions hold most cleanly — for both inductor and transformer cases.
- Across all configurations tested, the model predicts the self-resonant frequency (SRF) with a worst-case error of approximately 10%, with performance improving substantially for larger coresets.
- These results, spanning a deliberately broad range of configurations, support a planned submission to the IEEE Transactions on Power Electronics.

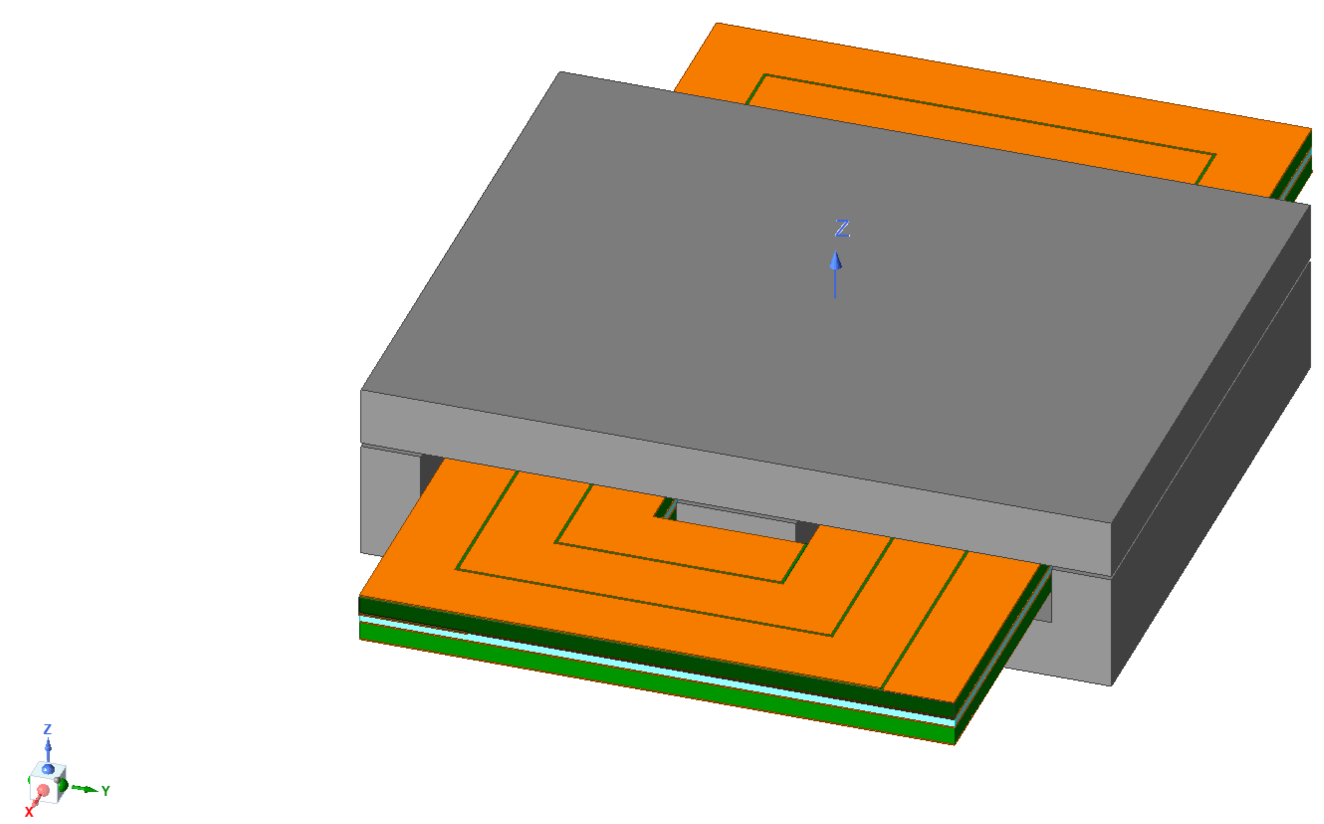

Figure 2: Planar Transformer modeled in ANSYS HFSS

Model Verification:

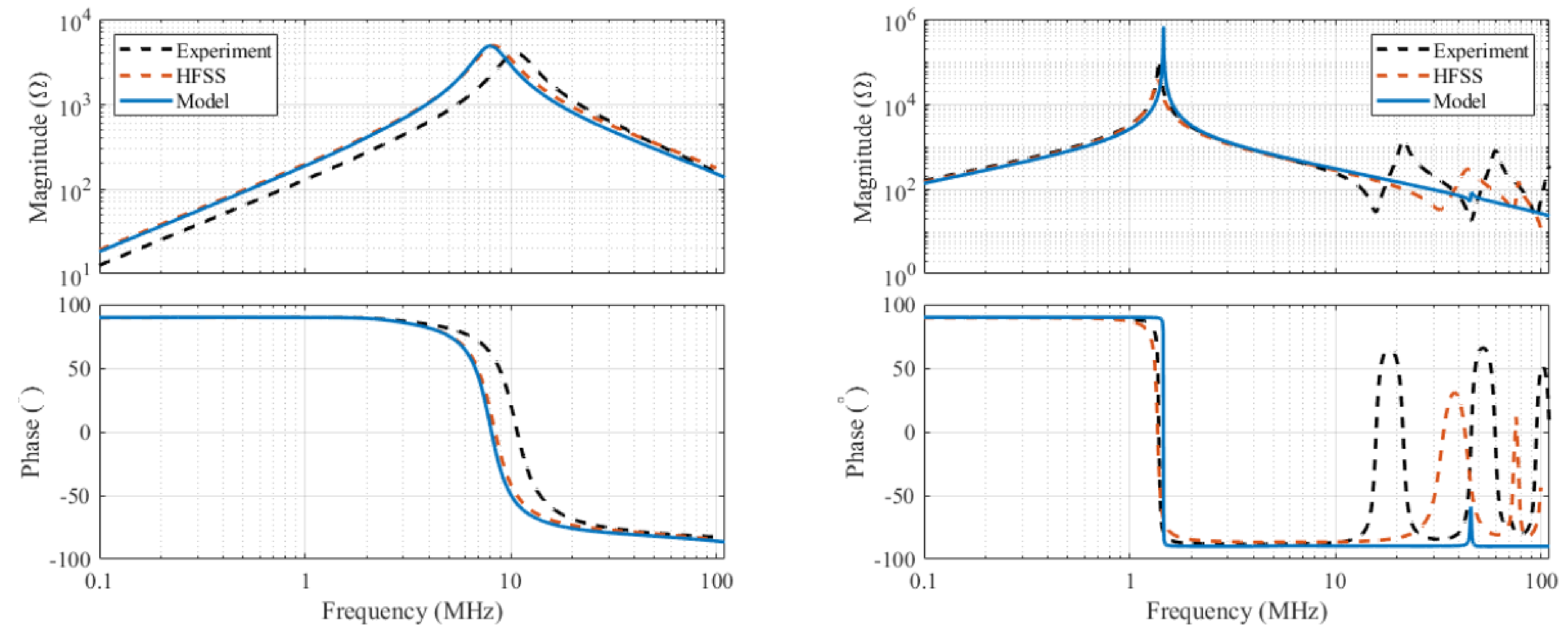

Figure 3: Impedance magnitude and phase vs. frequency comparison between the analytical model, ANSYS HFSS FEA, and experimental measurements for representative planar magnetic configurations.

Conclusion:

The electromagnetic transmission line model of Pniak et al. was extended to multiple-turns-per-layer planar inductor and transformer configurations, filling a gap in the existing literature relevant to high-frequency power converter design.

Acknowledgements:

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References:

[1] L. Pniak, B. Revol, L. Qu´eval, C. Gautier, J.-S. N. T. Magambo, S. N. B.Hung, and O. B´ethoux, "Planar Transformers Electromagnetic Modeling Considering Capacitive Couplings up to 100 MHz," IEEE Transactions on Power Electronics, vol. 39, no. 6, pp. 7290–7301, Jun. 2024.[Online].

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