Numerical Analysis Of An Integrated LLC Transformer With Multi Air Gaps And Litz Wire Windings

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Abstract

In this work, a novel approach is presented for analyzing the structure of a high-frequency integrated inductor-inductor-capacitor (LLC) resonant transformer through multiphysical simulation. The objective is to create a digital twin of the LLC transformer that closely resembles an actual device. An existing LLC transformer is utilized to validate the simulation model. In contemporary development processes, optimizing simulation models has become increasingly critical for reducing development time and costs. The developed model enables the extraction of equivalent circuit parameters for the LLC transformer based on its geometric specifications. Conversely, this knowledge can be applied to determine the geometric dimensions of an LLC transformer prior to the fabrication of a physical prototype.

A key aspect of the approach is the consideration of multiple air gaps in the middle leg of the transformer core. The magnetizing inductance, which is a critical design parameter for LLC transformers, can be precisely adjusted through the number and height of these air gaps. The simulation model enables parametric variation of these dimensions, allowing both the avoidance of core saturation and the reduction of magnetic flux fringing. Based on the simulated inductance factor, the required air gap configuration can be defined in advance for future designs - even before physical prototyping - based on a target inductance specification.

Traditional methods for simulating the equivalent circuit parameters of LLC transformers often struggle to accurately model high-frequency litz wire in the transformer windings. This is essential for capturing high-frequency losses due to skin and proximity effects. Our approach leverages the newly introduced capabilities in COMSOL Multiphysics to simulate these losses. The implementation is based on the Meeker method for hexagonally packed litz wires, extended by an additional factor to account for twisting [1].

In this work, various approximations of the litz wire windings are systematically compared to explore potential model simplifications. To validate the simulation, the equivalent circuit parameters of the modeled LLC transformer are compared with targeted measurements of the physical device.

Reference

[1] David C. Meeker, “An improved continuum skin and proximity effect model for hexagonally packed wires,” Journal of Computational and Applied Mathematics, vol. 236, no. 18, pp. 4635-4644, 2012.

Figures used in the abstract

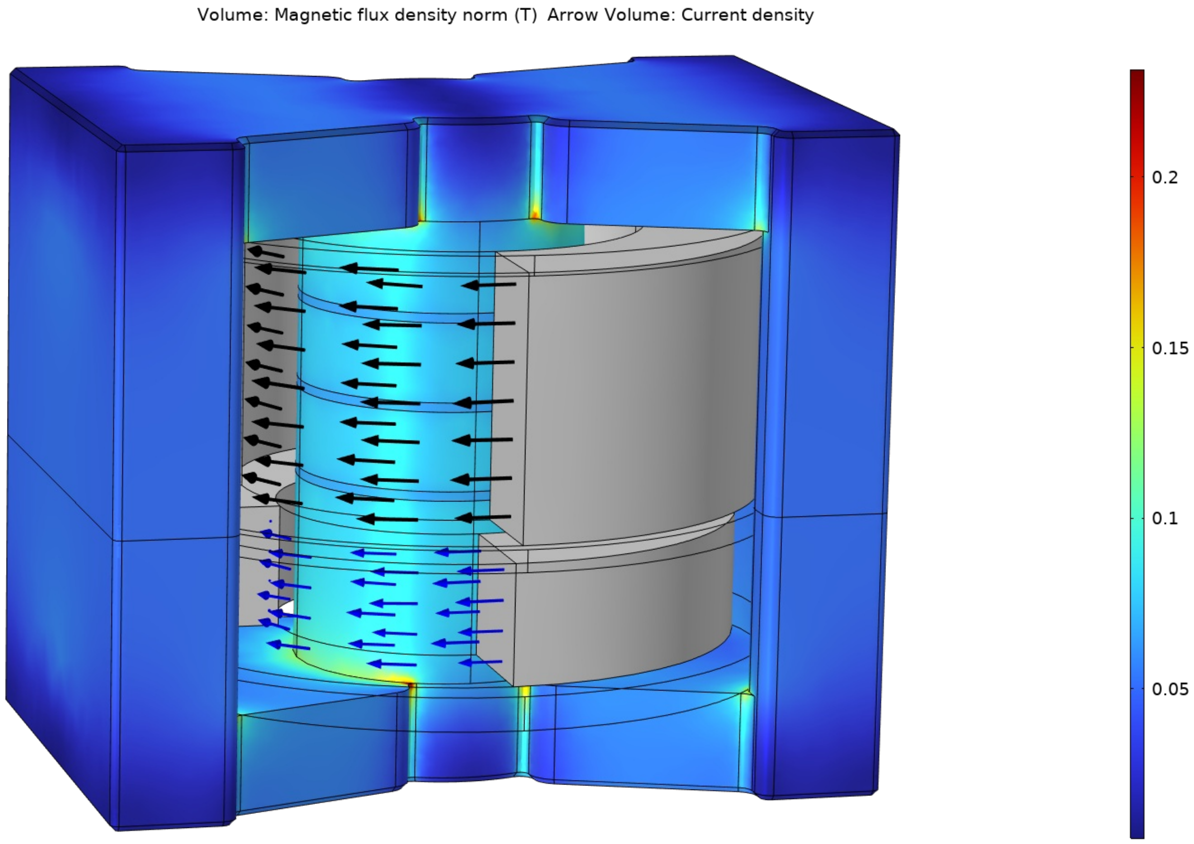

Figure 1 : Magnetic flux density norm in the core and the currents in the primary (black) and secondary (blue) coil.