

Design Optimization of Printed Circuit Board Embedded Inductors Through Genetic Algorithms with Verification By COMSOL Multiphysics®

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Abstract

Introduction: Inductors constitute the major part of modern switch-mode power supplies (SMPS), both regarding size and price. Recent research combines RF circuits and power electronics to design SMPSs with switching frequencies in the Very High Frequency range (VHF, 30-300MHz) [1]-[2].

The inductance needed at these frequencies are very low and the skin depth is 4-12 μm , so embedding these in the Printed Circuit Board (PCB), and thereby reducing the size and price even further, becomes a viable solution [3].

In order to keep the efficiency high at these highly elevated frequencies, soft switching is essential, as hard switching would lead to breakdown of the semiconductors. A key parameter to achieve this is an accurate inductance value. Equations for these are all based on approximations leading to small deviations. As the inductance cannot be fine tuned once the PCB has been manufactured, Finite Element Analysis becomes a very attractive way to insure that the circuit is correctly designed the first time.

System level: In order to design and produce the inductors, a small MATLAB® program with a GUI has been designed, see figure 1. The program takes the production parameters and the desired inductance and size as input and uses a genetic algorithm and formulas to find parameters for the initial design.

Then COMSOL Multiphysics® is used to investigate the current distribution and magnetic fields and to verify the inductance, interwinding capacitance and resistance.

Once the design has been verified in COMSOL and any error has been corrected, a PCB file is generated directly from the same interface.

COMSOL: The AC/DC Module is used to simulate the inductor structures, as it gives possibility for extracting the desired parameters. At VHF frequencies, the wavelength is still in the range of a few meters, while the AC/DC module is a viable approximation to the system.

For interfacing between MATLAB and COMSOL, Livelink™ for MATLAB® is used. It gives access to all the features of COMSOL with the scripting capabilities of MATLAB.

Five steps are used in the interface, see figure 2.

1. Generation of the inductor structure in full 3D for toroid and solenoids [4]. Spirals are generated in 2D [5], with infinite elements. See figure 3.
2. Setting up the physics - Use of the MEF with a Single-Turn Coil [6]. Use of Linear Discretization for faster simulation time.
3. Meshing - Custom mesh as there is great difference between the structure's size and the height of the copper traces.
4. Simulation setup.
5. The inductance, capacitance and resistance are added to a table from a global evaluation.

Results: The inductance and resistance of the inductors have been calculated, extracted from simulations and measured on prototypes; see figure 4. Results of the simulated 3D structures will be included in the final paper.

Conclusion: It has been demonstrated how LiveLink for MATLAB and COMSOL can be used to implement a simple GUI, from which a user can easily design PCB embedded inductors, verify performance in COMSOL, and produce the structures.

Reference

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- [2] M.P. Madsen, A. Knott et al. "Very high frequency resonant DC/DC converters for LED lighting," IEEE Applied Power Electronics Conference and Exposition 2013, vol., no., pp.835,839, 17-21 March 2013
- [3] M.P. Madsen, A.P. Mynster, et al. "Printed Circuit Board Embedded Inductors for Very High Frequency Switch-Mode Power Supplies", IEEE International Energy Conversion Congress and Exhibition Asia 2013
- [4] COMSOL model library: "Modeling of a 3D Inductor", Model ID: 10299
- [5] D. Kováč, M. Ocilka, M. Vansáč, "Calculating of Inductance of Spiral Coil Using Comsol Multiphysics", Electromechanical and energy systems, modeling and optimization methods, March 28-29, 2012, Kremenčuk. – Kremenčuk, Mykhailo Ostrohradskyi National University, 2012 P. 89-90. - ISSN 2079-5106
- [6] COMSOL model library: "Single-turn and Multi-turn Coil Domains in 3D", Model ID: 14067

Figures used in the abstract

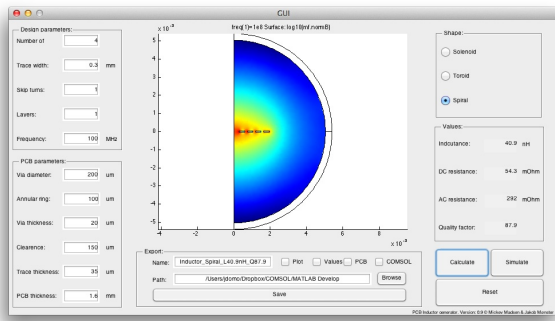


Figure 1: The Graphical User Interface for the program.

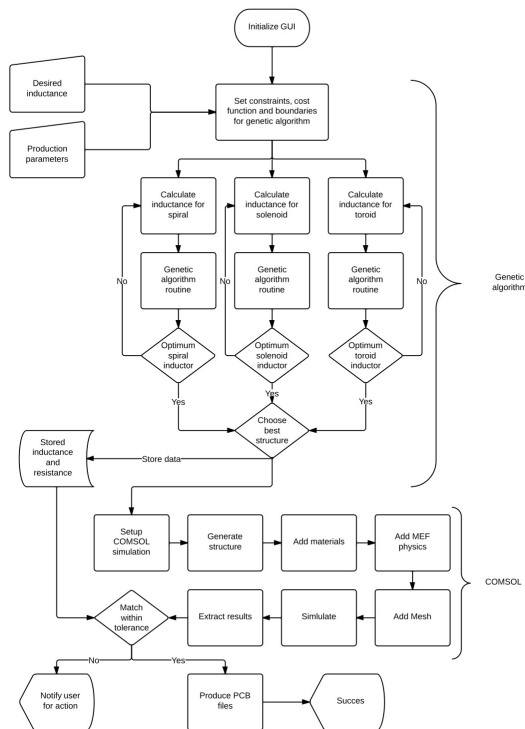


Figure 2: Flowchart of the implemented program for designing, evaluating and producing PCB embedded inductors.

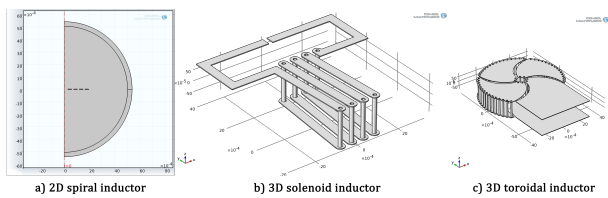


Figure 3: Examples of the three different structures for PCB embedded inductors.

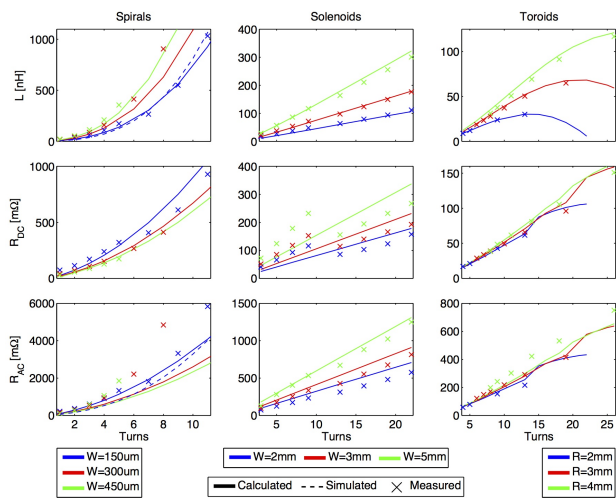


Figure 4: Calculated, simulated and measured values of various PCB embedded inductors.