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Numerical Simulation of PCB-Coil-Layouts for Inductive Energy Transfer Systems

Introduction

This paper presents the two dimensional (2D) Finite Element Method (FEM) COMSOL model of a PCB-Coil layout. The model comprises different coil layouts for a comparison. The scientific goal of the simulation is to find an optimized arrangement considering a high quality factor of the coil. The case of application for the simulated coils are inductive contactless energy transfer systems with a low magnetic coupling.

Contactless Energy Transfer

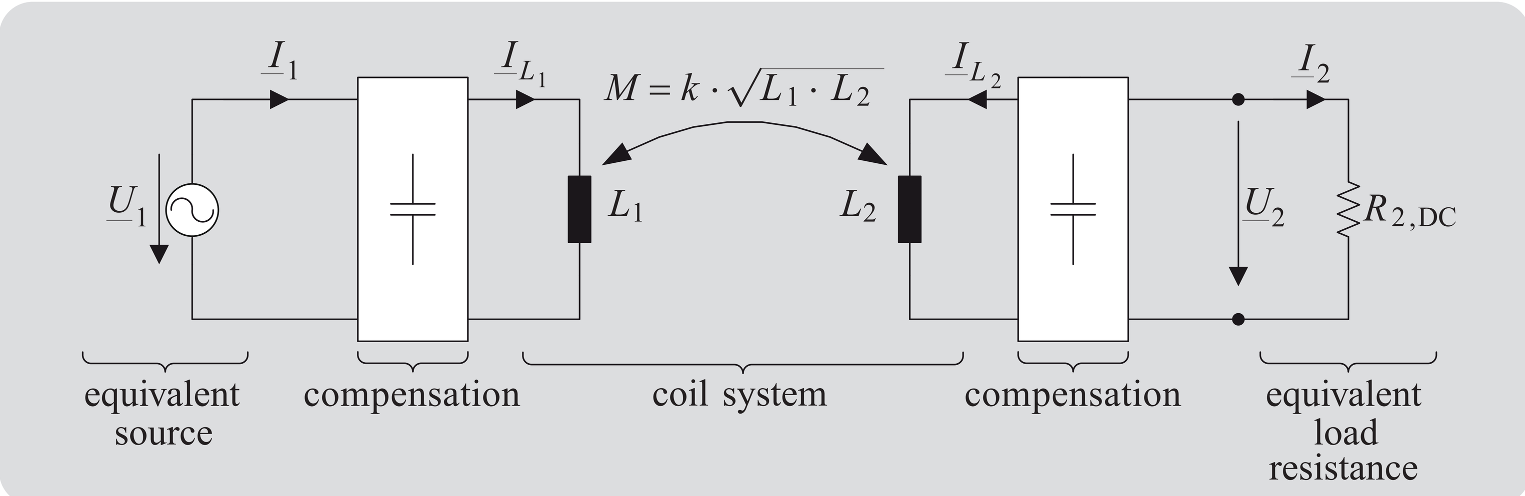

Figure 1: Overview of an inductive CET system with reactive power compensation and coil system

- Up to three resonant frequencies in the area of 500 kHz
- Low magnetic coupling between $k = 0.1$ and $k = 0.5$
- System behavior depends on kind of reactive power compensation

Geometry

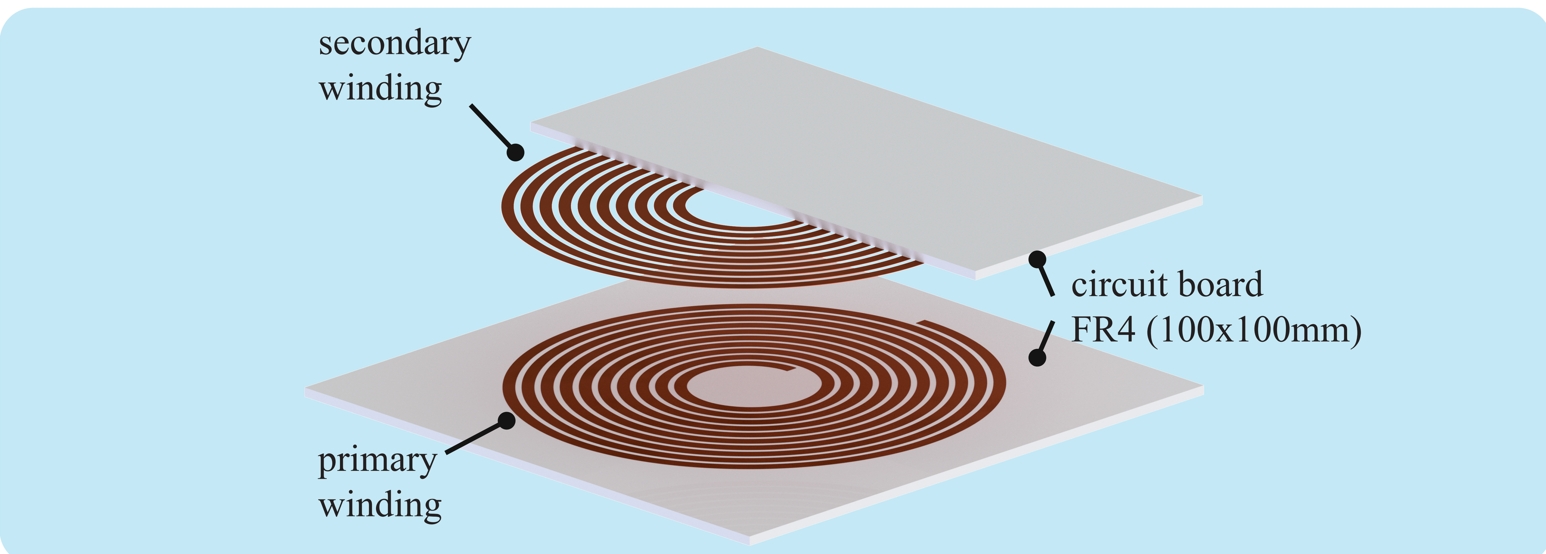

Figure 2: 3D model of the coil system with 10 copper windings on a FR4 PCB board. For improved visibility, only one copper layer of the coil is shown.

- 2D-COMSOL geometry with sweep of copper winding width
- Three coil arrangements are compared; the two shown in Figure 3 and one with an equal width of the copper winding

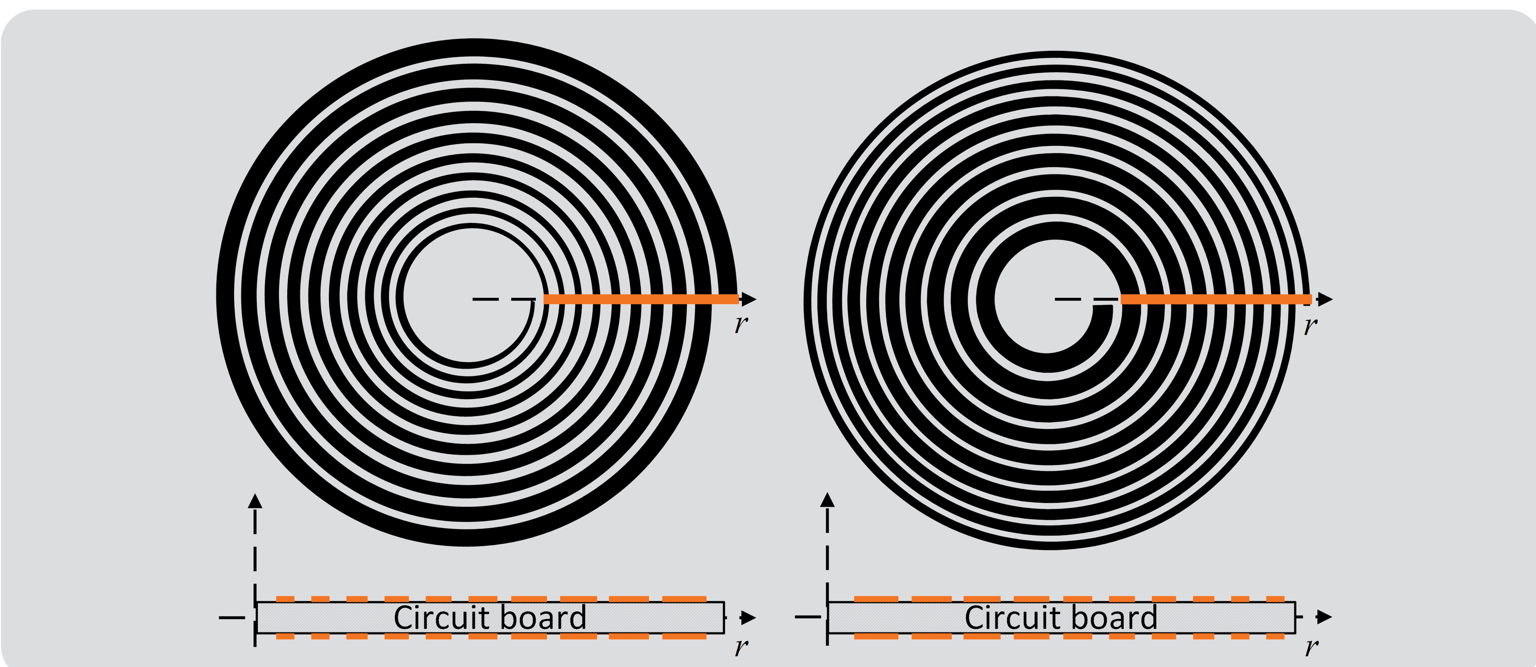

Figure 3: 2D-COMSOL model of Figure 3; sweep of copper winding width; orange line indicates the cut plane for COMSOL 2D geometry

Problem definition

- Magentic and electric fields physics
- Frequency domain with 500 kHz

$$\nabla \times H = J \qquad E = -\nabla V_m - j\omega A$$
$$B = \nabla \times A \qquad \nabla \cdot J = 0$$

Mesh

- User defined mesh with different areas see Table 2
- Quadrilateral mesh elements with a size of 14 µm for copper winding

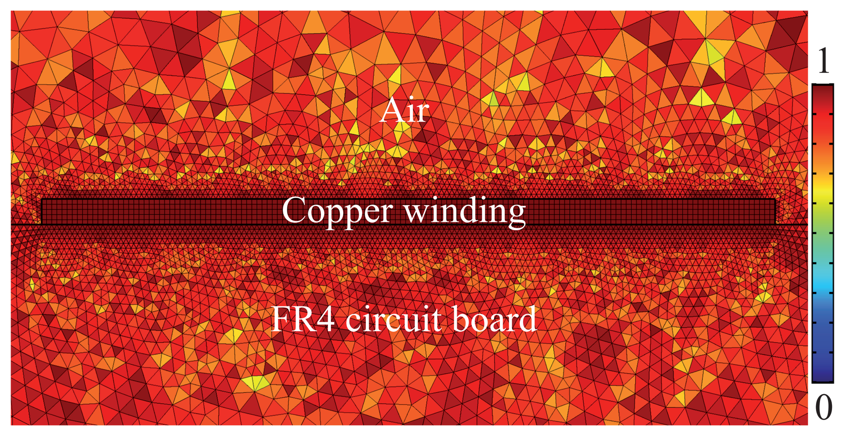

Figure 4: Mesh structure and quality of a single coil winding (approx. 70 µm thick and 2 mm width); quadrilateral and triangular mesh elements; legend from low (0) to high (1) quality

Table 1: Mesh data

Properties	Approx. values
Number of elements	420000
Triangular	392000
Quadrilateral	28600
Mesh vertices	225000
Edge elements	14000
Vertex elements	180
Average element quality	0.8869
Minimum element quality	0.5269
Mesh area	114200 mm²

Table 2: Mesh regions

Region	Type	Size
Air regions	Triangular	Normal, Finer, Extra Fine
Coil winding	Quadrilateral	Max. 14 µm
Circuit board	Triangular	Extremely Fine

Results

- Solutions for the three different geometries are compared
- Copper winding width and allocation have an influence on skin and proximity effect
- Out of the three geometries, the one with small inner copper width has the best quality factor

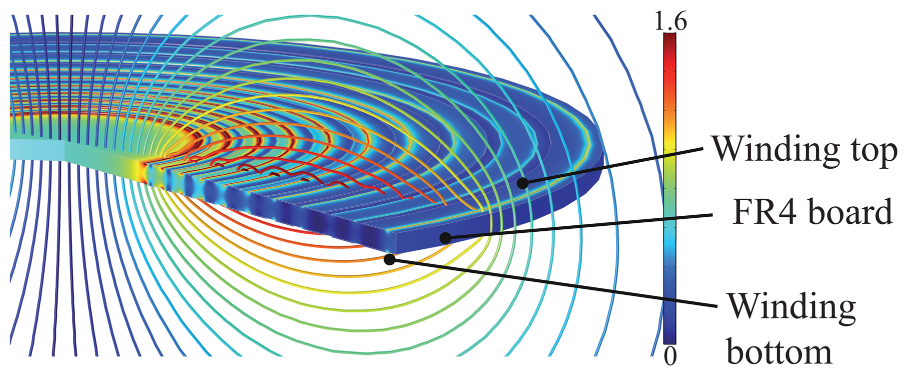

Figure 5: Primary coil with ten windings on each layer; absolute magnetic flux density in mT and pattern of magnetic field lines

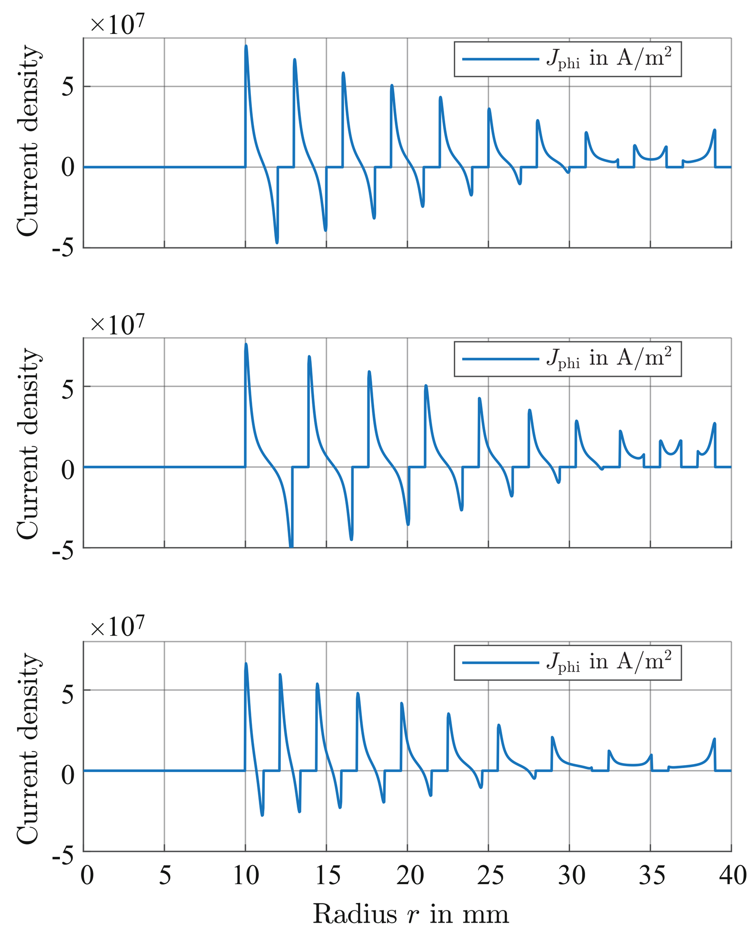

Figure 6: Current density measured in the center (35µm) of the top winding; Coil arrangement top to bottom: equal width, Figure 3 right, Figure 3 left

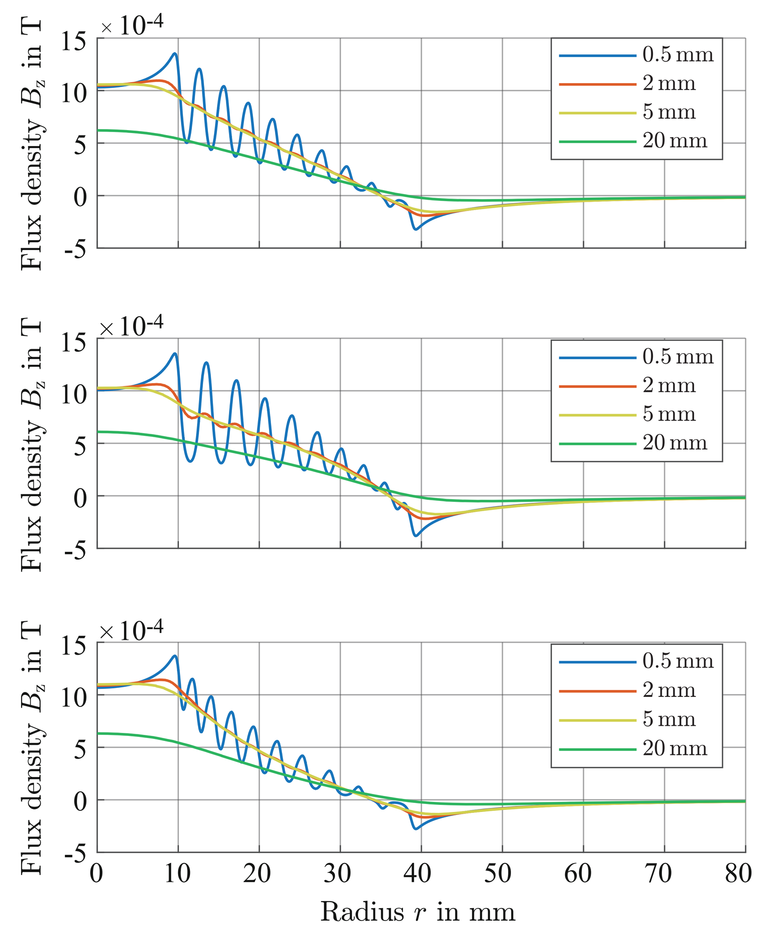

Figure 7: Magnetic flux density depending on the distance measured from the PCB's top etch layer for three different coil arrangements (see Figure 6)

Conclusion

- Optimization increases the quality factor of a PCB coil
- 3D simulation for final geometry based on CAD model
- COMSOL's optimization module can be used to verify more advanced geometries

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