FEM Based Design and Simulation Tool for MRI Birdcage Coils Including Eigenfrequency Analysis

Necip Gurler[1], Yusuf Ziya Ider [1]

[1]Department of Electrical and Electronics Engineering, Bilkent University, Ankara, Turkey

Abstract

Introduction: Designing a Radio Frequency (RF) birdcage coil used in Magnetic Resonance Imaging (MRI) at high frequencies where the wavelength is comparable with the coil dimensions is a challenging task. Before construction of the coil, not only calculating the capacitance value which is necessary for the coil to resonate at the desired frequency but also geometrically modeling the coil in a 3D simulation environment and making electromagnetic analysis inside the coil have importance in terms of observing the resonance behavior and other performance features of the coil. This study covers both design and simulation of low-pass and high-pass birdcage coils in COMSOL Multiphysics. Use of COMSOL Multiphysics: We have developed low-pass and high-pass birdcage coil models (geometries are illustrated in Figure 1) in COMSOL Multiphysics and have made two different analyses: frequency domain and eigenfrequency analyses. Since the thickness of copper strip used to construct the coils is larger than the skin-depth, rungs and end-rings are modeled as Perfect Electric Conductors (PEC) and distributed capacitors are modeled as parallel plate capacitors. In order to prevent reflections from the outer boundary of the solution domain enclosing the coil geometry, scattering boundary condition (or perfectly matched layer) is used. While in eigenfrequency analysis no sources are applied, in frequency domain analysis, lumped port boundary condition is used for voltage excitation. To provide linearly polarized field, coil is driven from one port whereas to provide circularly polarized field, it is driven from two ports that are geometrically 90° apart from each other. In the latter case the two driving signals are 90° out of phase (quadrature excitation). Additionally, we have developed a graphical user interface (GUI) shown in Figure 2 using MATLAB®. The user first specifies the coil properties and desired resonance frequency. By clicking the "Design" button, necessary capacitance value is calculated using a lumped circuit element model [1] which we have implemented in MATLAB®. Then, user specifies the type and parameters of the simulation. By clicking the "Simulate" button, the program connects to the COMSOL Multiphysics Server, and makes all the design and simulation calculations such as modeling the coil geometry, setting boundary conditions and solving electromagnetic field equations. When the simulation is finished, user can see the results by importing the model from the server. Results: Simulation study is made for 8-leg low-pass birdcage coil with 5 cm radius, 10 cm long rungs, 1 cm wide rungs and end-rings. Simulation results for frequency domain analysis at a frequency of 127.74 MHz and eigenfrequency analysis are given in Figure 3 and Figure 4 respectively. Experimental study is also made for different capacitor values to compare the results of our model with the results of lumped circuit element model at high frequencies. Conclusion: We have developed a user friendly software tool to design and simulate the birdcage coil accurately. Experimental results show that our model is more accurate than the lumped circuit element model in

terms of calculating the capacitance value and the resonance modes of birdcage coils even at high frequencies.

Reference

[1]. C.L. Chin, et al., "BirdcageBuilder: Design of Specified-Geometry Birdcage Coils with Desired Current Pattern and Resonant Frequency", Concepts in Magnetic Resonance, Vol. 15(2), 156-163 (2002).
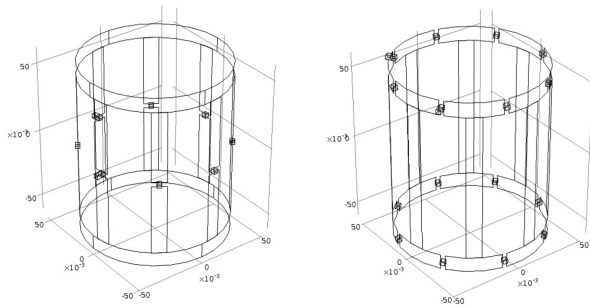
Figures used in the abstract

Figure 1: Low-pass (left) and high-pass (right) birdcage coil geometric models.
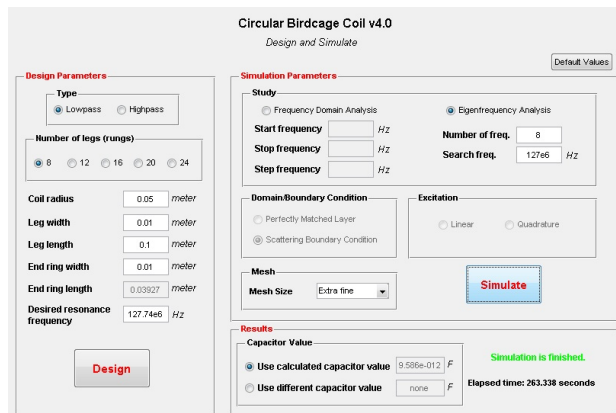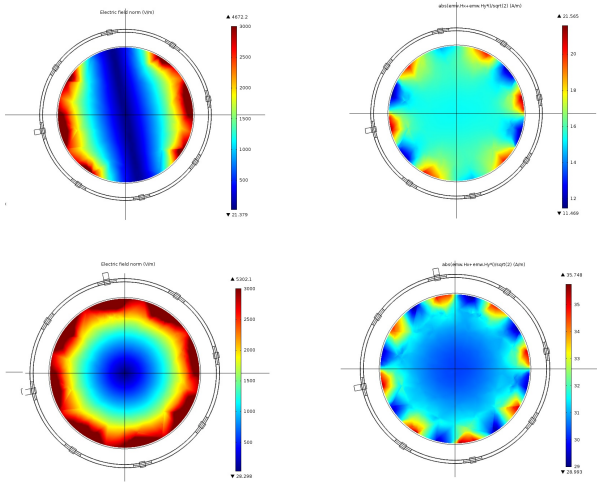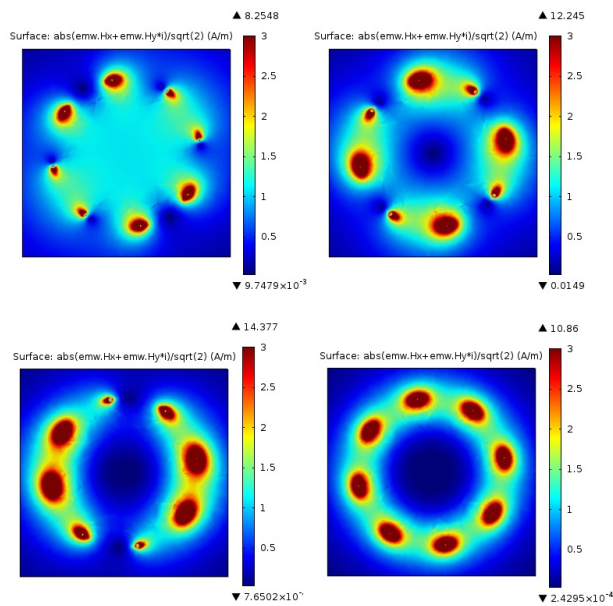

Figure 2: GUI of the developed software tool.

Figure 3: Magnitude images of E-field (left-top) and H+ (excitatory rotating component of the magnetic field) (right-top) at the central slice for linear excitation, magnitude images of E-field (left-top) and H+ (right-top) at the central slice for quadrature excitation, in frequency domain analysis.

Figure 4: Magnitude images of H+ at the central slice for calculated resonant modes in eigenfrequency analysis. 1st resonant mode (desired mode which has a uniform H+ inside the coil) (left-top) at 127.33 MHz, 2nd resonant mode (right-top) at 187.49 MHz, 3rd resonant mode (left-bottom) at 216.10 MHz, and 4th resonant mode (right-bottom) at 224.58 MHz.