Full-Wave Modeling of RF Exciters Using WIPL-D: Road to Real-Time Simulation and Optimization

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Abstract **—** Computational tools for full-wave three-dimensional (3-D) simulations of linear passive electromagnetic (EM) components have reached a point where they became both practical and necessary in computer aided design (CAD) of RF devices. Although circuit-based solvers still offer unprecedented speed and true real-time tuning, full-wave software tools, which take into account almost all physical EM phenomena, rapidly approach similar efficiency and applicability. This, however, is not possible by just using modern hardware environment, but it also requires the numerical method of choice, encapsulated within a software tool, to be extremely precise and conservative in consumption of computer resources, i.e., CPU and memory. We here report a case study which demonstrates highly efficient utilization of higher order large-domain method of moments (MoM) modeling and optimization using WIPL-D. The example includes an RF exciter, based on axial-mode helical antennas mounted on a dielectric support, designed for utilization in the state-of-the-art pre-clinical magnetic resonance imaging (MRI) scanners.

Index Terms **—** 7-T, antennas, bioelectromagnetics, computational electromagnetics, FDTD, helical antenna, high-frequency, imaging, microwave, resonance imaging, RF coil.

I. INTRODUCTION

Magnetic resonance imaging (MRI) is an important non-invasive diagnostic technique that is still being explored to its full potential. The radio frequency (RF) coil is a crucial element in any MRI system that is used to excite the water molecules inside the sample being imaged. This paper addresses application of computational electromagnetics (CEM) to the modeling and full-wave analysis of MRI RF coils for ultra-high field magnetic resonance imaging. Modeling of RF coil is generally performed using the finite difference-time domain (FD-TD) methods [1]. In this study we explore the possibility of using the method of moments (MoM) in the frequency domain to perform the same analysis.

We here compare the results obtained from the rigorous full-wave near field computational analysis in the frequency domain based on the MoM using the commercially available software WIPL-D [2] and the finite element method (FEM) using the commercially available software ANSYS HFSS, in the ANSYS Electronics Desktop [3].

II. FEM AND MOM MODELING

For our simulation models we consider a 7-T MRI system. The MRI bore contains a quadrifilar helical antenna RF coil [4] as the RF exciter with a phantom, as shown in Fig. 1.

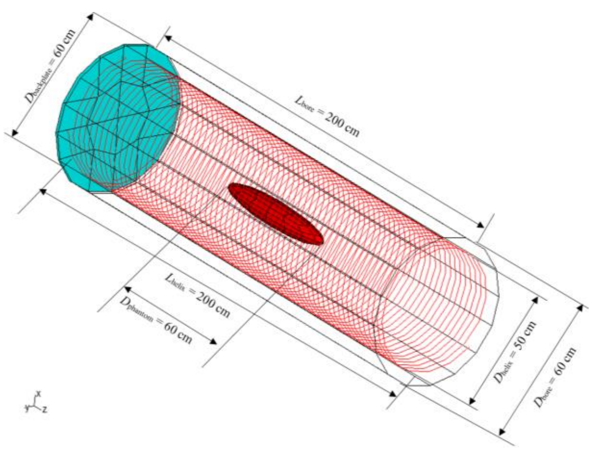

Fig. 1. WIPL-D model of the quadrifilar helical antenna RF coil with an ellipsoid phantom inside it.

The Larmor frequency for 7-T is 300 MHz. The diameter of the bore considered here is 60 cm and length is 200 cm. A helical antenna is a metallic wire antenna wound periodically with N wire turns and a pitch P about an imaginary (or dielectric) cylinder of diameter D_{helix} and length $L_{helix} = NP$ [5]. The pitch P relates to the pitch angle, α, as $P = C_{helix} \tan \alpha$, where

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$C_{helix} = \pi D_{helix}$ is the helix circumference. The antenna is fed at one wire end against a circular back plate, acting as a ground plane, i.e., the input power is supplied at a lumped excitation port between the wire end and the plate. A quadrifilar helical antenna is an array of four helical antennas connected to the same circular backplate and fed separately. The four helices (channels) are fed in proper phases in order to generate right handed circularly polarized magnetic field along the axis of the helices inside the coil.

The phantom used is a saline-water ($\varepsilon_r = 81$, $\sigma = 0.6$ S/m) filled ellipsoid. Ellipsoid longer axis is 60 cm long and aligned along the axis of the helix and the bore. It is rotationally symmetric and its shorter axis is 10 cm long.

In order to reduce complexity, the four "wire" helices were modeled in ANSYS-HFSS as a thin strips. The width of the strip is chosen as $a = 4r$, where $r = 1$ mm is the radius of the wire in the WIPL-D thin-wire model.

III. RESULTS AND DISCUSSION

In the results we plot and compare $\boldsymbol{H}_{\mathbf{rcp}}$, i.e., the right handed circularly polarized magnetic field and $\boldsymbol{H}_{\mathbf{lcp}}$, i.e., the left handed circularly polarized magnetic field inside the phantom. The aim of the RF coil is to maximize the right handed circularly polarized component of the magnetic field and to minimize the left handed circularly polarized component. Therefore $\boldsymbol{H}_{\mathbf{rcp}}$ should be as high as possible and relatively uniform throughout the phantom, whereas $\boldsymbol{H}_{\mathbf{lcp}}$ should be minimized and almost 0 on the longer axis of the phantom.

In order to equalize the feed powers in both models the excitation voltage of delta-type generators in the WIPL-D model is scaled to match that of the lumped excitation ports in the ANSYS-HFSS model such that:

$$V_x = \sqrt{\frac{P_{incx}\left(1 - |S_{xx}|^2\right)}{\mathrm{Re}\{Y_{xx}\}}}, \quad (1)$$

where Y_{xx} is input admittance and S_{xx} is the corresponding S-parameter for each of the individual helices.

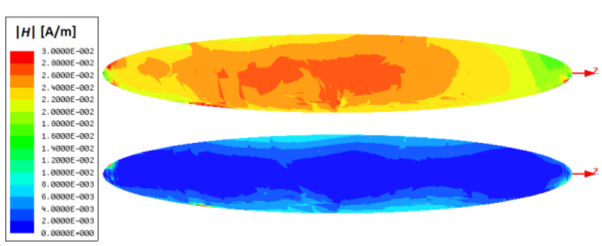

Fig. 2. $\boldsymbol{H}_{\mathbf{rcp}}$ and $\boldsymbol{H}_{\mathbf{lcp}}$ in *xz*-plane (sagittal/coronal) inside the phantom from ANSYS-HFSS.

The HFSS model run through 7 adaptive passes. Its final mesh comprised 299,584 tetrahedra and the matrix size was 5,394,535 unknowns. Total simulation time was 3 h : 20 m : 38 s. Simulated near field results are shown in Fig. 2.

The WIPL-D model had 11,736 unknowns. The order of polynomial expansion on the wires was 2 and on the plates it was a combination of 3 and 4. Total simulation time was 4 m : 24 s. Simulated near field results are shown in Fig. 3.

A comparison of $\boldsymbol{H}_{\mathbf{rcp}}$ and $\boldsymbol{H}_{\mathbf{lcp}}$ on the longer axis of the phantom, i.e., along the z-axis computed by ANSYS-HFSS and WIPL-D is shown in Fig. 4. We can conclude from Figs. 2-4 that the results are in a very good agreement.

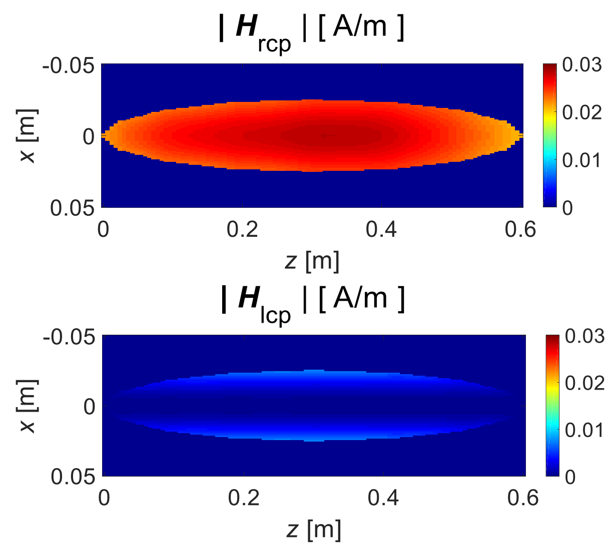

Fig. 3. $\boldsymbol{H}_{\mathbf{rcp}}$ and $\boldsymbol{H}_{\mathbf{lcp}}$ in *xz*-plane (sagittal/coronal) inside the phantom from WIPL-D. (Plotted using MATLAB).

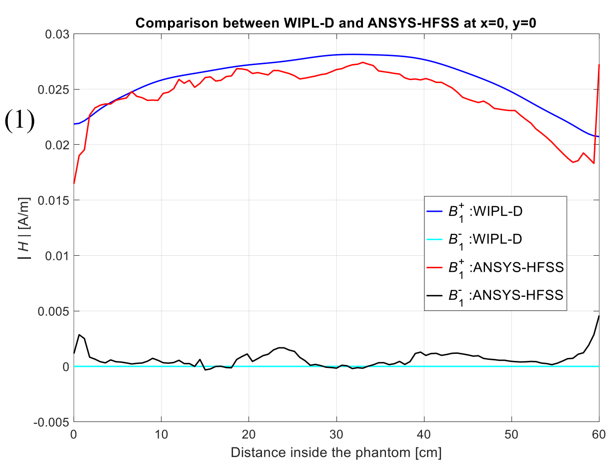

Fig. 4. Comparison of WIPL-D and ANSYS-HFSS results for $\boldsymbol{H}_{\mathbf{rcp}}$ and $\boldsymbol{H}_{\mathbf{lcp}}$ along the z-axis inside the phantom.

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