A multi-scale electromagnetic model of pacemaker lead heating in MRI

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I. INTRODUCTION

Heating of pacemaker leads by the radio frequency (RF) field in magnetic resonance imaging (MRI) is the main cause for standard pacemaker systems being contraindicated for MRI examinations [1]. This contraindication is highly unfortunate as MRI is the method of choice for imaging of soft tissues. Electromagnetic modeling of the RF field interaction with implant pacemakers is complicated due to (i) the highly heterogeneous body, and (ii) the small geometrical details of the implant. As a consequence of the latter, the length scales in the problem differ by a factor 1000 which yields a multi-scale problem.

Finite-difference time-domain (FDTD) computations can handle the heterogeneity of the body but fully resolving the shortest length scales would lead to overwhelming computation times. Neufeld et al. exploited FDTD to model heating of a single helical conductor in MRI [2]. However, clinically used pacemaker leads feature two helical conductors consisting of several filars each and the design of these details has been shown experimentally to influence the heating [3].

In this work, we therefore propose a modeling approach that emphasizes the multi-scale part of the problem. The method of moments in frequency domain is exploited to model the RF birdcage coil of a 1.5T MRI system together with a homogeneous human body phantom and an implanted pacemaker system. The pacemaker system consists of a pacemaker unit and a lead that features two coaxial helical conductors, insulation, and electrode surfaces. The helical conductors are modeled by straight thin-wire segments. An overview of the model geometry is given in figure 1.

II. RESULTS

First, the validity of the thin-wire approximation is assessed. A straight double helix in free space is modeled with (i) thin-wire segments and (ii) a surface discretization when illuminated by a plane wave with perpendicular incidence and polarization tangential to the helix axis. A comparison between the two modeling approaches is exploited to identify for which problem defining parameters the thin-wire approximation is valid. Within this part of the parameter space, a parameter study is then performed in the MRI setting as described above. The results show that the fine geometrical details of the lead highly influence the induced currents.

III. CONCLUSIONS

It is essential to include the multi-scale features of pacemaker lead heating in MRI during its electromagnetic modeling if accurate results are desired.

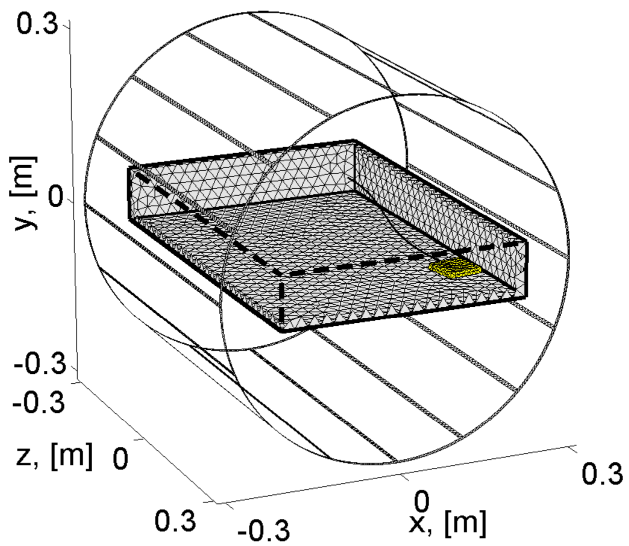

Figure 1: Model geometry with RF birdcage coil, human body phantom, and implanted pacemaker system.

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