High Frequency Electromagnetic Analysis using Hybrid MOM/FEM Method

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Introduction

As the magnetic field strength of current human MRI system increases, the size of the human body becomes comparable to the operating wavelength and coil-sample interactions become significant. Numerical techniques based on solving Maxwell's full-wave equations are essential for the prediction of fields in loads and can provide vital information in designing RF coils and in understanding the behavior of the coils when they are loaded with biological structures. Several, full-wave numerical methods have been suggested for use in MRI numerical simulation applications; for example, the popular finite difference time domain (FDTD) [1-3], hybrid method of moments (MOM)/FDTD [4] and hybrid dyadic green function (DGF)/MOM [5]. In this work, to explore more possible hybrid methods, a new full-wave electromagnetic modeling hybrid using MoM/finite element method (FEM) is tested.

Methods

MoM, an integral equation technique, is well-suited for modeling complex coil structures while in contrast, FEM is very well suited for modeling inhomogeneous dielectric bodies. The tetrahedral elements used in the volume discretisation for the FEM allow for accurate geometrical representation of volumes with curved surfaces, and the formulation furthermore allows for the variation in the material properties from tetrahedral element to tetrahedral element. Thus when these two methods are coupled together, the result is an extremely capable full-wave electromagnetic modeling technique. The hybrid MoM/FEM method that is used in this work is available using commercial software FEKO (www.feko.co.za). To investigate the capability of the hybrid MoM/FEM method and verify its accuracy in calculating the EMFs in biological samples, it is compared with FDTD [3] (in-house software) solution and hybrid DGF/MOM solution. Two simulation examples are demonstrated in this work. Firstly, a square surface coil with dimension of 120×120mm placed 40mm away from a heterogeneous 4 layer concentric spherical phantom that approximately represent a human head [6] and secondly, a shielded 16 rung high-pass birdcage coil also loaded with the spherical phantom is modeled. The operating frequency for both examples is set at 300MHz (7T) and the dielectric properties and the size of the spherical phantom used in the three different modeling techniques is the same.

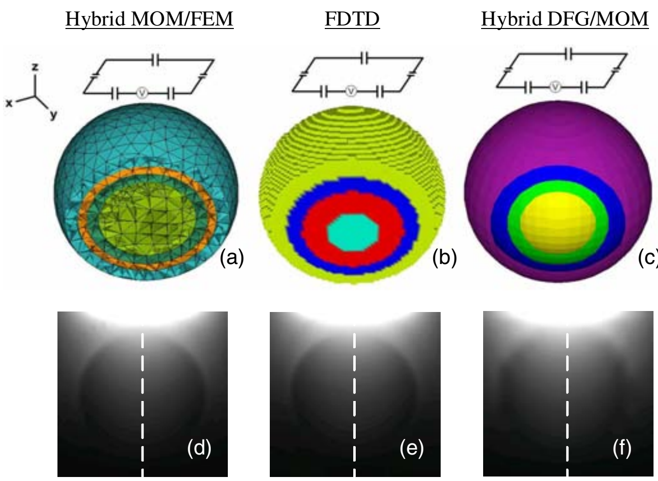


Figure 1. Surface coil simulation

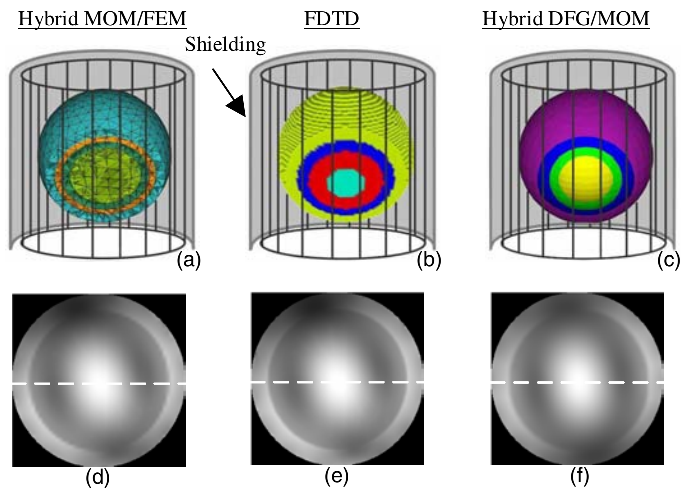
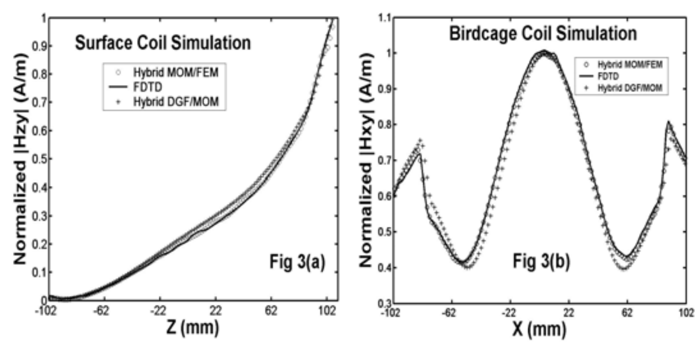


Figure 2. Birdcage coil simulation

Results and Discussion

The overall setup for the two simulation examples are shown in Fig 1(a-c) and Fig 2(a-c). Figure 1(d-f) show the H-field profiles in the spherical phantom (X=0 plane) calculated by the three different modeling techniques for the surface coil simulation while fig 2(d-f) are the H-field profiles in the spherical phantom (z=0 plane) for the shielded 16 rung high-pass birdcage coil simulation. Figure 3(a) is the plot of the three H-field distributions taken along the dotted line as shown in fig 1(d-f) and fig 3(b) similarly is the plot of the three H-field taken along the dotted line of fig 2(d-f). As can be seen from fig 3(a) and (b), the H-field profiles calculated by the hybrid MOM/FEM is very close to the result calculated by the FDTD solution and is also very similar to the hybrid DFG/MOM solution.



Conclusion

The results shown here demonstrated that the proposed hybrid MOM/FEM method is capable of accurately evaluating EMF behavior in biological loads and can be used as an alternative to the popular FDTD method. For this scale of problem, the computation time for Hybrid MOM/FEM is the fastest among the 3 modeling techniques. Further exploration of the algorithms' performance for larger scale problems in MRI is underway. It is anticipated that it can be used to aid in the design and optimization of high frequency RF resonators.

References

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