An Experimental Verification of a Hybrid MoM/FEM Method for RF Simulations in MRI

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Introduction

In previous work, a full-wave electromagnetic hybrid model using a combined method of moments (MoM)/finite element method (FEM) was proposed for use in MRI numerical simulations (1). To verify the accuracy of the MoM/FEM method, two numerical simulation examples involving the evaluation of the H-field profiles inside a heterogeneous 4 layer concentric spherical phantom under the influence of a surface coil and a 16 rung high-pass birdcage coil were each calculated using the proposed hybrid MoM/FEM method, the finite difference time domain (FDTD) method and the hybrid dyadic green function (DGF)/MOM method. A comparison of the results obtained from these three numerical methods show strong agreement, thus suggesting the proposed hybrid MoM/FEM method is capable of accurately evaluating EMF behavior in biological loads. However, as convincing as the numerical verification is, it is nevertheless advantageous and beneficial to verify the results experimentally. In this work, two experiments involving a 2T 2-element receive-only phased array coil and a shielded 11.1T transceive surface coil are both numerical simulated and tested experimentally.

Methods

In the first experiment, an overlapping 2T 2-element receive-only phased array coil is modeled using hybrid MoM/FEM and is shown in Fig 1. Each coil element measured 120×120 mm and 5 distributed capacitors are used for tuning and matching the coil to 85 MHz. An overlapping distance of 92 mm measured between the centers of the two coils is required for decoupling the coils (2). A cylindrical phantom is also modeled accordingly that is used in the imaging experiments. Using voltage sources, the coils are excited and the transmit B_1 fields with an axial plane (*xy* plane) profile, located at the mid section of the phased array coil, are calculated. Applying the reciprocity theorem (3), the receive B_1 fields are calculated from which signal intensity (*SI*) profiles are also calculated (4) and used for comparison purposes with the experimentally acquired images. Fig 2 shows the prototype 2-element phased array coil loaded with a cylindrical phantom. The prototype phased array coil is tested in a Bruker S200 2T wholebody MRI system and a gradient echo imaging sequence was used to acquire axial images of the cylindrical phantom, located approximately at the mid section of the phased array coil. Shown in Fig 3 are the hybrid MoM/FEM calculated *SI* profiles and the experimentally acquired images of the cylindrical phantom by each coil element. For the second experiment, a shielded 11.1T transceive surface coil loaded with a cylindrical phantom is modeled and shown in Fig 4 (part of the shielding is removed to show the modeled surface coil and phantom). The surface coil measured 135×135 mm and 12 distributed capacitors are used for tuning and matching the coil to 470 MHz. The shielding and the cylindrical phantom are modeled accordingly to the actual shielding and phantom used in the experiment. Exciting the surface coil with a voltage source, the transmit and receive B_1 fields located at the mid section of the surface coil are calculated from which the *SI* profile is also calculated. Shown in Fig 5 is the constructed shielded 11.1T transceive surface coil prototype loaded with a cylindrical phantom (Note that the shielding is not shown in the figure). The prototype is tested in an 11.1 T, 40 cm Magnex Scientific (Abingdon, UK) clear bore magnet interfaced with a Bruker Biospec (Billerica, MA) imaging/spectroscopy console and ancillary hardware. Depicted in Fig 6 are the MoM/FEM calculated *SI* profile and the experimentally acquired images of the cylindrical phantom at 11.1T

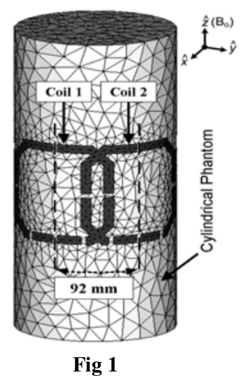

Fig 1

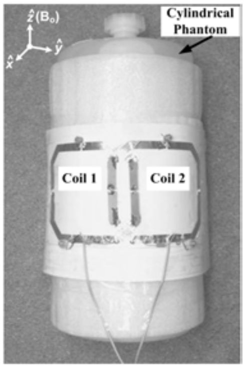

Fig 2

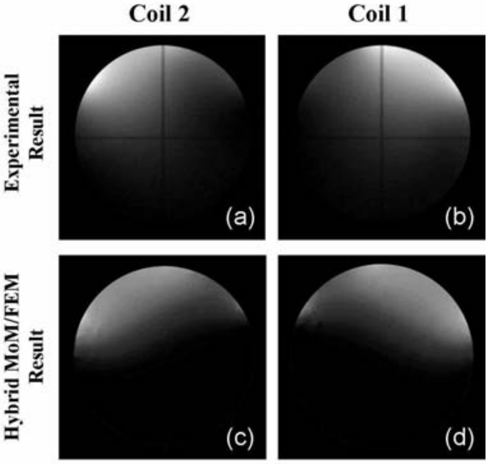

Fig 3

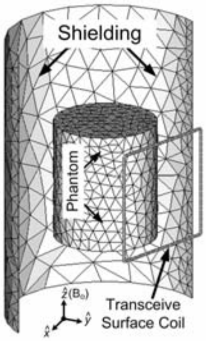

Fig 4

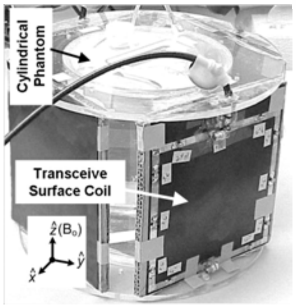

Fig 5

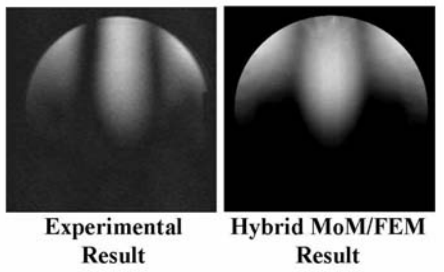

Fig 6

Results and Discussions

From Fig 3 and 6, it can be observed that the numerical results calculated using hybrid MoM/FEM are very close to the experimentally acquired images. In Fig 3, due to the weak isolation when using the overlapping method for decoupling coils, subtle portions of the neighboring coils can be distinguished in both the experimentally acquired and numerically calculated images. For the 11.1T results shown in Fig 6, it can be noted that at ultra high frequency, the wavelength in the phantom become comparable to the size of the surface coil and thus the sensitivity profile of the surface coil has, as expected, significant image inhomogeneity due to wave effects. However these inhomogeneities are still accurately reproduced in the simulation.

Conclusion

In this work, the hybrid MoM/FEM method is experimentally verified. The results for the 2T and the 11.1T experiments show remarkable similarity with simulations, which indicates that the hybrid MoM/FEM method can be used accurately and reliably for low to ultra high field MRI applications. The hybrid MoM/FEM is therefore an alternative powerful full-wave numerical technique that is well suited for a variety of MRI numerical modeling applications.

Acknowledgment

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References

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