Fast Full Wave RF Simulation Scheme for MRI

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INTRODUCTION: Electromagnetic simulation tools such as the finite difference time domain method can take significant calculation (CPU) time in MRI calculations. Not only this can dampen the progress of evaluating the performance of the coil, it renders these methods not viable for real time applications such as multi-transmission methods. This work aims at overcoming this obstacle through developing a stable and fast finite difference time domain (FDTD) [1-2] scheme that is suitable for MRI calculations.

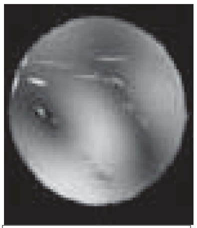
BACKGROUND: The alternating direction implicit FDTD method (ADI-FDTD) [1-2] was developed to overcome the minimum time step required for the standard FDTD method. Unlike the FDTD method, the ADI-FDTD method is unconditionally stable allowing for fewer time steps and shorter run times. ADI-FDTD however can render inaccurate results especially at higher frequencies when the dispersion error rises [2].

METHODS:

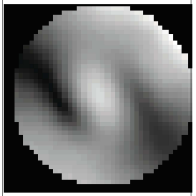
Coil and Experiments: A 16-element TEM resonator model was designed and constructed to image a spherical human head-sized phantom with a conductivity of 1.15 S/m and a relative permittivity (ε_R) of 78.0. The images and the experimentally extracted B1+ field were obtained at 8T (340 MHz).

Simulations: FDTD cell dimensions were 4.786mm in all three directions. The coil was tuned for Larmor precession frequencies corresponding to 3T, 4T, 7T, 8T and 9.4T B_0 fields. The modeled inner and outer rods had a square cross-section. A 2.1 ε_R dielectric fill was used for the 3T, 4T, 7 T, and 8T simulations. The 9.4T simulations required no dielectric filling between the inner and outer rods. A differentiated Gaussian pulse was applied to the two rods (outer and inner) in order to create a circularly polarized (plus and minus) B_1 fields.

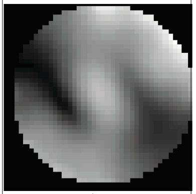
The ADI-FDTD and explicit FDTD methods were both run for each Larmor frequency. An initial FDTD run was accomplished with the phantom in place to record electric field values between the upper and lower inner rods and the outer rods. The time step used in the ADI-FDTD method was ten times the maximum time step (commonly referred to as *Courant-Friedrich-Levy condition*) [1-2] of the FDTD method. This led to a 30% time savings (using same desktop and programming mechanisms) for the ADI-FDTD method over the standard explicit FDTD method. Significantly more time savings could be gained with a better-optimized tri-diagonal matrix solver.



B1+ (Experiment)



B1+ (FDTD ADI)



B1+ (FDTD Explicit)

Fig. 1: Measured and calculated (via FDTD and ADI FDTD) B1+ field at 8T.

RESULTS: Results were captured in a discrete Fourier transform on the time-domain data. Figure 1 shows the calculated (via FDTD and ADI FDTD) and measured B1+ field distributions at 8T. The results show very good correlation between simulations and experiments and between the FDTD explicit (standard) and ADI schemes. Figure 2 displays a graphical depiction of simulation results and shows comparisons between the ADI-FDTD and the FDTD methods for 3, 4, 7, and 9.4 tesla static fields. Figure 2 shows comparisons for the B1+ fields and their respective calculated specific absorption rates (SAR) distributions. The B1+ fields clearly show better correlation at lower frequencies. This is because the ADI-FDTD method has greater phase errors for higher frequencies as well as field-splitting errors which alter the characteristics of the coil. Like the standard FDTD method, a higher resolution grid structure would also reduce phase errors.

The results demonstrate the potential of using a fast ADI FDTD scheme in calculating electromagnetic MRI relevant field components.

Acknowledgements: NIH 1R01EB

References:

1. F. Zheng and Z. Chen. *IEEE Trans. on Microwave Theory and Techniques*, 48, 2000.
2. A. Taflove and S. C. Hagness. Artech House Inc., Norwood, MA, 2000.

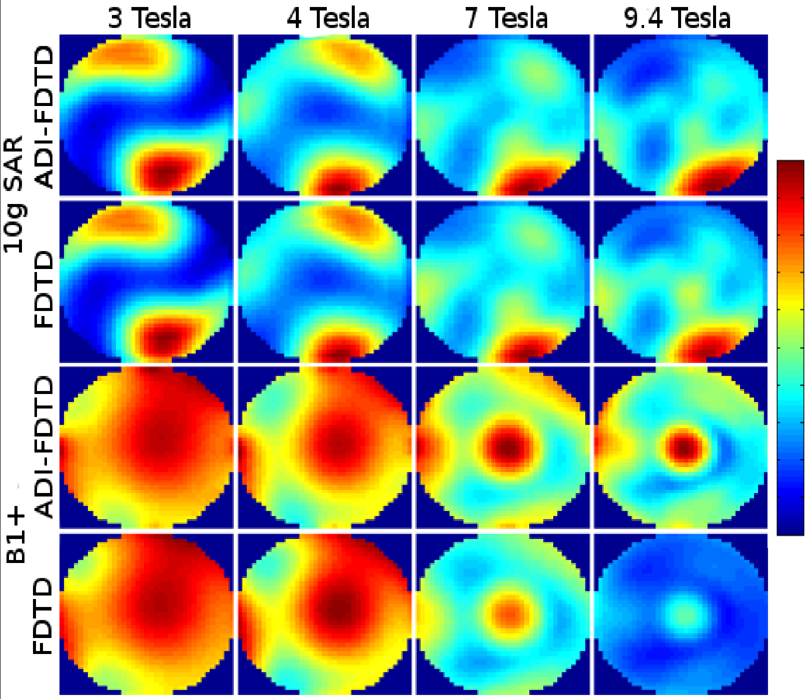


Figure 2: Comparison of the distributions of (IEC/FDA) 10-gram specific absorption rate (SAR) and B1+ field between ADI-FDTD (calculated at 10 X Courant-Friedrich-Levy condition) and the standard explicit FDTD methods for 3, 4, 7, and 9.4 tesla static fields