Simulated and Measured SENSE Array Performance at 7 Tesla

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Introduction: With the advance of parallel imaging, arrays have become the choice of detectors for MRI signal reception. The design of the array coil determines the ultimately achievable MRI signal-to-noise ratio (SNR) and SENSE (1) performance. Optimizing the design of the receive coil is complicated for human imaging at high field, where wave phenomena becomes dominant (2). In this scenario, full-wave electromagnetic simulation methods, such as the FDTD method, are necessary in coil design. In this work, we developed a FDTD simulation program to evaluate the accuracy of simulations to predict array performance, and applied this to a design that was optimized for SENSE imaging at low field (2).

Methods: The FDTD method is a suitable differential-equation-based numerical method for high-field MRI simulations, due to its geometric handling capability and the efficiency of solving very inhomogeneous problems. We have developed a FDTD program with the standard ANSI C++ language. In this work, simulations were performed on a Linux system with 2 GHz AMD Opteron 246 processor. We modeled a gapped eight-element whole-brain receive array built by Nova Medical (Fig.1) and a human head taken from the Brooks' man model (http://www.brooks.af.mil/AFRL/HED/hedr/hedr.html). The resolution is 3mm by 2.7mm by 3mm (in x, y, and z directions). The Perfectly Matched

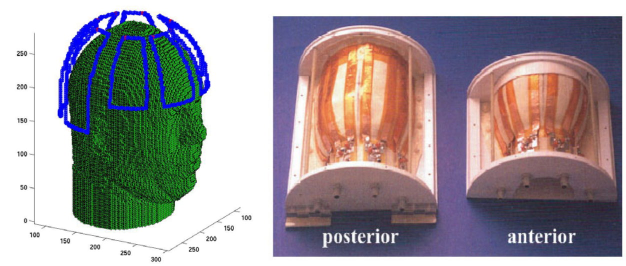

Figure 1: Left: simulation model. Right: the real coil.

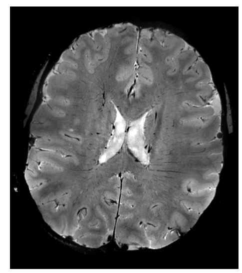

Figure 2: Acquired image.

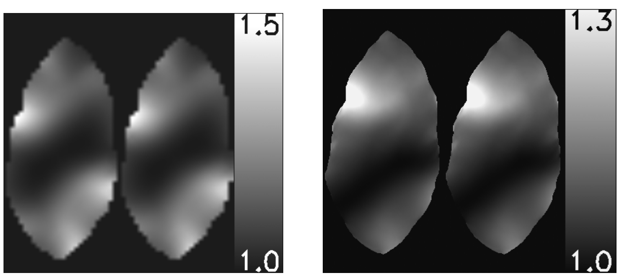

Figure 3: Left: simulated SENSE Rate 2 g-factors (scale MAX =1.51, AVE=1.11). Right: measured SENSE Rate 2 g-factors (scale MAX =1.49, AVE=1.07).

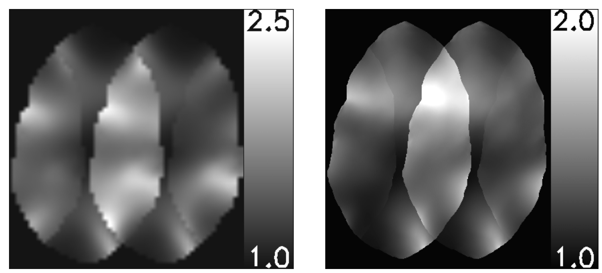

Figure 4: Left: simulated SENSE Rate 3 g-factors (scale MAX = 2.48, AVE=1.47). Right: measured SENSE Rate 3 g-factors (scale MAX=2.49, AVE=2.34).

Layers (PML) method was used to terminate all boundaries. The entire computational domain contains 162x177x147 cells. The core computation takes 339 MB memory and around 80 to 90 minutes CPU time for each coil element. Due to the curvature of the coil elements, about 4mm structural features can be effectively captured. Higher resolution is achievable at the cost of increasing memory and CPU times. First, we simulated both the electric and the magnetic field distribution. The circularly polarized coil sensitivity, noise correlation matrix, and g-factor maps were simulated subsequently. Measurements were made on a General Electric 7T MRI scanner on a human volunteer using a detunable transmit coil (Nova Medical) for excitation. Noise correlation was estimated from a separately acquired noise scan, and g-maps were calculated as described previously (2).

Results and Discussion: Fig. 2 shows an acquired image where the g-factor maps are calculated. Figs. 3 and 4, we compare the g-factor maps obtained by the simulation and measurements. Note that sensitivity maps are scaled individually to better show the fine features. Very good agreements are observed in both Rate 2 and Rate 3 cases. Especially, the simulated and measured maximum g-factors are nearly identical. The minor differences between the shapes of the g-factor maps are mainly attributed to numerical errors inherited in the FDTD method and the fact that the head model in the simulation is different from the subject in real measurements.

Conclusion: The above results demonstrated the effectiveness of full-wave methods in the design of ultra-high frequency SENSE array coil. With realistic models of the coil structure and human head, SENSE g-factors can be accurately predicted.

References: 1) Pruessman, K.P., et al, MRM 42:952-962, 1999. 2) De Zwart, J.A., et al, MRM 47:1218–1227, 2002.