Experimental and Numerical Investigations of SENSE Array Performances from High to Ultra-High Field Strengths

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Introduction: Although theoretical investigations suggest an improvement of parallel imaging (PI) performance at high field strength, few experimental PI performance data is available. Previous studies by using the basis-function methods 1) and the electrodynamic scaling method 2) suggest an improvement in performance for brain MRI at 7T, in particular for high acceleration rates. However, until now, this has not been demonstrated in practice for MRI of the human brain. Here, we employ numerical approaches to study the performances of eight-channel head coil arrays with a fixed geometric size at field strengths ranging from 1.5 to 21.0 Tesla. These simulations are supported by experimental data acquired at 1.5, 3.0 and 7.0 T.

Methods: Three receive-only coil arrays were built for 1.5, 3.0 and 7.0 Tesla respectively by Nova Medical (Wilmington, MA) based on a close fitting, gapped element design. Layout of the elements was, within the construction tolerance of 2-3 mm, identical for all coil arrays (Fig. 1). Experiments were performed on 1.5 Tesla Siemens Magnetom, 3.0 Tesla GE LX and 7.0 Tesla GE LX whole-body scanners respectively. An FDTD program was developed with the standard ANSI C++ language. The simulations were performed on a Linux PC with a 2 GHz AMD Opteron 246 processor. The coil model for the simulations was based on the 7.0 Tesla array and was kept the same for all other field strengths. The human head model was adapted from the Brooks' man (http://www.brooks.af.mil/AFRL/HED/hedr/hedr.html). The computer model of the coil array is shown in Fig. 1 together with the human head model and the transmit coil model. The FDTD resolution is $3.0 \times 2.7 \times 3.0$ mm^3 (in x, y, and z directions). The core computation took 339 MB memory. For each coil element, the CPU time range from 25 minutes for 21.0 Tesla to 6 hours for 1.5 Tesla (due to the conditional stability of the FDTD).

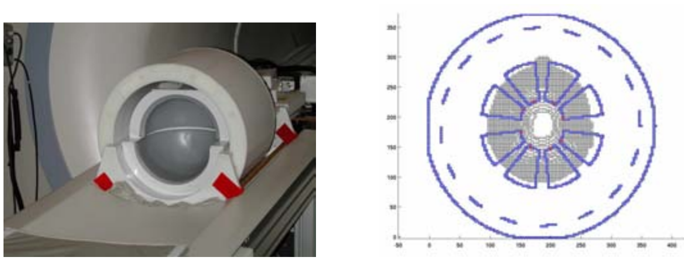

Figure 1: Left: 7 T coil array inside transmit coil. Right: top view of the model.

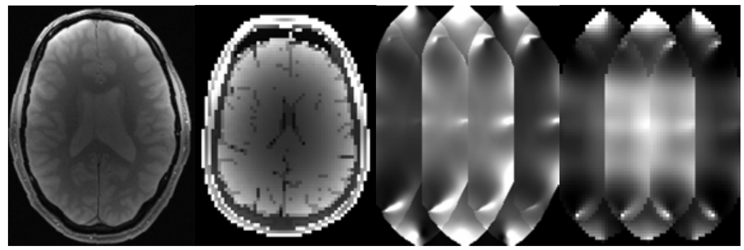

Figure 2: 1.5 Tesla results. Left: acquired Gradient Echo image. Mid-left: simulated phase-sensitive combined SNR map. Mid-right: measured rate-4 g-factor map. Right: simulated rate-4 g-factor. The image and the SNR map are scaled by 1.0. The g-factors are scaled by 6.0.

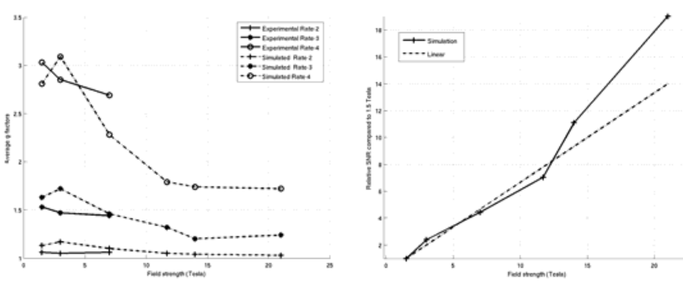

Figure 3: Left: measured and simulated g-factors Right: simulated SNR.

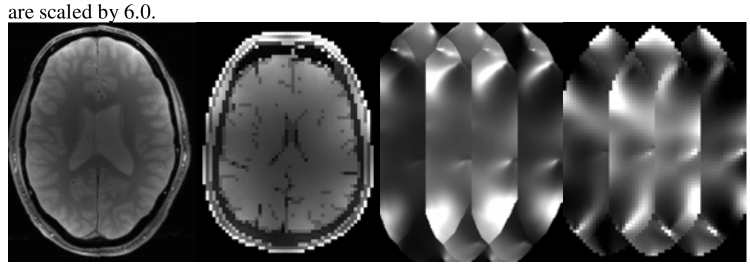

Figure 4: 7.0 Tesla results. Left: acquired Gradient Echo image. Mid-left: simulated phase-sensitive combined SNR map. Mid-right: measured rate-4 g-factor map. Right: simulated rate-4 g-factor. The image and the SNR map are scaled by 4.66. The g-factors are scaled by 6.0.

Results and Discussion: The measured and simulated g-factors are given in Figs. 2 and 4 for 1.5 and 7.0 Tesla respectively. The simulation and measurements agree well despite the difference of the anatomical structures. Rate-2 and rate-3 g-factor maps were also compared. Fig. 3 summarizes the average g-factor and the simulated SNR respectively. It is clear in both measurement and simulation that the g-factor in general decreases at high-field and high acceleration rate. This is because shorter wavelengths support more rapid field variations that are desired by the optimal SENSE performance 2). The slight increase of g-factors at 3.0 Tesla for fixed coil geometry also corresponds to the theoretical results 1) and 2) well. It is not observed in experiments likely because the differences in experimental conditions. Meanwhile, coils with fixed geometric size are electrically larger at higher fields (also due to shorter wavelengths). This is equivalent to geometrically larger coils which penetrate more deeply and cover the central brain better. Because of this improved SNR coverage in the brain, the average SNR increases faster than linearly at ultra-high fields.

Conclusion: The above shows that for a coil array with fixed geometric size, shorter wavelengths at higher field strengths benefit and the g-factor at higher acceleration rates. At ultra-high field strengths, the g-factor decrease levels off while the average SNR increases more than linearly.

References: 1) Wiesinger F et al, MRM 52:376-390, 2004. 2) Ohliger, M.A. et al, MRM 50:1018–1030, 2003.