Parallel Imaging and Acceleration in the Johnson Noise Dominated Regime

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Target Audience: Those interested in portable MRI, low field imaging, SENSE acceleration, and inductive coil and array construction at low magnetic fields.

Purpose: Low field imaging offers a potentially transportable and rapidly deployable human imaging system. Current research for low field human imaging is limited and generally uses superconducting quantum interference device (SQUID) sensors[1]. At conventional magnetic field strengths body noise dominates, resulting in strongly correlated noise on each receive coil in the parallel array. At low field, uncorrelated Johnson noise dominates, providing a benefit to parallel imaging and accelerated imaging using SENSitivity Encoding (SENSE). The aim of this study was twofold. First, construct an eight-coil receive only array for 276 kHz. Second, acquire accelerated images using SENSE.

Methods: NMR parallel imaging at low frequency is a new regime; optimal parameters for inductive receive coils are unknown from the literature. Three design parameters were identified: diameter, wire gauge and number of turns. Parameters were selected using a fractional factorial design at the factor levels indicated in Table 1. Only circular coils were tested.

Once optimal parameters were determined an 8 channel receive-only 276 kHz ring array was constructed. Imaging of 13.1 cm diameter phantoms filled with 0.04% Gadolinium doped saline (0.9% NaCl) was performed in a previously described[2] custom built very-low field MRI scanner with a 6.5 mT biplanar electromagnet and biplanar gradients and eight receive channels. A 3D balanced Steady State Free Precession (b-SSFP) sequence with full Cartesian acquisition of k-space was applied over five 20 mm thick slices, with FOV=225×160×100 mm^3, acquisition matrix=64×64×5, TE/TR=12/23 ms, number of averages (NA)=150. Image reconstruction was performed with a sum-of-squares method[3].

1D SENSE reconstruction (reduction factor R=2) was simulated on the middle slice of the fully sampled image using in-house code previously developed in our lab. The noise covariance matrix and coil sensitivity maps were estimated from the data. Finally, the corresponding experiment (R=2) was performed from a structured phantom. Noise data were acquired using a b-SSFP sequence with RF transmission disabled (sequence time = 704s). Sensitivity maps were estimated from the fully sampled data set acquired previously using third-order polynomial smoothing. Aliased images were unfolded using a modified version of the simulation code.

Diameter	Gauge (AWG)	Number of Turns: 3	10	20	30	50	100
8 cm	20	+	+	+		+	
8 cm	24		+		+		
8 cm	28					+	+
14 cm	24						+

Table 1. Fractional factorial design for determing optimal coil design. Parameters tested were number of turns, size of wire and diameter of coil.

Figure 1. 8 channel receive only 6.5 mT parallel imaging array.

Results: Optimal coil design parameters were identified as 8 cm diameter, 24 gage and 30 turns. An 8 channel receive only array with an inner diameter of 15.6 cm was built (Figure 1). Geometric decoupling between neighbors was -38 dB or less for nearest neighbors and -11dB or less for next nearest neighbors. Figure 2 shows the design of the structured phantom (2a), as well as the reconstructed image of the structured phantom (2b) and a homogeneous phantom (2c) acquired with the 8 channel array. Figure 3 shows the noise covariance matrix (3a) and the correlation coefficient matrix (3b) of the array. Figure 4 shows the results of simulated (left) and actual (right) SENSE reconstructed images.

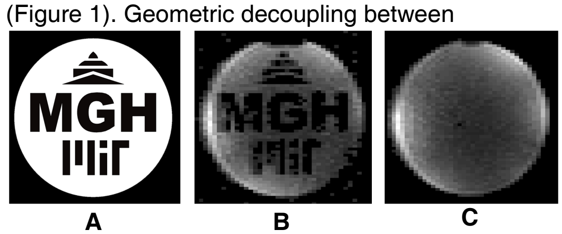

Figure 2. Phantom pattern (**A**), reconstruction of structured phantom (NA=150, **B**) and reconstruction of homogeneous phantom (NA=200, **C**). Images are masked to the phantom.

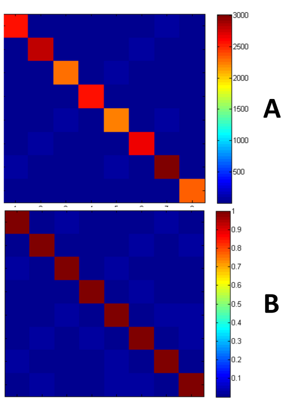

Figure 4. Noise covariance (**A**) and correlation coefficient (**B**) matrices.

Discussion: Due to low thermal signal, low field imaging requires signal averaging, increasing scan time. With the eight channel array, SENSE acceleration can be implemented, reducing scan time by at least a factor of 2. The negligible noise correlation between channels benefits this approach.

Conclusions: These results represent the first parallel and SENSE reduction images attained in the Johnson noise dominated regime. Development of parallel imaging and SENSE acceleration are important steps toward human imaging at very-low field. Future work will optimize the sequence to further improve image quality. Additional array designs will be tested and SENSE combined with random undersampling strategies will be investigated.

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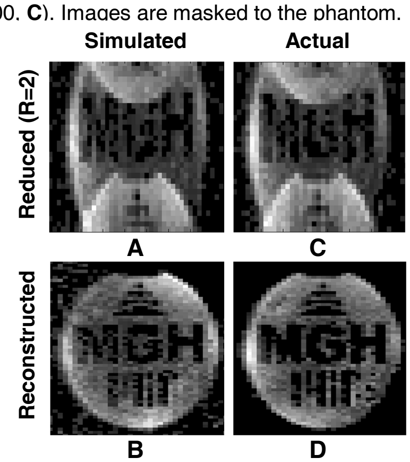

Figure 3. Simulated (**A**,**B**) and actual (**C**,**D**) results for SENSE reconstruction. Images are masked to the phantom.

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3. Roemer PB, et al. MRM. Nov 1990;16(2):192-225