Parallel Imaging and Acceleration in the Johnson Noise Dominated Regime

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Introduction

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 high 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.

Material and methods

NMR parallel imaging at low frequency is a new regime and the optimal receive coil parameters are unknown from the literature.

Coil design and construction

A phased array coil was built on a cylindrical form with the 8 coils individual elements forming a ring. This results a circle with an inner diameter of 15.6 cm. The design for the coil former was created in a 3D CAD program (Google Sketchup) (Figure 1.A) and printed on a 3D printer (Dimension SST 1200es) in polycarbonate.

Optimal coil design parameters were identified as 8 cm diameter loops, 24 gauge and 30 turns. Each individual element required its own tuning and matching circuit board, which was designed and made on our circuit board router. Each coil element was placed on the 3D form and tuned/matched to 276 kHz with at least -20 dB return loss (Table 1). A photograph of the complete 8-channel receive array coil is shown in Figure 1.B.

<table>
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<th>Coil</th>
<th>Freq (kHz)</th>
<th>dB</th>
<th>Coil</th>
<th>Freq (kHz)</th>
<th>dB</th>
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<td>8</td>
<td>276.25</td>
<td>-35</td>
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</table>

Table 1: Tuning frequency (in kHz) and return loss (in dB) for the 8 receive coils in the parallel array coil.

A decoupling solution was decided upon because it could be quickly implemented with minimal modification to the array and hardware and required no extra cables or circuitry. It consisted of placing high-speed silicon crossed-diodes (BAW99) in series with the transmit coil and in parallel with each receive coil. A schematic is shown in Figure 2.

The crossed-diodes in the transmit circuit allow the transmit pulse to reach the transmit coil when the pulse voltage is greater than the bias voltage (nom. 0.7 VDC), a condition easily met during RF transmit. When receiving, however, the voltage induced in the Tx coil from precessing magnetization is too small to forward bias the crossed diodes, and the Tx coil remains decoupled during receive.

On the receive coil, the crossed-diodes short to ground any induced voltage greater than the bias voltage, thus decoupling Rx during transmit.

MR Acquisition

Imaging of a 13.1 cm diameter structured phantom filled with doped-water was performed in a previously described [2] custom built very-low field MRI scanner, with a 6.5 mT biplanar electromagnet and biplanar gradients. A 3D balanced Steady State Free Precession (b-SSFP) sequence (see diagram Figure 4) with full Cartesian acquisition of k-space was used with FOV=192×169×256 mm3, acquisition matrix=64×64×64, TE/TR=14/29 ms, number of averages (NA)=60. The readout duration was 7.04 ms with a total readout bandwidth of 9091 Hz. Total acquisition time was 17 min. Image reconstruction was performed with a sum-of-squares method [3].

Conclusion

These results represent the first parallel and SENSE reduction images attained in the Johnson noise dominated regime. 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. 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.

References


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