A single channel spiral volume coil for in vivo imaging of the whole human brain at 6.5 mT

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Purpose: MRI at low magnetic field (<10 mT) without cryogenic or hyperpolarization techniques presents unique engineering challenges. Imaging coils must maximize coverage over the volume of interest while minimizing losses in a regime unusual in contemporary MRI—where Johnson noise dominates the noise floor. Our previous work validated our scanner hardware and pulse sequences MRI at 6.5 mT. The purpose of the present work is to construct a high-performance coil for low-field imaging of the human brain *in vivo*.

Methods: Our previous coils focused on implementing array coil technology common at clinical field strengths, and we constructed an 8 channel receive-only coil for our 6.5 mT low-field imager at 276 kHz. While our results were promising[1,2], a lack of low noise high-impedance pre-amplifiers at our frequency regime prevented us from achieving sufficient coil decoupling, resulting in images with poor SNR. We present here a single channel coil with greatly improved SNR for these applications.

Figure 1: Form fitting helmet with 30-turn spiral design.

We designed a spiral volume coil design for combined Tx and Rx and optimized for human head imaging in the transverse B0 field of our low field scanner. This places the receive element close to the head while still covering the entire volume uniformly. Additionally, the symmetry of a spherical spiral results in a homogeneous magnetic field over its volume, minimizing B1 inhomogeneity[3,4]. Losses in low field imaging are mainly due to resistive losses in the coil (the so-called Johnson noise regime). Rather than lower this resistance by cooling, we instead use of multistranded Litz wire. When compared to a solid copper wire of the same gauge, a loop made of Litz wire will have the same inductance but a fraction of the AC resistanc, resulting in a lower noise floor and higher image SNR.

The optimal number of turns and appropriate wire gauge were determined through simulation. The helmet shape was designed to fit closely to an anatomically accurate human head model. The spiral path was generated in a custom MATLAB (Mathworks Inc.) script and imported into BiotSavart (Ripplon Software Inc.) for an estimate of inductance. Resistance was computed from the estimated wire length and the characteristic impedance per length of wire for that gauge. Coil Q was estimated as ωL/R. Bandwidth was estimated from the Q value. We iterated through several designs until we achieved our target Q~40 and BW=6kHz.

Results: From simulations, we built a 30-turn spiral wound with Type 1 40/38 Litz wire. Our aligned turn-to-turn spacing was 5.6 mm. The final design was 3D printed using fused deposition modeling technology with polycarbonate in a Fortus 360 mc printer (Stratasys, Eden Prairie, MN, USA), (Figure 1).

Images were acquired at 6.5 mT in a head shaped phantom using 3D b-SSFP with 50% undersampling. Resulting voxel size was 3.9×3.5×16.7 mm^3 (NA=110) (Figure 2a). A maximum in-plane SNR of 130 was calculated. An image of a similar slice obtained with the 8-channel array coil is shown for comparison (Figure 2b, combined image using RSS, voxel size = 4.4×4.2×22 mm^3, NA = 80, max SNR = 16.5).

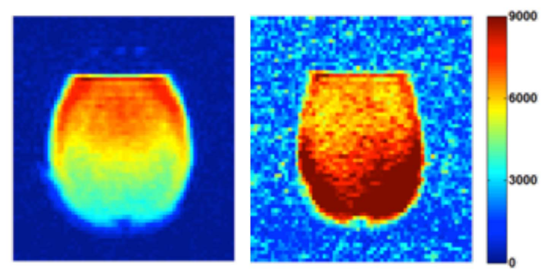

Figure 2: Equivalent slices in a head phantom acquired using the single channel spiral coil (A) and the 8-channel array (B) at 6.5 mT. Images are scaled by their maximum intensity.

19 slices of structured resolution phantom imaged with optimized spiral volume coil are shown in Figure 3. This four-quadrant phantom is filled will liquid-filled spheres of various diameters. Voxel size in this scan is 3.5×2.5×5 mm^3 with NA=40 and maximum SNR of 24.8. Total acquisition time is 10 minutes.

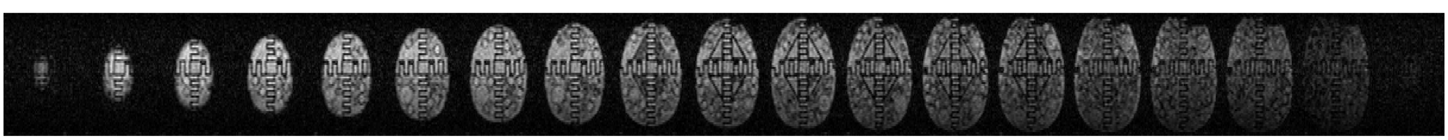

Figure 3: Axial view of a multi-compartment head-shaped phantom acquired with the Litz spiral volume coil at 6.5 mT in 10 minutes.

Discussion: A 30-turn single channel volume spiral coil designed for low field imaging significantly outperformed our 8-channel array coil. By minimizing losses in the coil, maximizing filling factor and eliminating coupling issues, we were able to obtain significantly higher SNR.

Conclusions: A high filling factor human-head Tx/Rx spiral volume imaging coil was successfully designed and constructed for 6.5 mT (276 kHz).

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