# Low Cost High Performance MRI

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## Purpose

Magnetic Resonance Imaging (MRI) is unparalleled in its ability to non-invasively visualize anatomical structure and function with high spatial and temporal resolution and a broad range of clinically relevant contrasts. Yet to overcome the low sensitivity inherent in NMR-based detection, the vast majority of clinical scanners incorporate superconducting magnets operating at 1.5, 3 tesla (T), and more exceptionally at 7T. These powerful magnets are massive, costly to purchase and maintain, and operate with very strict infrastructure demands and siting requirements that preclude operation in many environments. For brain imaging, low-field alternatives have been developed that rely on superconducting quantum interference devices (SQUID) detector arrays combined with magnetic field cycling techniques [1-4]. To date, this approach is limited by prohibitively long acquisition times (> 1 hr) and restrictions on attainable fields of view. We demonstrate here 3D brain MRI *in vivo* at 6.5mT (more than 450 times lower than clinical MRI scanners) in 6 minutes, by combining a high performance single channel Tx/Rx coil with modern undersampling techniques and b-SSFP [5].

**Figure 1 :** 3D printed single channel volume head coil. The coil was used for both transmit and receive at 276 kHz (6.5 mT)

## Methods

To minimize $B_1$ inhomogeneity and maximize filling factor, a close fitting single channel inductive head coil for operation at 276 kHz was designed and 3D printed (Fig. 1). The coil features a 30-turn 3D spiral with turn-to-turn distance of 5.6 mm, thus ensuring the $B_1$ field produced is everywhere orthogonal to the main magnetic field $B_0$. The hemispheric spiral design results in a very homogeneous magnetic field [6,7] over the volume of interest, making it suitable for both RF transmit and receive. Litz wire was selected due to its lower AC resistance compared to solid copper wire, reducing the Johnson noise of the coil while maintaining the same inductance. Previously [8], we described our use of undersampling strategies to accelerate low-field imaging. We make use of this here by randomly sampling 50% of k-space using a variable density Gaussian pattern. Once reconstructed, the images were apodized and processed using Perona and Malik anisotropic diffusion filtering [9] (ADF).

## Results

Three-dimensional undersampled images acquired in 6 minutes (NA=30) are shown in Fig. 2 for each of the three spatial orientations (axial, coronal, and sagittal). We obtain 2.5×3.5×8.5 $mm^3$, 2.5×3.5×14.4 $mm^3$, and 2.5×3.5×11.5 $mm^3$ voxel resolution images in axial, sagittal and coronal orientation, respectively. Images with NA=160 acquired at 6.5 mT are compared to b-SSFP images acquired at 3T in Fig. 3.

## Conclusion

At 6.5 mT, (more than 450 times lower than clinical MRI scanners) we demonstrate 2.5×3.5×8.5 $mm^3$ resolution in the living human brain in 6 minutes. We contend that robust non-field-cycled low-field implementations of MRI (< 10 mT) have the potential to make clinically relevant images and set new standards for a completely new category of affordable and robust portable devices.

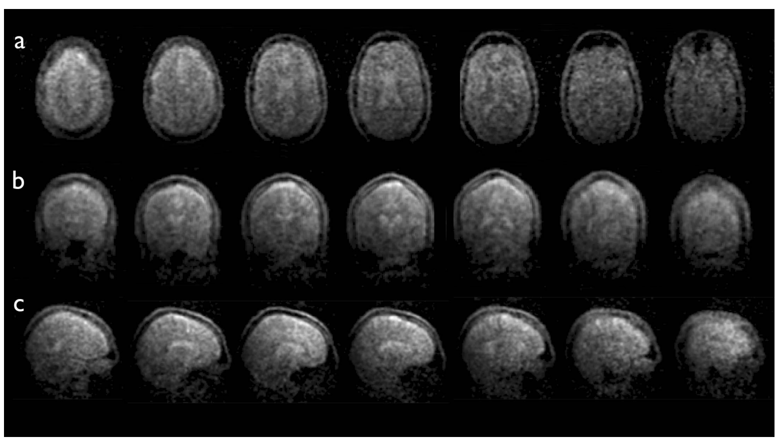


**Figure 2:** 3D images of the living brain (7 central slices of 15 slice dataset are shown) acquired in 6 minutes at 6.5 mT (276 kHz) in a. axial, b. coronal, and c. sagittal orientation. Acquisition matrix: 64×75×15, Flip angle = 70°, BW = 9091 Hz, TR/TE= 23/11.7 ms, NA=30, voxel size: a. (2.5×3.5×8.5) $mm^3$, b. (2.5×3.5×11.5) $mm^3$, and c. (2.5×3.5×14.4) $mm^3$.

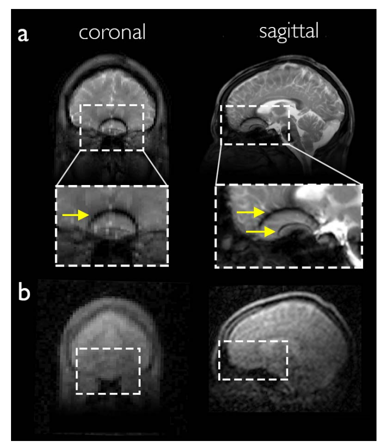


**Figure 3:** Comparison of b-SFFP images at a. 3T and b. 6.5 mT. Strong banding artifacts appear at high magnetic field (yellow arrows) whereas no artifact is seen in the images acquired at low field.

**References:** [1] Zotev *et al.* J. Magn. Res. 2008 194(1):115-120; [2] Espy *et al.* J. Magn. Res. 2012 228:1-15; [3] Vesanen *et al.* Magn. Reson. Med. 2012 69(6):1795-1804; [4] Inglis *et al.* PNAS 2013 110(48):19194-201; [5] Scheffler K *et al.* Eur Radiol 2003 13:2409-18; [6] Harpen J. Magn. Res. 1991 94(3):550-556; [7] Everett *et al.* J. Scientific Instruments 1966 43:470-474; [8] Sarracanie *et al.* Magn. Reson. Med. 2013 71:735-745; [9] Perona *et al.* 1990 IEEE Trans. Pattern Anal. Mach. Intell. 12(7):629-639.

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