Balanced SSFP Imaging using a Biplanar MR Microscope

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Introduction Magnetic resonance microscopy (MRM) places high demands on all elements of the imaging system, particularly the gradient set. The drive for higher spatial resolution imaging is generally limited by a combination of the amount of time available and a minimum acceptable contrast-to-noise ratio in the final image. Pulse sequences which improve the temporal SNR efficiency are therefore extremely valuable in MRM applications. Balanced steady-state free precession (bSSFP) provides a very high temporal SNR efficiency but has an off-resonance response that introduces null signal banding. Various methods exist to minimize or eliminate these bands, including phase-cycling over multiple averages (1). We present here a biplanar gradient coil designed to minimize eddy currents and allow high SNR efficiency bSSFP with repetition times of 2.5ms at isotropic spatial resolutions significantly less than 100 microns.

Methods The biplanar magnetic field gradient set consists of a pair of opposed planar, water-cooled x, y and z gradient coil modules (2) supported within a frame (Figure 1 Left). Each axis pair is driven in series and the coils are coupled to the gradient amplifiers with a matching inductance to prevent current oscillations. Water cooling is coupled to the gradient modules via a high thermal conductivity ceramic block (Shapal-M). A single-turn Helmholtz RF coil was used for RF transmission and reception. The gradient-RF coil assembly is mounted in a frame designed to fit within the 120 mm diameter bore of the standard cylindrical gradient set (deactivated for biplanar gradient use). All images were acquired with a 7 Tesla 310 mm horizontal bore magnet and a Bruker Biospec Avance console. Demonstration imaging of a fixed mouse brain enhanced with 5 mM gadoteridol using 3D bSSFP (TR/TE = 2.5ms/1.25ms, 128 x 128 x 128 matrix, 55um x 62um x 60um voxel) at four phase advances was performed for a total imaging time of 11m22s.

Results and Discussion Eddy currents were found to be negligible due to the large coil to cold-surface distance, requiring no additional pre-emphasis of current waveforms. Four volumetric bSSFP images with phase advances of 0°, 90°, 180°, and 270° were acquired with a mean tissue SNR following Euclidean averaging of 42 estimated using the median absolute deviation (MAD) of a noise-only ROI. Mean temporal SNR efficiency (SNR/√T), was 1.6 /√s. A high intensity "annafact" was observed, due to unencoded cooling water signal, and was minimized by baseline correction in k-space. Geometric distortion was minimal within the designed target volume and is correctable using estimated field maps at the periphery of the mouse brain outside the target volume.

Conclusions Biplanar gradient coils are very well suited to high temporal efficiency pulse sequences including bSSFP which place stringent demands on gradient waveform accuracy, maximum gradient amplitude and slew rate. We have demonstrated the utility of this class of gradient coil for high resolution structural imaging of fixed mouse brain samples with high SNR temporal efficiency and isotropic spatial resolutions on the order of 60 microns at 7 Tesla. This hardware is well-suited to high resolution MR imaging of chemically-fixed tissue samples, including whole early-stage mammalian embryos, whole mouse brains and thick tissue slices.

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References (1) Bangerter et al. Analysis of multiple-acquisition SSFP. Magn Reson Med (2004) vol. 51 (5) pp. 1038-47 (2) Demyanenko et al. A uniplanar three-axis gradient set for in vivo magnetic resonance microscopy. J Magn Reson (2009) vol. 200 (1) pp. 38-48

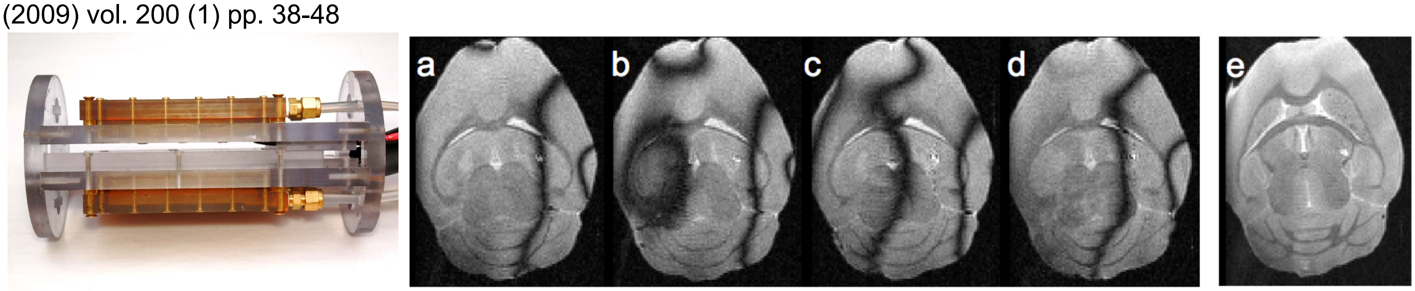

Figure 1: (Left) Biplanar gradient set consisting of a pair of opposed three-axis, water-cooled planar gradient coil modules. (Right) bSSFP imaging of a fixed mouse brain at 7 Tesla using the biplanar MR microscope. bSSFP images at four different RF phase advances are shown: (a) 0º (b) 90º (c) 180º (d) 270º (e) Euclidian sum of (a)-(d). Total imaging time was 11 minutes 22 seconds at a spatial resolution of 55 x 62 x 60 microns for a mean SNR of 42.