Design of Multiple-Imaging-Region Gradient Coil for Parallel Mouse Imaging

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Introduction: Imaging of mice using MRI is a critical part of studies investigating human diseases such as cancer, multiple sclerosis, and stroke. Currently it takes multiple hours to image a single mouse, and the number of mice required to properly complete a large experiment can be on the order of several hundred [1]. This represents a huge time and financial burden for researchers and granting agencies that support mouse imaging. In this abstract we apply stream function methods to design gradient coils capable of imaging three mice in parallel. We simulate the performance of multi-imaging-region (MIR) coils and compare inductance, imaging region size, gradient efficiency, and figure of merit against standard single-region gradient coils. Additionally, we show that a MIR coil provides significant performance increases over standard gradient designs, and that the concept can be extended to more than three imaging regions.

Methods: We have written an extensible software library capable of analyzing a coil based on its wire pattern called MPCODE. By representing a wire pattern as a finite number of straight elements, we can calculate the resulting magnetic field, gradient field, gradient uniformity, imaging region size, and inductance. To produce the wire pattern required, stream function design methods were used. The contours of a stream function give the location of wires required to produce a given current density. All gradient designs shown are Y-Axis gradient coils. The stream function for a Y-Gradient coil is characterized by a sinusoidal Φ profile and a "saw tooth" shaped Z-profile. By manipulating these profiles, we derived the wire pattern for gradient coils with a standard single imaging region, a stretched single imaging region, and three imaging regions. All coils were initially modeled with a 1m radius and were then scaled down to 0.1m radius for performance evaluation.

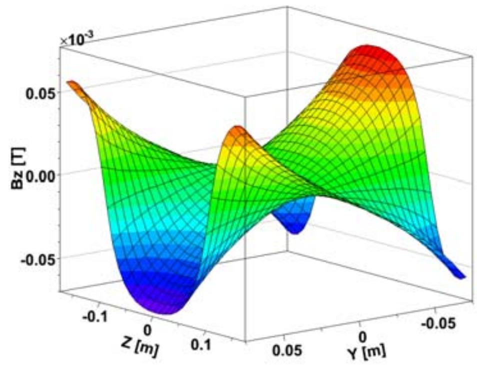

Figure 1: B-Field of Single Imaging Region Gradient Coil at R = 0.1m

To compare the coil designs, we calculated the gradient efficiency at the centre of the imaging region and the percent deviation over the YZ plane. The size of the imaging region for these coils is length limited in the Z-Axis; therefore, the imaging region size was calculated to be the length in the Z-direction which maintained <= 30% deviation in local gradient strength. This is a conservative estimate as image warping due to gradient inhomogeneities of up to 50% can be corrected in post-processing on commercial scanners.

To quantify the gradient coil's performance for all imaging regions, we use a figure of Merit that is invariant to winding density and coil radius. Merit is defined as $\eta \cdot a^{2.5} \cdot L^{-1/2}$ where η is gradient efficiency at the centre of the imaging region in mT/M/A, a is the radius of the coil in meters, and L is the inductance of the coil in Henries.

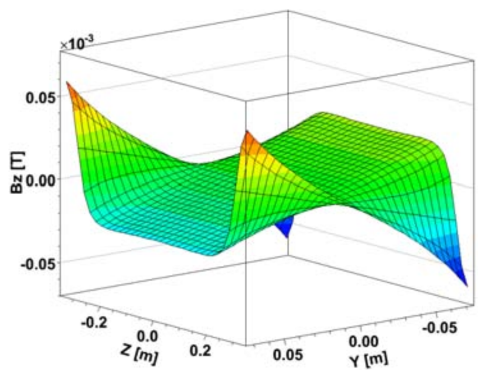

Figure 2: B-Field of Stretched Single Imaging Region Gradient Coil at R = 0.1m

Results and Discussion: Table 1 summarizes our results for the three designs investigated, and illustrates that there are significant benefits in designing a MIR gradient coil. Figure 1 shows the magnetic field produced by a standard gradient coil of 10cm radius. This design has the best figure of merit at 0.3130, with an imaging region of 11.8 cm. Another standard single-region, 10cm radius gradient design was produced with an imaging region of 47.4 cm. Figure 2 shows the resulting magnetic field. The increased inductance and reduced gradient efficiency causes a dramatic decrease in merit to 0.0889. Comparing this to the MIR (3 region) design (Figure 3), we find the MIR coil provides 3 imaging regions of at least 11.7cm in length, and merit drops by only 28% to 0.2330 in the worst case. This means that three animals could be imaged simultaneously without significant performance penalty.

Table 1: Simulated Coil Properties

Coil Type	Inductance [μH]	Imaging Region Centre Z [m]	Imaging Region Size [m]	Gradient Efficiency [mT/m/A]	Merit
Single	76	0.0	0.118	-0.8638	0.3130
Single Stretched	114	0.0	0.474	-0.3040	0.0889
3 Region	151	+0.2	0.117	-0.8680	0.2230
		0.0	0.118	0.8743	0.2246
		-0.2	0.117	-0.8653	0.2230

In order to collect independent and distinguishable signals from each subject in the MIR coil, multiple independent RF channels (one per mouse) would need to be implemented; however, with current generation scanners now routinely equipped with 16 receive channels, this is not a significant problem. In fact, the separation of the imaging regions would facilitate the design of independent RF receive channels. The obvious difficulty with this concept is the fact that the main magnet must be designed with a sufficiently long homogeneous field region to cover the multiple gradient regions. Although this would likely be infeasible for human imaging on large magnets, it would be possible to construct a MIR gradient coil insert for use with small animals on a clinical MRI system. In this configuration, the relatively long (40 to 50cm DSV) uniform region of the main magnet would be sufficient to accommodate several small animals within a suitably designed MIR gradient coil.

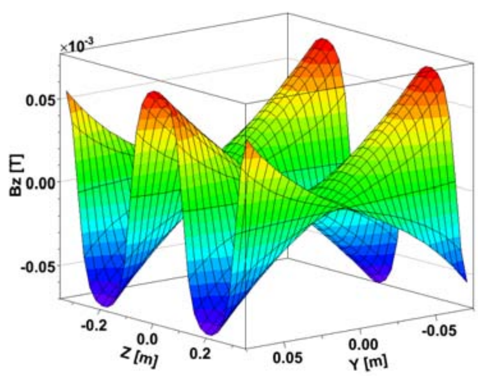

Figure 3: B-Field of 3 Imaging Region Gradient Coil at R = 0.1m

References: [1] Nieman BJ, Bock NA, Bishop J, Sled JG, Chen XJ, Henkelman RM. MRM 54 (3): 532-537 (2005)

Acknowledgements: NSERC Discovery Grant Program