Optimized Longitudinal and Transverse Gradient Coils with up to Seven Imaging Regions

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Introduction: Imaging of mice using MRI is a critical part of studies investigating the genetics behind human diseases such as cancer, atherosclerosis, and cardiac disease. It can take 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 tens of thousands [1]. This represents a huge time and financial burden for researchers and granting agencies that support mouse imaging. It has been shown that parallel imaging of mice using a standard clinical MRI scanner is both possible and provides significant increases in throughput [1]. A gradient coil insert with multiple imaging regions would allow significant increases in throughput while maintaining gradient strengths required for high performance imaging [2]. In this abstract we present the results of a systematic computer simulation design study of multiple-imaging-region (MIR) gradient coils. The parameter space has been mapped for one, two, three, four, five, and seven imaging region gradient coils, and an optimal three-axis, three-imaging-region, gradient coil insert design was selected for construction.

Methods: There are three parameters considered in this study: number of imaging regions (*N*), spacing between imaging regions (spacing), and the desired extent of uniform gradient (length). Both Transverse and Longitudinal gradient coils were considered. To allow rapid and complete coverage of the parameter space, a computer simulation was created capable of generating gradient coil designs using stream function (Transverse) and Constrained Current Minimum Inductance (Longitudinal) methods. Each design was capable of generating multiple imaging regions along the *z*-direction, and the wire pattern of each gradient coil was discretized to allow for numerical evaluation of coil performance. Gradient efficiency (η), imaging region size (Diameter Spherical Volume (DSV)), inductance (L), and resistance (R) were calculated for each coil design. For each value of N, approximately 144 designs were evaluated, and the study compares over 1400 coil designs in total. To quantify the performance of each gradient coil, a figure of Merit (*M*) was defined as $M = \eta\, a^{2.5} / L^{-1/2}$ 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. All coils were modeled with a 0.1m radius. DSV for each imaging region was calculated by mapping percent deviation of eta from the center of the imaging region. The largest sphere fitting within 30% gradient deviation was set as a conservative figure for DSV. In practice, the wire pattern for a multi-imaging-region coil is connected in series and all regions are assumed to be driven simultaneously by a single amplifier.

Results and Discussion: Figure 1 shows *M* as a function of length and spacing (both per unit coil radius) for transverse designs with 3 imaging regions. The optimal design (largest *M*) is marked with a (+), but an area of near optimal lengths and spacings is evident. Achieved DSV (per unit radius) as a function of length and spacing is shown in Figure 2. Smaller lengths and spacings result in smaller DSVs, and the required imaging volume will depend on the application. Imaging region spacing is an important parameter both in terms of its impact on gradient coil performance, as well as its indirect effect on the degree of possible interactions between adjacent RF receiver coils.

The performance of the optimal transverse design for each *N* is summarized in Table 1 where all designs have been scaled to a common inductance of 600uH. Similarly, the results for the longitudinal study are presented in Table 2. Although Merit (and therefore eta) decreases monotonically with increasing N, the critical observation is that N can be increased from 1 to, for example, 3, with an approximate decrease in performance of only 31%. This suggests that the idea of producing and operating multiple region gradient coils for parallel mouse imaging is a potential means of dramatically increasing overall throughput. Our results indicate that gradient coils with at least 7 separate imaging regions can be created without difficulty.

In practice, these gradient inserts are used with a clinical MRI scanner, and therefore all imaging regions must fit within the homogeneous region of the main field (typically 40-50cm). Ultimately, this is the fundamental restriction on multiple-imaging-region gradient coils. Based on the results of this design study, a three-axis gradient insert for mouse imaging was designed for a 3T scanner with 40cm main field homogeneity. This coil is currently being constructed at the University of Western Ontario.

References: [1] Bock N.A. et al. MRM 49: 158-167 (2003)
[2] de Bever J.T. et al. Proc. ISMRM 14th (2006): 2605
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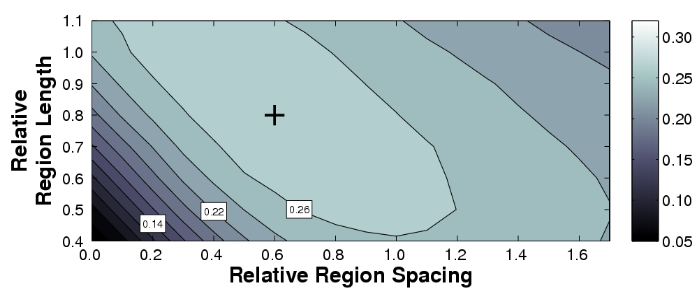

Figure 1: Transverse, 3-Imaging-Regions, Merit vs Length vs Spacing

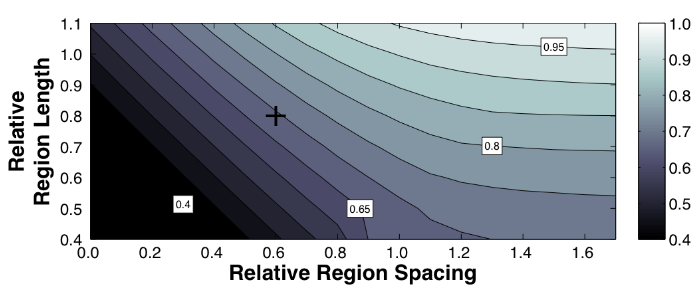

Figure 2: Transverse, 3-Imaging-Regions, Relative DSV vs Length vs Spacing

N	η [mT/m/A]	Merit	% of 1-Region
1	3.07	0.396	100.0
2	2.47	0.318	80.3
3	2.12	0.217	68.9
4	1.88	0.243	61.3
5	1.71	0.221	55.6
7	1.48	0.191	48.1

Table 1: Comparison of Optimal Transverse Designs

N	η [mT/m/A]	Merit	% of 1-Region
1	2.89	0.373	100.0
2	2.31	0.298	79.8
3	1.97	0.254	68.0
4	1.75	0.226	60.6
5	1.59	0.205	54.9
7	1.27	0.164	44.0

Table 2: Comparison of Optimal Longitudinal Designs