

# Power versus Inductance: finite length shim coil design for high-field MRI

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**Introduction:** High field magnetic resonance imaging and spectroscopy place increasing demands on resistive shim systems. We are ultimately interested in high performance, high power shimming for a variety of in vivo applications at 7T, although these results apply directly to other field strengths. In this abstract we quantitatively compare shim coil performance for coils designed using either minimum power (i.e. minimum resistance) or minimum inductance design algorithms. The ability to constrain coil length is included in both algorithms. The primary goal was to determine how the performance of the two design approaches depended on the length of the coil. These specific, quantitative comparisons are critical steps in the optimization of practical high power, high order shim coil sets.

**Methods:** A Fourier series algorithm was implemented which allowed for the design of finite length shim coils. The z-variation of the current density was expressed as a sum of variable frequency sinusoids over a finite region in the z-direction. A total of 16 frequencies were allowed for each design. The azimuthal variation was varied depending on the order of tesseral harmonic desired for the shim. The magnetic field, inductance, and resistance were derived in terms of current density in the reciprocal domain, allowing the functional containing the coil's parameters to be minimized. Either minimum inductance or minimum power coil designs could be obtained using this method.

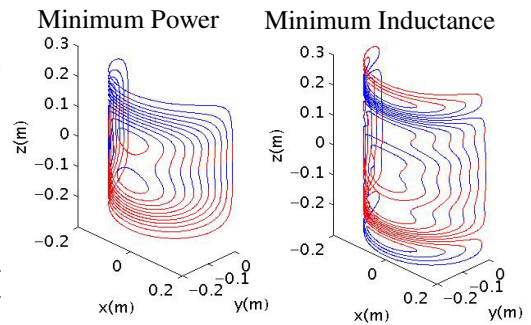
The algorithms were implemented in MATLAB® (Mathworks) and applied to the design of a set of shim coils for four different coil lengths: 50cm, 60cm, 80cm, and 100cm. The diameter of each shim considered was 40cm. The magnetic field targets were identical for the two methods, and specified over a 30cm region for all four lengths. The following 10 axes were designed using both methods: X, Y, Z, XY, X2-Y2, YZ, XZ, Z2, Z3, Z4. Inductive merit (ML) was defined to be  $\eta/\sqrt{L}$  and the resistive merit (MR) was defined to be  $\eta/\sqrt{R}$  where L is coil inductance, R is coil resistance and  $\eta$  is the field efficiency of the respective coil. The resistive merit equation is based on the assumption that the radial thickness of the conducting layer used for the coil fabrication is constant, while the width of the conducting path is determined by the minimum wire spacing (as would be the case for constructing coils by milling a pattern out of a continuous copper sheet). Discrete wire patterns were generated from the current densities and used to numerically evaluate inductance and resistance for the wire patterns. For each shim axis and for each coil length, the percent difference between the merit values obtained using the minimum inductance as compared to the minimum power algorithms was calculated.

**Results and Discussion:** The current paths for an example coil (the YZ axis) are shown in Fig. 1, for both minimum inductance and minimum power design algorithms. The basic characteristic features of the two methods are apparent: minimum inductance designs tend to feature oscillations within the current density more than minimum power designs. Fig. 2 and Fig. 3 show the percent differences between ML and MR values for the 10 different shim axes. In all cases, the minimum inductance algorithm achieved better ML values than the minimum power algorithm, and the minimum power algorithm achieved better MR values than the minimum inductance algorithm. This was of course to be expected; however, it was also determined that the differences between the two algorithms were very small (less than 6% across all designs). This indicates, for example, that the expected reduction in inductance for a minimum inductance coil as compared to a minimum power coil will only be approximately 10%. This reduction must be balanced against the generally increased complexity of the minimum inductance coil design wire patterns, and in the opinion of the authors, will rarely be justified. For this reason, we are proceeding to use minimum power design algorithms for the majority of our restricted-length shim coil designs. It was also found across all shim axes that the 80cm length designs had the highest merit values (both for power and inductance) and the 50cm length designs had the lowest merit values. The differences between the 50cm and 80cm length coil merits were always less than 25%. These results motivate and guide us in the pursuit of high strength, minimum power shim coils for a variety of imaging and spectroscopy applications at field strengths of 7T and above.

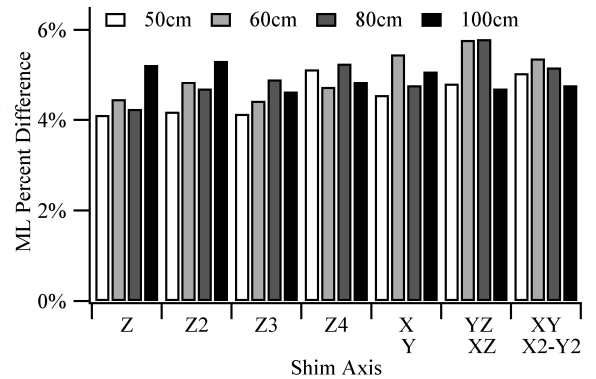
## Acknowledgements:

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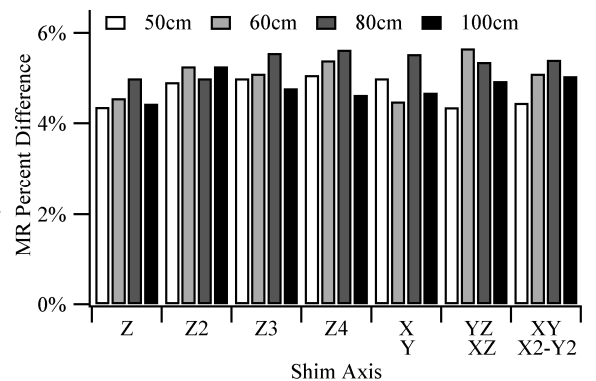
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**Fig. 1.** Half of wire pattern for YZ shim coil given by Minimum Power and Minimum Inductance methods.



**Fig. 2.** Percent difference of inductive merit for minimum inductance and minimum power methods, for 10 shim axes, each at four lengths: 50cm, 60cm, 80cm, 100cm.



**Fig. 3.** Percent difference of resistive merit for minimum inductance and minimum power methods, for 10 shim axes, each at four lengths: 50cm, 60cm, 80cm, 100cm.