Effect of active shielding on zonal shim coils for a 31cm bore 9.4T MR system

D. W. Haw[1], and B. A. Chronik[1]

[1]Department of Physics and Astronomy, University of Western Ontario, London, Ontario, Canada

Introduction: MRI and in-vivo spectroscopy in preclinical applications at very high field (9.4T and above) require improved shimming capabilities. Our goal is to develop and optimize high strength, dynamic shim systems for our 31cm bore 9.4T MR system. It is clear that dynamic shim systems will need to be actively shielded; however, we are interested in investigating how shim performance of shielded shim coils changes as a function of shim order. In this abstract, we report on overall performance and shielding requirements for zonal shim coils from zeroth to fourth order, designed using a realistic constrained length minimum inductance algorithm.

Methods: A Fourier series method [1] was implemented to design zonal shims of various orders with predetermined fixed length. This method expands the current density over a specified interval as a Fourier series. Outside the interval the current density is set to zero [Fig 1]. Magnetic field, inductance, and resistance are expressed in terms of the Fourier transform of current density, which allows for a functional that reflects these parameters to be minimized. This algorithm was used to design zonal shim coils up to fourth order: Z^0, Z^1, Z^2, Z^3, and Z^4. Each coil had radius 10 cm, and length 50 cm, and identical field targets were used to ensure all coils shared the same field uniformity over a 10 cm DSV. Seven terms were used in the Fourier expansion for each design. Discrete wire patterns were generated to allow for the evaluation of field efficiency and inductance for all coils. For each shim coil, an active shield was obtained using the relationship shown by Turner et al. [2]. The shield radius was set to be 14 cm, compatible with our Varian 9.4T 31cm bore system. The final current density profiles of all coils (shielded and unshielded) were sampled with a finite number of windings such that each had a final inductance of 200 µH. The field efficiency of each shim coil was determined by fitting the calculated field profile to a polynomial. The units of shim coil efficiency expressed this way depend on the order of the coil, and in general they are $mT/m^N/A$, where N is the order of the shim. When shim efficiency is expressed in this way, the efficiency of high order shims is typically numerically higher than for lower order shims. The efficiencies can be converted to absolute field efficiencies at the outer edge of the 10 cm DSV simply by multiplying by $(0.05\ m)^N$.

Results and Discussion: The Z^2 shim coil along with its shielding counterpart is shown in Figure 2 as an example. The coil efficiencies for the unshielded and shielded versions of each shim design (all scaled to a constant inductance of 200 uH) are presented in Table 1. In all cases the efficiency of unshielded shim coils is better than that of shielded shim coils, as expected. However, the difference decreases considerably with increasing shim order. This is due to the fact that magnetic fields decrease more quickly as the complexity of the current density increases, and therefore, high order shims should require less shield current density in order to shield effectively. The requirements for active shielding will be different for the different axes as well. All even orders of shim will require active shielding or at least some form of net flux cancellation because of strong coupling to the windings of the main magnet. The Z^1 axis is actually the Gz gradient axis, which will in general be switched extremely rapidly during imaging and would require highly optimized shielding. The Z^3 axis would be expected to require shielding the least, because its antisymmetric design represents a greatly reduced net flux coupling to the main magnet. We are in the process of constructing a complete shielded zonal shim set based on these designs for evaluation on our 9.4T system.

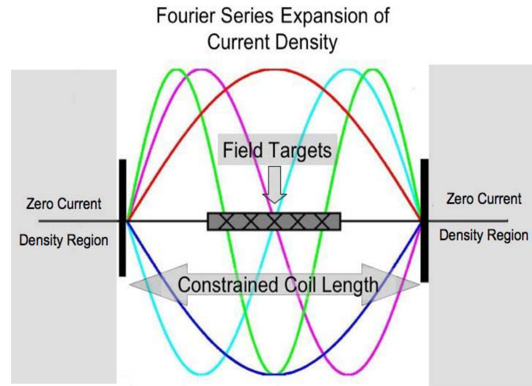

Figure 1. Schematic representation of Fourier expansion of current density over a finite region.

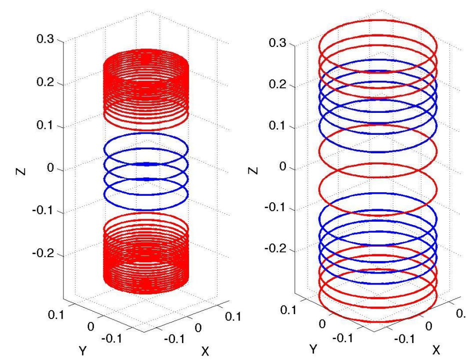

Figure 2. Z^2 Shim coil (left) and corresponding shielding coil (right).

	Coil Efficiency [$mT/m^N/A$]		Efficiency Ratio Shielded/ Unshielded
Shim Order	Unshielded	Shielded	
Z^0	0.124	0.08	0.645
Z^1	1.01	0.689	0.682
Z^2	4.69	3.92	0.836
Z^3	55.3	54.6	0.987
Z^4	183	178	0.973

Table 1. Simulation results.

References:

[1] Carlson J W et al. 1992 Magn. Reson. Med. **26** 191-206

[2] Turner R et al. 1986 J. Phys. E: Sci. Instrum. **19** 876-879