Simple minimum energy method for calculating shielding coils on arbitrary geometries

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Introduction: Virtually all applications in MR require the rapid switching of gradient fields within the scanner, and many emerging applications take advantage of rapidly switched shim coils; therefore, eddy-currents generated in the surrounding system structures are a constant challenge. Mitigation of inductive coupling between an insert coil and the MR system is typically accomplished using active shielding. In many cases, geometrically complex insert coils may be desired, which are difficult to shield with conventional analytic methods. Here we propose a new method for designing active shields of arbitrary geometry. This method does not require the placement of field constraints outside the coil geometry, but rather arrives at the shield current density simply by minimizing the total magnetic energy in the primary-shield system.

Methods: The total magnetic energy stored in two conductors can be expressed as a function of the self-inductance of each conductor and the mutual inductance between the two conductors. The self and mutual inductances are parameterized in terms of the current density of the primary coil and shielding coil. For any given primary current density and shielding surface, the shielding current density on that surface that minimizes the total magnetic energy in the system can be calculated via the boundary element (BE) method [1]. Two cylindrical shielded gradients (X, and Z) with primary and shielding radii of 40 cm and 60 cm respectively were designed as a test of this shielding method, with the results compared against the well-known analytic results for infinite cylinders [2]. As a second test, a shielded planar y-gradient, 20 cm by 30 cm, was simulated and the shield was compared against known analytic planar shielding solutions. Finally, to demonstrate the power of this method, the same cylindrical primary gradient used for the analytic comparison mentioned above was instead shielded with rectangular shields—a problem that would be exceedingly difficult to solve using conventional methods.

Results and Discussion: For the cylindrical shielding test (both for Gx and Gz), the maximum percent difference between the minimum energy shield current density and the analytic shield current density was less than one percent at any location. For the planar gradient case, the new method also produced a shielded y-gradient that was equally consistent with analytically calculated shields for this geometry. The solutions for the rectangular "box" shields using the new minimum energy method, against which there are no analytic solutions to compare, are summarized in Figures 1-4. We find that the calculated box-shields obtained using this method are indeed achieving the required shielding effect. A limitation of this method is that the shielding solution obtained is essentially global in nature; that is, it minimizes energy over all space and does not focus shielding over any one region of space. This is not a major problem when shielding outside of typical gradient or shim coils; however, the method will not likely be as effective for applications that require specific, localized areas to be highly shielded. The obvious advantage of this method is that the shield geometry can take any form; furthermore, the method is not a time-consuming, iterative method. It is a direct calculation of an energy minimizing total current density.

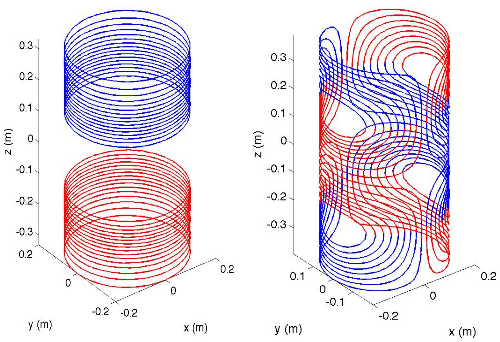


Fig. 1 shows the Z-gradient (left) and X-gradient (right).

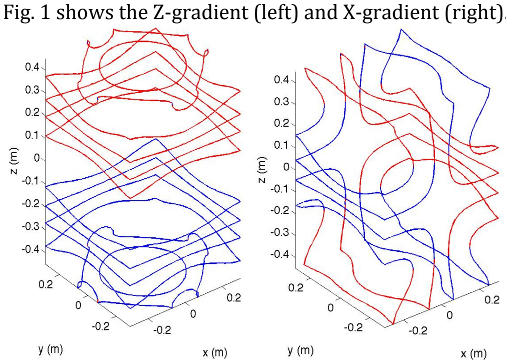


Fig. 2 shows the rectangular Z-shield (left) and X-shield (right).

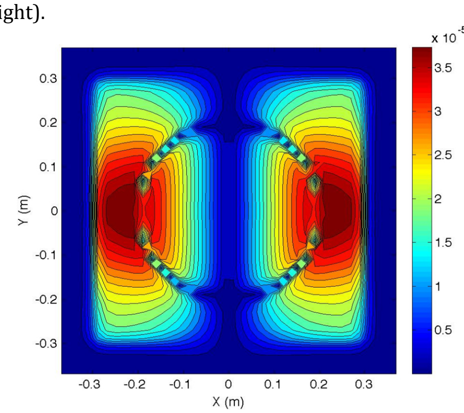
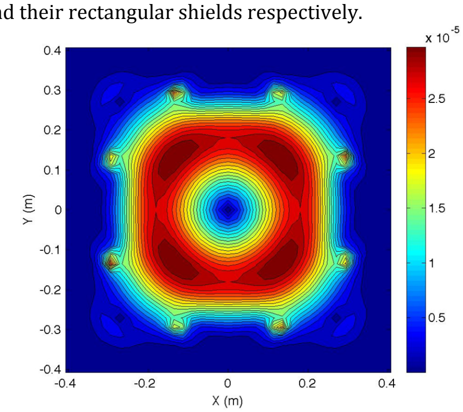


Fig. 3 (above) and Fig. 4 (below) show the magnitude of magnetic field in the XY-plane for the x and z gradients and their rectangular shields respectively.



References and Acknowledgements:

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[1] Lemdiasov RA et al. 2005 Magn. Reson Part B, Vol.26B (1) 67-80.
[2] Turner R. et al. 1986 J. Phys. [E] **19**:876-879.