Hybrid Quadrupole Gradient Coil Design for MRI of the Breast

K. L. VanderWerf[1], J. deBever[2], B. A. Chronik[2]

[1]Medical Biophysics, University of Western Ontario, London, Ontario, Canada, [2]Physics, University of Western Ontario, London, Ontario, Canada

INTRODUCTION: Very high gradient slew rates and strengths are necessary for real-time SSFP and diffusion weighted imaging of breast lesions. High-strength gradients can only be achieved practically by using small, more efficient gradient coils. However, dedicated gradient coils for breast imaging are not commercially available and have only been described in the literature on one occasion [1]. We are developing a transverse orientation three-axis hybrid gradient coil for breast imaging on an open, General Electric double-donut MRI system. The subject would lie prone, with the breast protruding down into the imaging region of the cylindrical, vertical axis gradient coil. In this abstract, we report the results of a design study for the Gx and Gz axes of the gradient set. The Gy axis will be a fingerprint coil, designed using methods similar to those reported in [1].

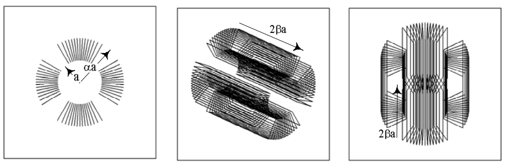


Figure 1a: (left) Top view (xz plane) of 60 wire coil.
Figure 1b: (centre) 3D schematic of a 60 wire coil; angled for additional visualization.
Figure 1c: (right) 3D schematic of a 60 wire coil; positioned as it would sit in an MRI system (slightly tilted forward for better visualization).

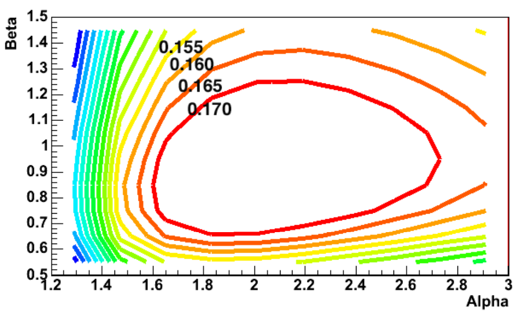
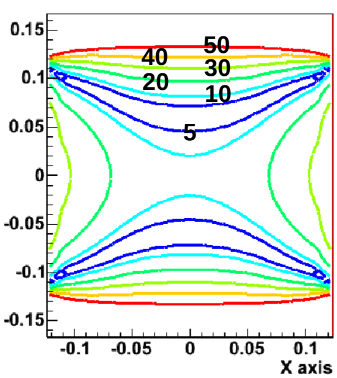


Figure 2: Contour plot of Merit; the region within the 0.170 contour represents coil designs with Merit values within 5% of the optimal value.

Figure 3: (right) Gradient Uniformity plot in the xy plane; Coil Geometry: 13 cm inner radius, 23.4 cm coil length, 60 windings.



METHOD: The basic architecture of a hybrid quadrupole coil axis is shown in Figure 1. The windings are spaced azimuthally according to a quadrupolar cos2θ current density distribution. The windings on the inner cylinder provide the imaging gradient field, while the outer cylinder serves as a return path for the inner windings. We define alpha to be the ratio of outer to inner cylinder diameter, and beta to be the ratio of the coil height to the inner cylinder diameter. This basic architecture was chosen in order for the imaging region to be placed adjacent to the top of the coil; furthermore, this design yields a naturally torque-balanced coil.

We produced designs for an entire range of coils with alpha ranging from 1.2 to 3, and beta ranging from 0.5 to 1.5. For each design, we computed a figure of merit: M = eta*a^2.5/sqrt(L), where eta is the gradient coil efficiency in mT/m/A; 'a' is the inner radius of the coil in m; and L is the coil inductance in Henries. We also computed the size and position of the imaging region. We define delta to be the position of the outermost edge of the imaging region with respect to the physical edge of the gradient coil, with a negative value indicating the imaging region extends beyond the physical edge of the coil. Gradient uniformity is defined as the percent difference between gradient values and a central value, denoted by Gxo. The central values were taken to be 5 cm below the top of the coil. For each design, contour plots of gradient uniformity were produced and the maximum imaging region boundaries were based on the 50% uniformity contour.

RESULTS/DISCUSSION: The coil merit as a function of alpha and beta is shown in Figure 2. The highest merit was found to be 0.177, which occurred at (alpha, beta) = (2.0, 0.9). The gradient uniformity is shown in figure 3. For an inner coil diameter of 26 cm, 246 windings are required to give an inductance of 800 uH. This yields: gradient efficiency of 0.82 mT/m/A; cylindrically shaped region of 50% gradient uniformity 20 cm in diameter and 26 cm in length; delta of –9 mm; coil outer diameter of 52 cm; coil height of 23.4 cm; minimum wire spacing of 2.1 mm; resistance of 650 mOhms (assuming round copper wire, 2.1 mm diameter). With the 200A, 300V gradient amplifiers available on the open MR system, this coil would produce a maximum gradient strength of 164 mT/m in a minimum rise time of 533 us (slew rate of 308 T/m/s). This represents an improvement factor of more than 16 in strength and 30 in slew rate as compared to the currently available gradient system on the open MR system.

One obvious question regarding the utility of the hybrid quadrupole gradient design for human breast imaging is the possibility of peripheral nerve stimulation. Because the subject would be in very close proximity to the electrical windings, the induced electric fields in the breast and surrounding chest would be expected to be significantly higher for this design than for others. We are currently in the process of constructing a single axis prototype of this design and we will conduct human studies to evaluate the stimulation thresholds and compare them against those measured in gradient coils of conventional design.

REFERENCES:

[1] Maier, CF., et al. Practical Design of a High-Strength Breast Gradient Coil. MRM 39:392-401 (1998).