A Target Field Approach to the Design of RF Phase-Gradient Coils

J. Bellec1, C-Y. Liu1, S. B. King2, and C. P. Bidinosti1,3
1Physics and Astronomy, University of Manitoba, Winnipeg, Manitoba, Canada, 2MR Technology, NRC Institute for Biodiagnostics, Winnipeg, Manitoba, Canada, 3Physics, University of Winnipeg, Winnipeg, Manitoba, Canada

INTRODUCTION: Conventional MRI utilizes a set of \(B_0\) gradient coils to impose magnitude gradients onto the \(B_0\) field. This induces a spatially varying phase in the transverse magnetization. However, there are complications attributed to the rapid switching of the \(B_0\) gradient fields, such as induced eddy currents in nearby conductors (including the patient), nerve stimulation, mechanical vibrations, and loud acoustic noises. Transmit array spatial encoding (TRASe) [1] is a novel gradient-free imaging technique relying on Tx RF phase gradients expressed as \(B_1 = |B_1|\exp(i\phi(r))\), to spatially encode the transverse magnetization as \(M_1 = |M_1|\exp(i\phi(r))\), where \(\phi(r) = 2\pi k_e \cdot r\). Ideal phase gradients have a uniform \(|B_1|\) and strong-linear \(\phi(r)\) over a large volume. To optimize TRASE MRI, a target field method was introduced to optimize phase gradient coils relative to previous designs [1].

APPROACH: The target field method was originally introduced for the design of cylindrical gradient coils [2], but has recently been used in RF coil design [3,4]. As an initial investigation, we are taking particular interest in Eq. (4) of Ref. [4]. From this equation, it follows that there is a direct relation between the Fourier components of the \(B_1\) field and Fourier components of the current distribution on a cylindrical shell. We have adopted these relations to determine the winding pattern on a cylindrical shell (oriented with the patient axis) that generates a target RF phase gradient field. The method is comprised of the following steps: (1) the Fourier components of the target field are determined; (2) the current distribution is constrained to a cylindrical shell and the Fourier components are calculated, which is subsequently used to obtain the actual current distribution; (3) a stream function approximation is implemented to determine discrete winding patterns of unit current.

In this technique, the RF phase gradient fields are modeled as \(B_1^{\phi}(r) = A(l,z)\cos((s/a)\pi)\hat{e}_x + \sin((s/a)\pi)\hat{e}_z\), where \(\hat{e}_x\) and \(\hat{e}_z\) are perpendicular to the \(B_0\) field, \(s\) is the phase gradient strength, \(a\) is the coil radius, and \(x\) is the direction of the gradient. The function \(A(l,z)\) is an apodization factor that rapidly sets the field to zero near \(z=\pm l\), restricting the coil length. It was modeled as \(A(l,z) = (1 + (z/l)^2)^{-1}\).

RESULTS/DISCUSSION: For a horizontal \(B_0\) magnet, a \(G_x\) phase gradient coil for \(s = \pi\) was obtained and is shown in Fig. 1(a). For a vertical \(B_0\) magnet, the \(G_z\) phase gradient coil for \(s = \pi/2\) is shown in Fig. 2(a). From simulated magnetic fields, the \(B_1\) magnitude and phase for both coils were calculated. The magnitude plots are normalized to the central \(|B_1|\) value, and display contours of 10% deviation from the central value. The contours in the phase plots correspond to \(10^\circ\) intervals, where the central contour is zero.

CONCLUSIONS: The target field approach has been used to determine current distributions that produce linear phase gradients and uniform magnitude, but over limited volumes. The fact that the horizontal-\(B_0\) \(z\)-phase gradient design resembles initial spiral birdcage phase gradients, suggests that the approach is valid and deserves more attention. More work emphasizing uniform magnitude over a larger volume is needed to optimize the designs (including other gradient directions), but determining such complicated winding patterns may be difficult without a target field approach.