Exact analytic 2D solution to obtain optimal B_1 excitation field in ultra-high field MRI applications

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A current challenge for ultra-high field human brain imaging is the non-uniformity of the excitation B_1 field. This is a particular problem at ultra-high field since the excitation frequency of the B_1 field is proportional to magnetic field strength. At high magnetic fields, the required B_1 field has a relatively short wavelength. A superposition of such waves results in stationary waves that causes a non-uniform tip-angle and ultimately affects the quality of the final images. RF shimming is a promising technique to solve this challenge. RF shimming applies concepts from array antenna theory and suggests a different improved design for the RF coil, where the coil is designed as a transmit array with its elements separately controlled by different channels. By appropriately adjusting the driving voltage signal at each channel, the uniformity of resulting B_1 magnetic field can be improved (W. Mao et al., "Exploring the limits of RF shimming for high-field MRI of the human head", Magnetic Resonance in Medicine, 56:918-922, 2006; C.M. Collins et al., "Array-optimized Composite Pulse for Excellent whole-brain homogeneity in high-field MRI", Magnetic Resonance in Medicine, 57:470-474, 2007.).

In this work, we study a 2D geometry where a circular lossy object, representing the brain, is surrounded by a dielectric shell, representing the skull. Both the objects are located in the xy plane. The excitation field is produced by a system of M wires parallel to the z axis and located at the vertices of a regular polygon concentric with the other objects and coplanar with them. The wires represent the legs of the birdcage coils normally used in MRI scanner to produce the B_1 RF excitation field.

This is a simplified geometry with cylindrical symmetry for which it is possible to obtain an analytically exact solution. The analytic solution is then applied to study the field produced by the birdcage inside the volume of interest. The advantage of the exact solution is that (1) it allows to apply optimization methods to compute the best scheme for the current (both amplitude and phase) in each individual wire to minimize the spatial fluctuation of the total B_1 field; and, (2) is very fast compared to full wave 3D simulations. Even though these results are obtained for a simplified model of the human head, they constitute a valuable starting point to exploit in further studies where more realistic human head models are applied.