Design and Optimization of Helical RF Coils for Use in High-Field Strength Magnetic Resonance Imaging at 4.7T

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High field strength magnetic resonance imaging (MRI) is an actively developing technology and a comprehensive area of research in RF engineering. Compared to traditional MRI scanners in human medicine, with static (polarizing) magnetic field $\mathbf{B}_0$ strengths (usually referred to as magnet strengths) of 1.5T, high field strength scanners utilize $B_0 \geq 3$T, and therefore exhibit improved signal to noise ratio that, in turn, yields improvements in scanning spatial resolution and imaging time. A primary challenge in the development of high field strength scanners has been the design and optimization of RF coils (exciters), actually antennas, that can produce a strong circularly polarized RF magnetic field ($\mathbf{B}_1^+$) inside an imaged subject, which is both spatially as uniform as possible and exhibits a sufficiently low specific absorption rate (SAR) in the subject. This is a highly challenging RF engineering problem, as these specifications must all be accomplished at high Larmor frequencies accompanying the strong B_0 field. Thus, traditional RF coil designs for lower field strength scanners are no longer valid, and new solutions and designs are required.

We present a four-channel helical antenna RF coil designed to operate in a 4.7T human sized MRI scanner, at the Larmor frequency (RF magnetic field frequency) of 200 MHz. The coil exhibits a cylindrical prism design with copper traces for all four channels wound symmetrically around the plexiglass body. With four relatively decoupled input channels, the coil is designed to be driven in phase quadrature for maximum $\mathbf{B}_1^+$ efficiency (transmit efficiency), or with a more complex RF shimming scheme to optimize for field uniformity in a specific subject or a part of the subject.

Using finite element method (FEM) simulations by means of ANSYS HFSS code, two variations of the coil design have been heavily optimized for various crucial RF coil characteristics and parameters such as $\mathbf{B}_1^+$ field uniformity, S-parameters, and coupling with a saline phantom. The versatile and efficient FEM tool has allowed us to go through many design iterations relatively quickly and arrive at a nearly optimal design. These designs have been physically fabricated for future testing in a 4.7T MRI scanner. The electrical characteristics of the prototypes have been thoroughly tested and verified in an electromagnetics laboratory, on an RF bench. Each physical model and prototype shows acceptable S-parameters without matching, and excellent S-parameters with matching. The coils demonstrate good potential for RF shimming and further optimizations of designs.