Simulation and Experimental Results for Helical-Antenna RF Coils in Ultra-High-Field Magnetic Resonance Imaging Applications

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Magnetic resonance imaging (MRI) is currently one of the most widely used noninvasive medical imaging techniques. At the forefront of the MRI research is the use of high and ultra-high polarizing static magnetic fields, i.e., $B_0 \geq 3$ T, in an MRI scanner. Among the most widely used RF coils, which are aimed at exciting RF magnetic field, $\mathbf{B}_1$, inside the MRI bore, are birdcage coils, stripline coils, dipole antennas, loops, and patches. The principal desired objectives of RF coil designs are achieving acceptable level of power efficiency, good right-hand circular polarization (RCP) for the transverse components of $\mathbf{B}_1$, high spatial uniformity of the transverse $\mathbf{B}_1$ field inside the phantom (subject), strong coupling of the field/wave with the phantom and strong field penetration in the entire phantom or the imaged part of the subject, and acceptable and allowable prescribed specific absorption rate (SAR) levels.

In order to address these demands and challenges, we present multifilar helical antennas as RF coils, namely, as subject-loaded volume coils. The coil has multiple interleaved helix arms with the back-plate acting as a ground plane for all of them. Each helix arm is fed separately and is time-phased in a way that ensures a strong RCP RF field, $\mathbf{B}_1^+$, inside the phantom (subject). We present our ongoing studies aimed at improving the $\mathbf{B}_1$ RF field inside the imaged sample by carrying out extensive modeling and simulations of 3-T, 7-T, and 10.5-T MRI systems with various subject-loaded multifilar helical-antenna RF coil designs and different phantom configurations. The investigations include helical antennas of various lengths, diameters, pitch angles, and numbers of channels, phantom containers filled with different solutions, a human body model phantom, and various relative positions of the RF coil and phantom in order to find the optimal performance.

Some of the simulation results are then validated with MRI experiments at 7 T and 10.5 T at the Center for Magnetic Resonance Research (CMRR), University of Minnesota. The basic model of 7-T quadrifilar helical-antenna RF body coil is experimentally tested and validated in March 2015, with very promising results. Based on these results, new designs are performed and new prototypes built – for CMRR experiments in August 2015, which have shown very significant improvements over the first prototype. The power efficiency is very significantly increased and the amount of power delivered to the imaged phantom is sufficiently high for all experiments and MRI processing. Octafilar helical-antenna coil at 7 T is also tested, where too the measurements are in agreement with the simulation results. CMRR experiments with quadrifilar and octafilar helical-antenna RF coil prototypes at 10.5 T have also shown good results, with the measured $\mathbf{B}_1$ field maps verifying the simulation data, and have demonstrated the scalability and versatility of the coil design. Overall, with the helical coils, we have observed – in MRI experiments – good field strengths, RCP, and flip angle, as well as an interleaved field pattern due to multiple helices, and thus capability for parallel imaging and acceleration.