

Simulation, Design, Development, Fabrication, RF Testing, and MRI Measurements of Novel 4.7-Tesla RF Coils for Next-Generation Magnetic Resonance Imaging

Christopher Erickson⁽¹⁾, Pranav Athalye⁽¹⁾, Milan M. Ilić^{(1),(2)} and Branislav M. Notaroš⁽¹⁾

(1) Electrical & Computer Engineering Department, Colorado State University, CO, USA
(Christopher.Erickson@colostate.edu, athalye@rams.colostate.edu, notaros@colostate.edu)

(2) School of Electrical Engineering, University of Belgrade, Serbia (milanilic@etf.rs)

This work deals with introducing, developing, and establishing novel RF volume exciters, to advance RF coil designs in human magnetic resonance imaging (MRI) at both 3 T – 4.7 T [high field (HF) MRI; current state-of-the-art clinical scanners] and 7 T [ultra-high field (UHF) MRI; predicted next-generation clinical scanners]. The main area of engineering research in advancing MRI scanners is in improving RF coils (exciters) and RF-excitation magnetic fields, B_1 , more precisely, right-hand circularly polarized (RCP) RF magnetic fields, usually denoted as B_1^+ . Our approach and novel method for multi-channel excitation of RF B_1^+ field is predominantly based on subject-loaded multifilar helical-antenna RF volume coils as well as microstrip array coils for HF and UHF MRI. Our focus is developing, optimization, and realization of RF coils for 4.7 T operation, chosen for this research right midway between 3 T (current best, yet to be advanced and broadly adopted at clinics and hospitals) and 7 T (expected next big clinical overhaul in the near future, yet with lots of unknowns and challenges). This research is aimed to, in a longer term, advance both state-of-the-art clinical HF MRI scanners and next-generation UHF MRI systems.

We performed a comprehensive study of the helical antenna RF coil and microstrip array RF coil for high-field MRI at 4.7T, a Larmor frequency of approximately 200 MHz using various in-house and commercial computational electromagnetic (CEM) methods and software. The CEM simulation were used in optimizing key electrical and geometrical characteristics of the coils to produce optimized power to field efficiency, saline phantom field uniformity and minimized coupling between channels.

We used computer aided design (CAD) to model and manufacture 4.7T coils based on the optimal characteristics found in the CEM simulations. The design was built with modularity, and robustness in mind. Various feed networks and associated RF circuitry were developed to properly phase and split the power into each channel. All manufacturing was done in the electromagnetics laboratory via fuse filament fabrication (FFF) and computer numerically controlled (CNC) machining, to ensure the highest quality possible and accuracy to designs. We tested and validated all designs with their simulation counterparts.

We built an accurate MRI test bench in the electromagnetics laboratory to properly reflect the actual MRI testing facility. We conducted a rigorous validation and testing of the microstrip array and helical antenna coil designs. An automated near field probe positioner was used to validate current distribution and magnitude. A VNA was used to measure the full S-parameter matrix across all channels to confirm coupling was sufficiently low. Q factor measurements were taken using near field probes to determine sensitivity to saline phantom loading. System integrations and interfacing was meticulously assessed to ensure proper power distribution and minimal RF reflections.

Finally, we performed MRI experiments, testing, evaluations, and post-analyses of microstrip array and multi-channel helical antenna RF coil prototypes in a 4.7 Tesla human MRI scanner at The Peter S. Allen MR Research Centre, Alberta, Canada, and at Colorado State University. The resultant images validated the promising results found in CEM simulations, showing ample field distribution across the phantom and clear images. Post-imaging analysis using rigorous analytical expressions were conducted on the resultant scans, validating the field distributions and efficacy of each coil.