Improving Traveling-Wave RF Fields inside Magnetic Resonance Imaging Bores by Incorporating Dielectric Loadings

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The next-generation magnetic resonance imaging (MRI) systems at ultra-high static magnetic fields (magnetic flux densities), $B_0 > 3$ T, and ultra-high Larmor frequencies, $f_0 > 127.8$ MHz, utilize RF excitation magnetic fields, $\mathbf{B}_1$, in the form of traveling waves (TWs) in the MRI bore. Hence, the images of subjects are generated and received by far-field coils, namely, by excitation probes that essentially operate as antennas, in place of the traditional quasi-static, near-field RF coils used in 3-T clinical MRI scanners (e.g., birdcage coils). When compared to traditional, quasi-static, MRI systems, TW MRI systems can provide more homogeneous $\mathbf{B}_1$ field distribution, better signal-to-noise ratio, larger field of view, more comfort for patients, etc. Moreover, it is possible to potentially benefit from the advantages of TW concepts also at relatively lower (but still considered high) field strengths (e.g., $B_0 = 3$ T; $f_0 = 127.8$ MHz), in order to address challenges and enable substantial improvements of current clinical MRI scanners at 3 T.

The generation and control of TW $\mathbf{B}_1$ RF fields inside a MRI bore and a phantom or a subject under MRI imaging are very challenging tasks. There has been limited work done on TW excitation using loops, dipole antennas, microstrip patch antennas, etc. as antenna probes. Such excitations of TW are highly localized, which results in rapid power dissipation in the body and thus in high local specific absorption rate (SAR) levels in regions of the body and quick attenuation with distance away from the antenna. However, one approach to improve the TW $\mathbf{B}_1$ RF fields inside a MRI bore loaded with a human (or animal) body or body part or phantom is to incorporate various dielectric and other material loadings into the bore, in order to reduce the cutoff frequencies of the bore viewed as a metallic circular waveguide, enable traveling waves along the bore, and control the field in the bore and the phantom.

This paper presents our ongoing studies aimed at improving the TW $\mathbf{B}_1$ RF fields inside a MRI bore by carrying out extensive modeling, simulations, and analysis of 3-T and 7-T MRI systems for different excitation and load configurations, using full-wave rigorous computational electromagnetics tools. The exciters include a double-loop coil (orthogonal loops loaded by lumped capacitors for tuning and matching and fed in time-phase quadrature) and arrays of wire dipoles. The loadings include dielectric rod arrays with different placements inside the MRI bore and relative to the phantom, in both axial and lateral arrangements, as well as dielectric layers (linings) of different compositions and complex dielectric constants. The principal desired objectives of such designs are achieving TW regime, good right-hand circular polarization 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, and acceptable and allowable prescribed SAR levels.