A Method for Optimization of a Cylindrical Metasurface for Traveling-wave MRI Applications

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Abstract— Ultra-high-field (UHF) magnetic resonance imaging (MRI) offers high signal-to-noise ratios and spatial resolution. However, UHF MRI (≥ 7 T) suffers from poor radiofrequency (RF) field homogeneity and low transmit (Tx) efficiency. Traveling-wave (TW) MRI [1] provides a possible solution for improving homogeneity by exciting guided electromagnetic modes (traveling waves) propagating along the axis of the magnet bore. However, this method requires additional means for efficient RF magnetic field concentration in the region of interest for reaching competitive Tx efficiency levels. Previously, a local high-permittivity dielectric waveguide was proposed to improve Tx efficiency of TW MRI at 7 T in the human brain region [2] being, however, a relatively bulky and heavy structure. On the other hand, it was shown that flat dielectric pads used for homogeneity improvement in abdominal imaging at 3 T (classical RF excitation with a birdcage coil) can be replaced with light and flexible metasurfaces (MSs) [3].

In this work, we numerically evaluate the feasibility of replacing a cylindrical dielectric waveguide from [2] with a light and thin cylindrical MS in TW MRI at 7 T. Following [3], the MS is built as a square grid of intersecting copper strips (0.3 mm wide) with a unit-cell period of 34 mm, loaded with 3.9 pF capacitors. The unit-cell parameters are selected for a flat configuration according to [3], but at the Larmor frequency of 298 MHz, to approximate the slow-wave factor of a flat dielectric slab with a thickness of 28 mm and relative permittivity of 21 [2]. Numerical simulations confirm that the cylindrical MS (with the same unit cells arranged on a cylindrical dielectric holder) supports a guided mode with phase velocity dispersion closely matching one of the HE_{11} mode propagating in a hollow cylindrical dielectric waveguide of the same outer diameter (with the same wall thickness and permittivity as for the flat slab). In other words, for diameters of more than the human head size, the curvature has only minor effect on the equivalence between the MS and the waveguide in terms of the dispersion characteristics. This conclusion is verified by numerical simulations of a complete TW MRI setup, including a voxel model mimicking the human body, the bore, and the Tx patch antenna, where both structures with finite lengths surround the human head. We calculate the magnetic field distributions in the human brain region with the Tx-efficiency demonstrating a 24.1% improvement with the 280-mm-diameter cylindrical MS compared to the dielectric waveguide. The implementation of the proposed cylindrical MS offers reduced weight and avoids image artifacts caused by the water signal [2]. These results indicate that the cylindrical MS represents a lightweight and effective solution for prospective RF excitation setups for TW MRI.

REFERENCES

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