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Passive RF shimming with fractal metasurfaces in a 7T head coil

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Synopsis

B_1^+ inhomogeneities in the temporal lobes of the brain are common while using a birdcage coil at 7T. Different approaches have effectively targeted this problem, at the cost of decreasing the B_1^+ field in other important areas or being uncomfortable to the patient. Here, we present a new approach based on two resonant fractal metasurfaces. These fractal resonators improve simultaneously the B_1^+ field in each temporal lobe without affecting the B_1^+ field in other parts of the brain.

Introduction

Passive RF shimming approaches such as dielectric pads¹⁻³ and metamaterials^{4,5} have been used to reduce the B_1^+ inhomogeneity observed in birdcage head coils working at 7T. While these approaches locally improve B_1^+ amplitude in regions of interest like temporal lobes, such improvements come at the cost of reducing the RF field in other ROIs like the cerebellum or being limited to use a single element. In this work, we present two passive RF shimming resonators for improving the B_1^+ field amplitude in each temporal lobe without diminishing the transmit efficiency of the birdcage coil elsewhere.

Material and Methods

The resonant fractal metasurfaces are copper structures printed on a 0.4-mm-thick FR-4 substrate. The design of each resonant fractal was based on 4th-order Hilbert fractal⁶ metallic strips as shown in Figure 1. Each fractal was placed on each side of the head, within the receive array. The fractal on the right side being slightly higher than the left one. The fractals were tested with a 1Tx/32Rx proton head coil (Nova Medical, Wilmington, MA, USA) in a 7T Magnetom MRI scanner (Siemens Healthineers, Erlangen, Germany) on a head specific anthropomorphic phantom (SPEAG, Zurich, Switzerland) filled with a liquid of permittivity $\epsilon=45.3$ and conductivity $\sigma=0.87$ S/m.

We measured Flip Angle (FA) maps and amplitude maps using the XFL MRI sequence⁷ in sagittal and axial orientation with TR= 20 s, TE= 1.4 ms, FA= 8°, Shinnar-Leroux minimum-phase saturation pulse= 90°, FOV= 256 mm, matrix= 64x64 and 12 slices of thickness=8 mm (17 slices in axial orientation). A mask extracted from GRE images was applied to the FA maps. The relative FA and amplitude signal gain expressed in percentage were computed for a quantitative analysis of the fractals' effect. All images were acquired using the same reference voltage of 260V.

Results

Flip angle maps in sagittal and axial orientations of the birdcage coil, alone (top row) and with the fractals (central row), are shown in Figure 2. The effect of the fractals can be seen at different locations in the head through the three axial slices denoted with dash lines. The first one is located at 12 cm from the top of the head. The space between the two axial slices is 24 mm. A relative FA gain

map is shown in the bottom row of Figure 2. The green rectangles next to the axial slices represent schematically the position of the fractals with respect to the phantom. We can see a significant increase of the FA while using the fractal. It corresponds to a 30% gain around the area where the fractals were placed and 10% on average in the ROIs that denote the temporal lobe regions. Moreover, from the sagittal slice, no loss is observed in other regions of the brain such as the cerebellum.

Figure 3 presents GRE signal maps (unprocessed data from the XFL sequence) of the birdcage coil alone (top row) and with the fractals (central row). All GRE images were acquired with the same input power of 260V. Similarly, the last row of Figure 3 shows the relative gain between the fractals over the reference signal. We can see that the 30% enhancement obtained in the FA maps is reflected on the GRE images while the average gain in the ROIs seems to increase slightly and low loss is observed in the remaining brain region.

Discussion

We based the design of the metasurface pads on a Hilbert fractal with the aim to obtain compact, thin and flexible resonant structures. Due to their complex design, the fractals are quite sensitive to the location and orientation with respect to the birdcage coil. The optimized positions were found to respect the original asymmetry of the B_{1+} field amplitude in the reference flip angle maps. The presence of fractals shows a maximum +30% gain of B_{1+} amplitude for both temporal lobes, for the same input voltage which is interpreted as a large increase in transmit efficiency (Figure 2). Moreover, they maintain the B_{1+} amplitude almost intact in the remaining brain volume. This effect is particularly interesting for the cerebellum region which usually suffers when high dielectric constant pads or metamaterials are inserted in the birdcage coil. In our case, most of the loss seems to be directed towards the lower part of the head away from the brain ROI where the birdcage coil stops. This can be seen in the sagittal slices in Figures 2 and 3. Moreover, as the relative gain observed in the FA maps in Figure 2 is conserved and slightly improved in the GRE images, it indicates that the fractals do not interfere with the receive array.

Conclusion

We designed metasurface pads inspired by a Hilbert-fractal design to reduce the transmit field inhomogeneity artefacts observed in head imaging with high-field MRI. We found that resonant fractal metasurfaces improve the B_{1+} amplitude up to a maximum 30% and 10% on average in the two temporal lobes without compromising the B_{1+} amplitude in the cerebellum. Their compact and flexible design allows them to fit easily between the phantom and the receive array of the head coil. Hence our approach promises better performance and patient comfort over conventional dielectric pads or metamaterials.

Acknowledgements

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References

- [1] Webb A. G., *Concepts Magn. Reson. Part A* 38A (2011), 148
- [2] O'Reilly T. P. A., *et al.*, *J. Magn. Reson.* 270 (2016), 108-114
- [3] Neves A. L., *et al.*, *Magn. Reson. Med.* 79 (2018), 1753

- [4] M. Dubois, *et al.*, Phys. Rev. X 8 (2018), 031083
- [5] M. Dubois, *et al.*, Proc. Intl. Soc. Mag. Reson. Med. 27 (2019) 1552
- [6] Hilbert D., Mat. Ann., Springer, 38 (1935), 459-460
- [7] Amadon A., *et al.*, Proc. Intl. Soc. Mag. Reson. Med., 23 (2015) 2377

Summary of Main Findings

In this study, we demonstrate that Hilbert fractal-based metasurface pads enhance the B_1^+ amplitude in two different regions of the head such as the temporal lobes, without diminishing the rest of the field.

Figures

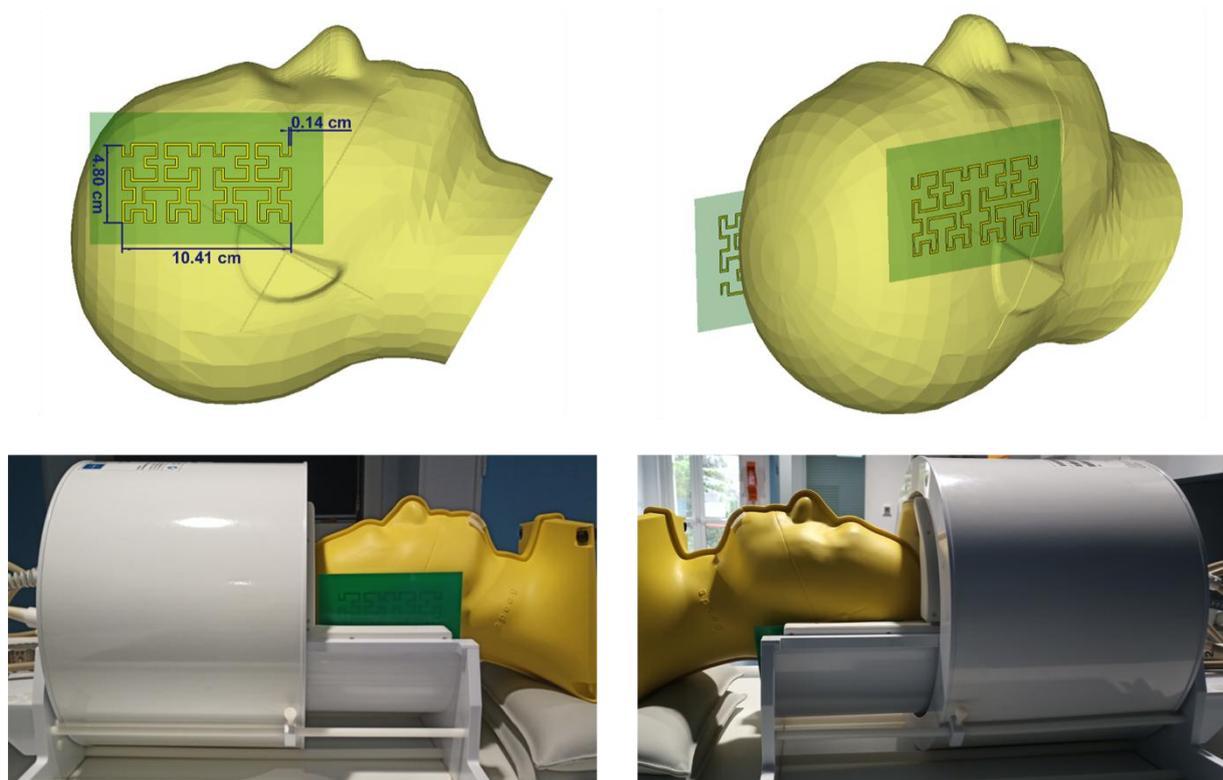


Figure 1. Design (top row) and position (bottom row) of the Hilbert fractal-based metamaterial pads. The fractal on the right side is slightly higher than the left one.

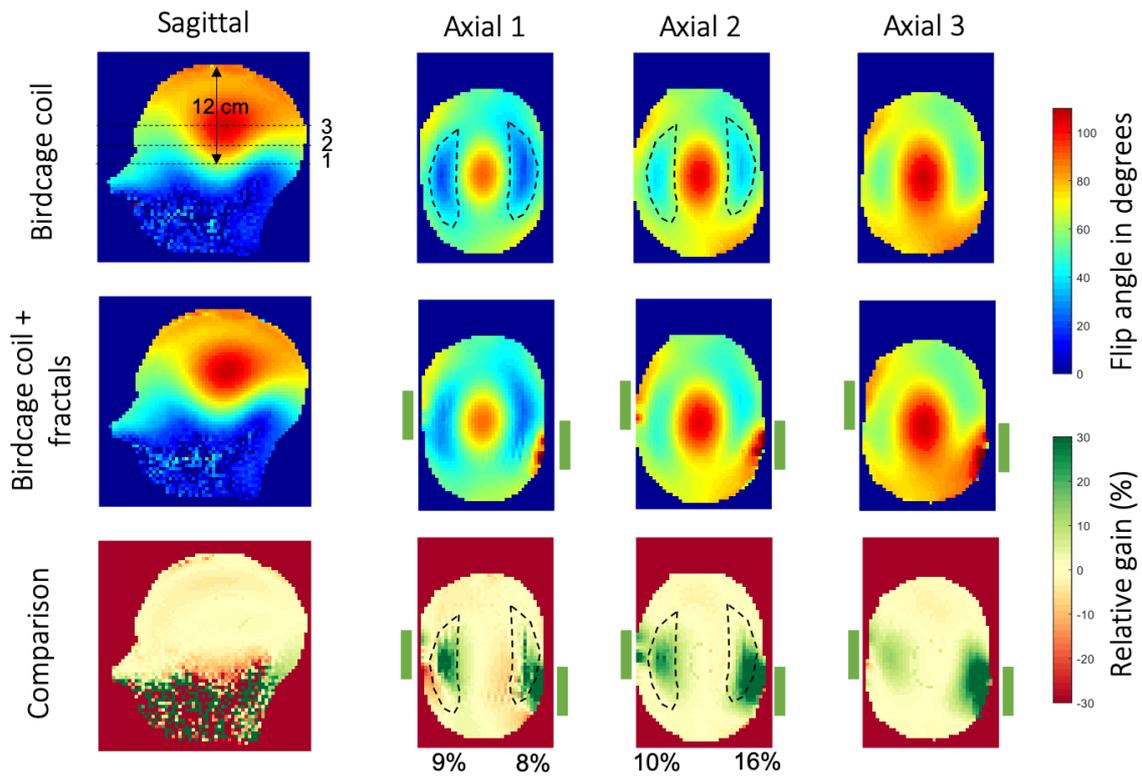


Figure 2. Experimental FA maps of birdcage coil (top) and birdcage coil with resonant fractals (middle) in sagittal and axial orientations. The bottom row shows the relative gain between fractals and reference map. The schematic position of the fractals is represented with green rectangles. The dashed lines on the sagittal slice show the location of the axial slices. We defined the temporal lobe ROIs from the reference scan (top row). The values below the bottom row are the mean values obtained inside each ROI.

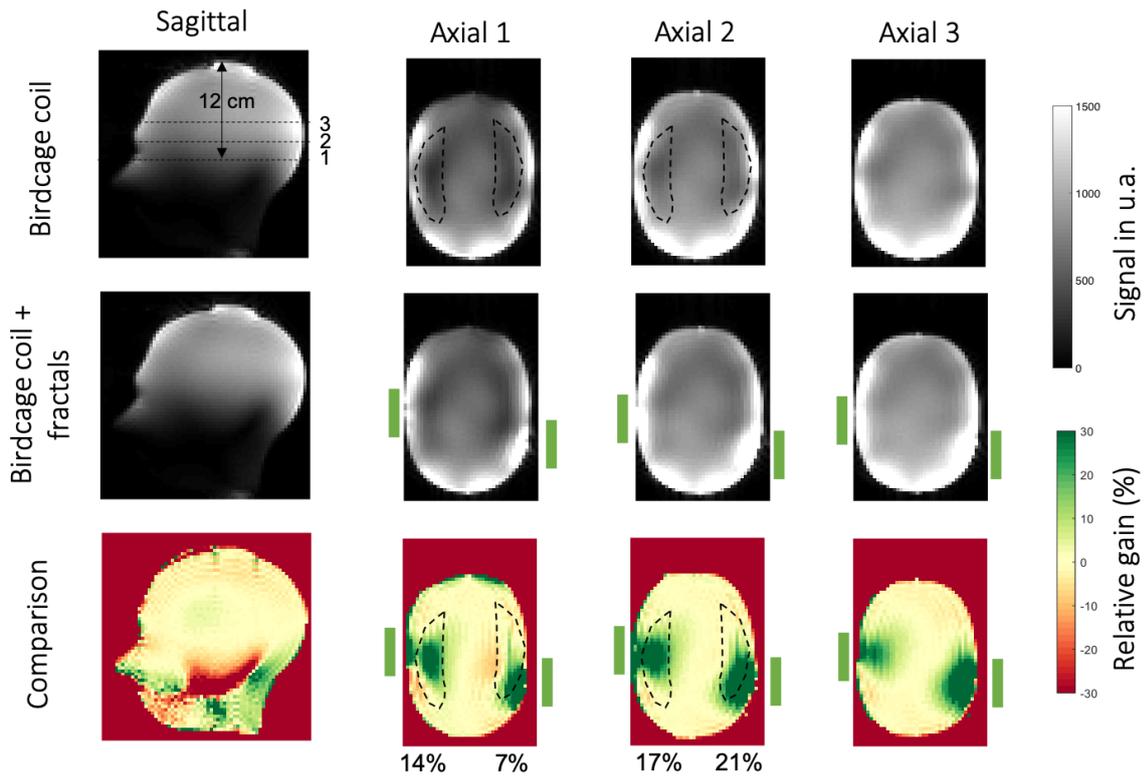


Figure 3. XFL amplitude signal maps of birdcage coil (top) and birdcage coil with resonant fractals (middle) in sagittal and axial orientations. The bottom row shows the relative gain between fractals and reference map. The schematic position of the fractals is represented with green rectangles. The dashed lines on the sagittal slice show the location of the axial slices. We defined the temporal lobe ROIs from the reference scan (top row). The values below the bottom row are the mean values obtain inside each ROI.