New low-order pre-fractal geometries of high permittivity pads further increase sensitivity at high magnetic fields

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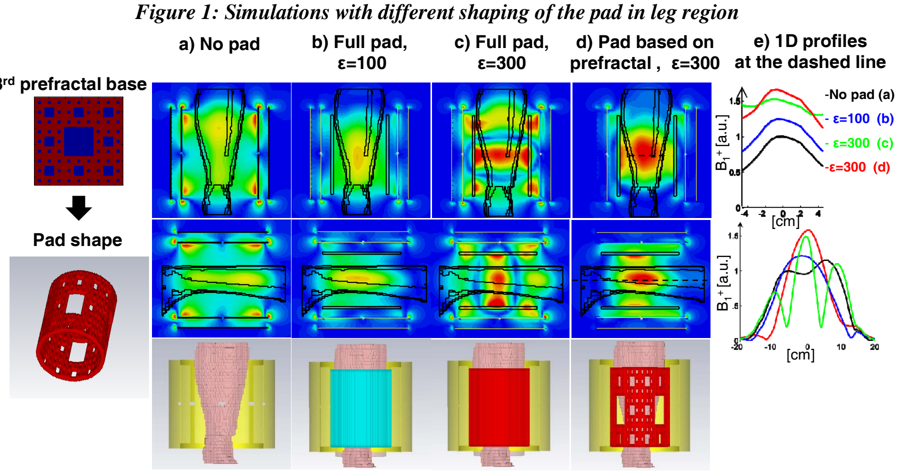
Target audience. Scientists working at 3T and 7T in applications with significant dielectric image artifacts.

Purpose. In previous work the concept of using high permittivity materials [1-4] to increase the strength and homogeneity of the B_1 field has been shown at 3T and 7T. However, it was also shown that at ultrahigh field (7 T and more) instead of a monotonic sensitivity improvement, high permittivity pads can also be a source of local signal decreases due to wavelength effects within the material, producing severe image artifacts. So far, all of the studies have used very simple rectangular geometries of homogeneous high permittivity material, without any exploration of different types of shape. In this study we investigate how the wavelength effects can be mitigated by using a low order prefractal geometry [5] for the dielectric pad, which maintains the overall coverage of the pad, but gives an increase in sensitivity and homogeneity in the relevant region of interest.

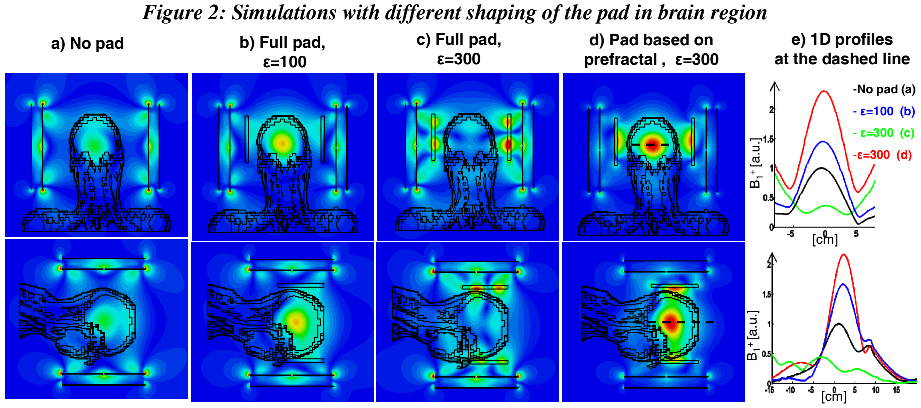
Methods. Electromagnetic simulations of B_1^+ field were performed using FDTD software (CST Microwave Studio). The setup included a birdcage coil that was loaded with the CST Bio model "Gustav": simulations were performed for both the head and leg regions. The geometry of the high dielectric pad with ε_r (relative permittivity) of 300 was designed in MATLAB and imported into CST Studio. The shaping of the prefactal pad was based on a cylindrical shell built from sub-sections of a "Sierpinski carpet" [5] up to a third order. The size of the central hole in the "Sierpinski carpet" base was 3.8x7 cm^2. As a comparison, fully filled pads of the same thickness (8 mm) with ε_r of 100 and 300 were designed. All B_1 maps were normalized to the accepted power of 1watt.

Figure 1: Simulations with different shaping of the pad in leg region



Results. Figure 1(b) shows that the ε_r =100 cylindrical pad increases the sensitivity by ~20%. Greater increases are shown in Figure 1(c) with a pad with ε_r =300, but there are significant inhomogeneities introduced by the higher dielectric. Using the prefractal geometry in Figure 1(d) maintains the high sensitivity but increases the longitudinal homogeneity significantly (the effect was improved from 1st – main holes only - to 3rd prefractal order). Figure 2 shows that results in the brain show similar behavior, but that the effects are even more pronounced in terms of the improved performance of the prefractal geometry. All maps are scaled to the same maximum value.

Figure 2: Simulations with different shaping of the pad in brain region



Conclusions. The results show that by using a prefractal geometry rather than a solid structure, as has been used in all previous studies, higher permittivity materials can be used to produce greater increases in sensitivity than currently possible, without introducing image artifacts associated with wavelength effects.

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References. [1] Haines K. et al. J.Magn.Reson. 2010; 203: 323-327. [2] Yang Q.X. et al., Magn Reson Med. 2011; 65:358–362. [3] Teeuwisse W.M. et al., Magn Reson Med. 2012; 67:912-918. [4] Brink W.M. et al. Magn.Reson.Med. 2014; 71: 1632-1640. [5] Allouche J-P. Cambridge University Press 2003.