Dipole antenna without ceramic substrate and still low SAR: the fractionated dipole antenna.

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Introduction Ultra-high field body imaging is facing a change in paradigm for transmit/receive array element design. Due to the higher frequency, and consequently smaller wavelength, deeply located imaging targets like the prostate are located at a depth comparable to the wavelength of the B_1 signals in tissue. This requires coil array elements that are designed as antennas rather than coils. One example of such an element is the single-side adapted dipole antenna (SiSiAD) [1], figure 2a, (also known as 'radiative antenna'). A dipole is accompanied by large E-fields in its vicinity. In antenna terms: it has a large E/H ratio (wave impedance). Away from the antenna, the E/H ratio decreases and converges to the equilibrium wave impedance of a plane wave travelling in tissue. The ceramic substrate ensures that these conditions are achieved within a reasonable spacer thickness (4.2 cm). Without ceramic substrate, the use of dipole antennas in MRI would lead to high SAR levels. In this study, an alternative dipole antenna design is investigated where the E/H ratio on a dipole antenna is manipulated (decreased) by lumped elements. This avoids the need for a ceramic substrate to keep high E-fields outside of the tissue. The resulting element is called a 'fractionated dipole antenna'. This highly innovative transmit array design allows similar or better B1+/SAR performance while being lighter and cheaper than the SiSiAD antenna.

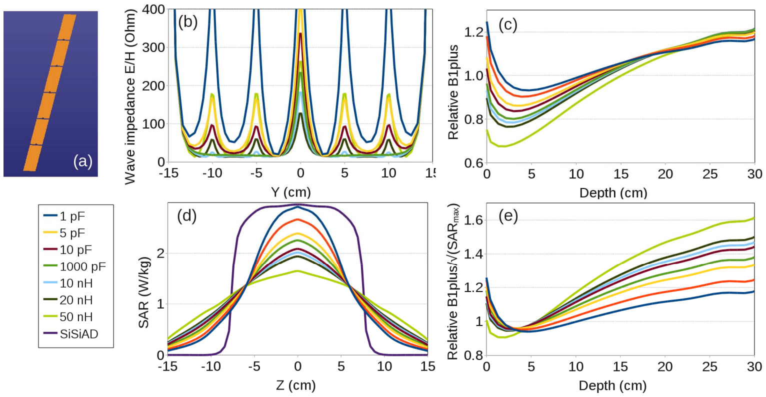

Figure 1: Optimization study. a) Simulation setup b) Wave impedance at 10 mm from dipole c) In-depth B_1 profiles, relative to SiSiAD d) Longitudinal SAR profiles, 10g averaged e)In-depth B_1^+/sqrt(SARmax) profiles, relative to SiSiAD

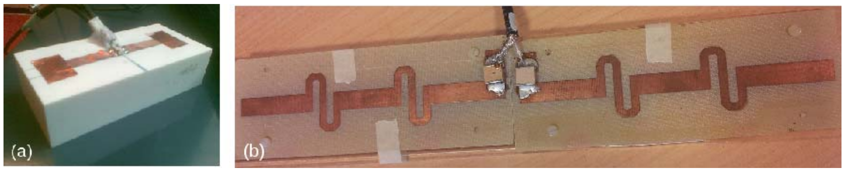

Figure 2: a) Single-side adapted dipole antenna (SiSiAD) b) Fractionated dipole antenna (FD)

Methods First, an optimization study was performed by FDTD simulations (SEMCAD X, Speag, Schmid&Partner, Zurich). The legs of a 2 x 15 cm dipole antenna were split into three 5 cm segments. The segments were interconnected by variable lumped elements while the dipole antenna was fed in the center by a voltage source (figure 1a). The antenna was placed 2 cm over a large phantom (0.5 m cube) with tissue properties. The wave impedance, B_1 and SAR distribution were evaluated for a range of lumped element values. Subsequently, a prototype was built from PCB where the optimal lumped element value (20-50 nH) was realized by a meander structure [2], figure 2b. The PCB was mounted on a 8 mm PMMA spacer to allow 10 mm spacing, including 2 mm PCB thickness. The element was placed on a 14 liter pelvis shaped phantom (40 x 20 x 25 cm^3) filled with ethylene glycol with 35 g/l NaCl (ε_r=34, σ=0.4). AFI B_1^+ measurements were performed to compare the performance of the fractionated dipole to the SiSiAD antenna (7 x 4.2 x 14.3 cm^3, ε_r = 37). The same setup was also simulated in Semcad X using the 380 W net arrived input power from the measurements. Due to the finite size of the phantom, reflections may cause interferences that disturb the B_1 pattern. To enable a plain and uncorrupted comparison, simulations were repeated on a larger phantom (0.5 m cube). The spacer thickness was varied (10 and 20 mm) to investigate the impact of this parameter.

Results Results for the optimization study are presented in figure 1. The decrease in wave impedance for increasing C or L mostly goes alongside with improving SAR/B_1^+ performance.The combination of these results shows that the optimal lumped element between the dipole segments would be an inductor of 20-50 nH (good B_1/SAR at 10-15 cm depth). The prototype B_1^+ measurements and simulations are indicated in figure 3. Simulations and measurements are in good agreement. The B_1^+ level at 10cm depth for the fractionated dipole is a little lower, which is confirmed by the large phantom simulations presented in figure 4. Although the B_1^+ efficiency of the fractionated dipole is lower than the SiSiAD antenna its SAR levels are also lower. The B_1^+ over square root of SARmax is highest for the fractionated dipole with 20 mm spacer.

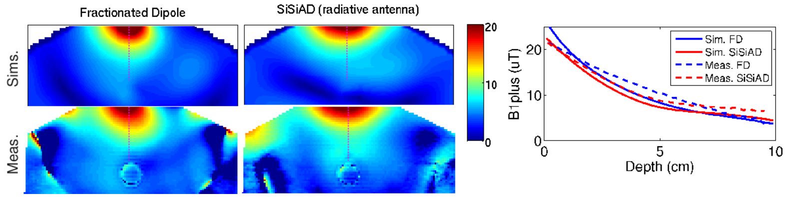

Figure 3: Simulated and measured (AFI) B_1^+ maps for fractionated dipole and SiSiAD, graphs of B_1^+ along indicated profiles

Conclusion The fractionated dipole is another antenna designed according to radiative principles. It is a promising and highly innovative approach for transmit or transceiver array elements at ultra-high field strengths. It is lighter and cheaper than the single-side adapted dipole antenna and has similar or better B_1^+/SAR performance.

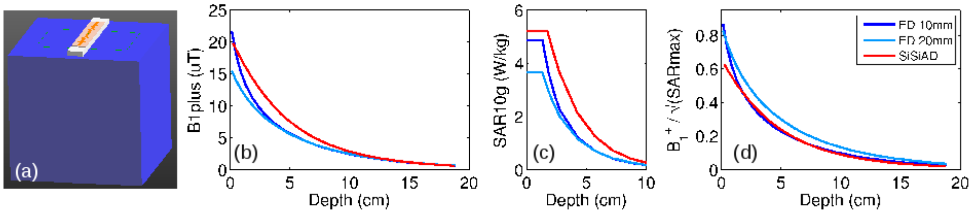

Figure 4: FDTD simulations for fractionated dipole with spacer of 10 and 20 mm and the single-side adapted dipole antenna. a) setup b) B_1^+ profiles c) SAR profiles (10g avg) d) B_1^+ profiles per square root of SARmax.

[1] Raaijmakers et al. MRM 2011
[2] Orzada et al. Proc. ISMRM 2009

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