Successful body imaging at 7 Tesla: The Fractionated Dipole Antenna

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Dipole antennas are emerging rapidly in the ultra-high field community, and many design variations have been presented [1-4]. One of these design variations is the 'fractionated dipole antenna' [5], where the legs of the antenna are separated in segments that are interconnected by lumped elements (capacitors or inductors). In this way the field distribution around the antenna can be manipulated. It has been shown that when using inductors (meanders) of approximately 50-100 nH, SAR levels underneath the element are reduced while maintaining the same level of efficiency. Although the design looks promising, its full potential in an array setup has not yet been characterized. Here we present a fixed-tuned 8 element array design with a full analysis by FDTD simulations and example MR images for various body applications at 7 Tesla.

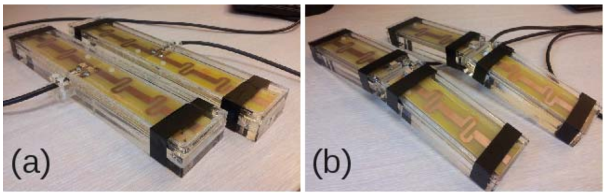

Figure 1: a) Fractionated dipole antennas b) Fractionated dipole antennas with an angle between the legs of 14 degrees.

A transmit/receive array of 8 fractionated dipole antennas (30 cm length) is realized from PCB board with 20 mm PMMA spacers towards the body. PMMA covers of the elements ensure EMC safety (figure 1a). For cardiac imaging, elements are built that adapt to the curvature of the chest (figure 1b).

EM simulations (Semcad X, Speag, Zurich, CH) of this design have been performed for a prostate setup and compared to simulated results for an array of 8 single-side adapted dipole antennas [1] (also known as: 'radiative antennas'). SAR levels in an array setup depend heavily on phase settings. For comparison (and to determine scan parameter restrictions for RF safety) the worst-case SAR distributions have been calculated [6]. These are the 10g averaged local SAR values (SAR_{10g}) for each voxel that can possibly be reached with the most disadvantageous phase settings. Results in figure 2 clearly show the lower SAR levels for the fractionated dipole antenna array, while the B_1 efficiency is similar. Abiding a safety limit of 20 W/kg for the SAR_{10g} results in a maximum allowed average power on the elements of 8x3.9W for prostate and 8x3.3W for cardiac (data not shown), using the restrictive worst-case maximum SAR_{10g} values that the array could potentially reach.

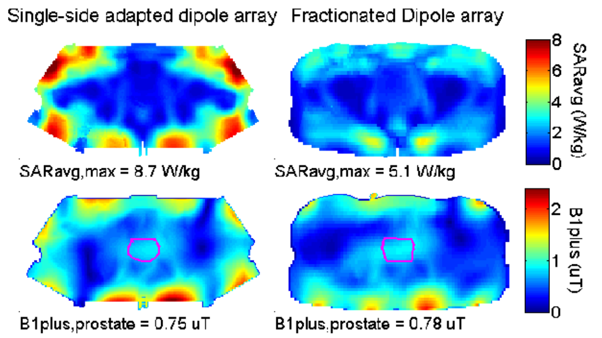

Figure 2: EM-simulations for prostate imaging with the indicated array designs. All distributions normalized to 8x1W. Upper row: SAR_{10g} (distribution of maximum potential SAR for each voxel) Lower row: B_1^+ distribution when phase-shimmed on the prostate. Actual maximum SAR_{10g} levels for these phase settings are 7.6 and 2.8 W/kg (data not shown) .

Imaging performance of this new array setup has been explored for cardiac, kidney and prostate imaging. Cardiac imaging setup and results are presented in figure 3. Note that the depicted coronary arteries (LAD and LCX) are the more challenging arteries to image. Figure 4 shows results for kidney imaging. Both T1w IR-TFE and T2w TSE images are depicted, which are demanding sequences in terms of B_1 efficiency and homogeneity. This reflects the good efficiency and shimming performance of the array. Figure 5 shows a T2w TSE image of a prostate cancer patient with a combination of a 2-channel endorectal coil [7] with the fractionated dipole antenna array. The tumor is the hypo-intense region at the bottom right of the prostate (in the image).

Overall, the array is robust, fixed-tuned (easy setup), does not need baluns or cable traps, provides little coupling (S12 < -13 dB), is at least reasonably well matched for any subject (S11 < -10 dB, mostly much better), longitudinal FOV is large and efficiency/SNR is high (8-10 uT in prostate for 8x350 W nett power arrival). Clinical body applications at 7 T using these elements are now being explored.

References: [1] Raaijmakers et al. MRM 2011 [2] Winter et al. PloS One 2013 [3] Eryaman et al. ISMRM 2013 [4] Wiggins et al. ISMRM 2013 [5] Raaijmakers et al. ISMRM 2013 [6] Ipek et al. MRM 2013 [7] Arteaga et al. NMR Biomed.

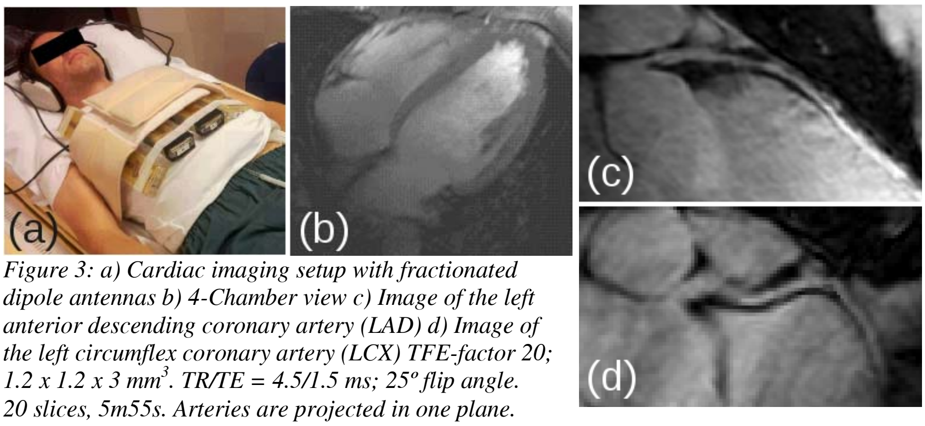

Figure 3: a) Cardiac imaging setup with fractionated dipole antennas b) 4-Chamber view c) Image of the left anterior descending coronary artery (LAD) d) Image of the left circumflex coronary artery (LCX) TFE-factor 20; 1.2 x 1.2 x 3 mm^3. TR/TE = 4.5/1.5 ms; 25º flip angle. 20 slices, 5m55s. Arteries are projected in one plane.

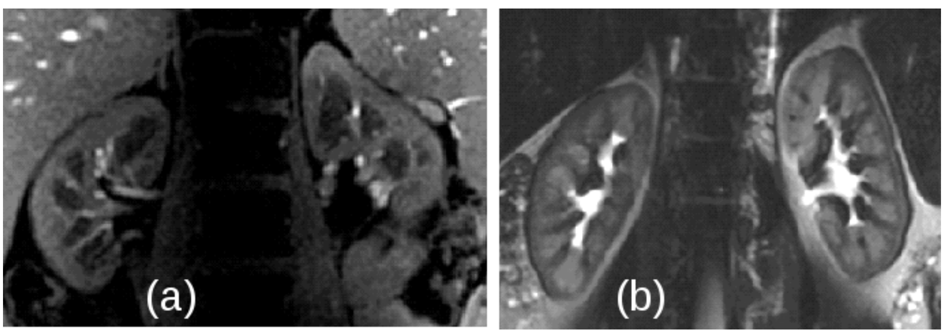

Figure 4: Kidney imaging results a) Single Shot T1w IR-TFE image TR/TE = 5.1/2.1 ms, 1.5 x 1.5 x 3 mm^3 SENSE 2, 12 slices, 10º flip angle, 3-point Dixon IR=2000ms, 0m45s b) Single Shot T2w TSE image TR/TE = 14000/137 ms, 1.4 x 1.6 x 5 mm^3, SENSE 4, 1 slice, 0m14s

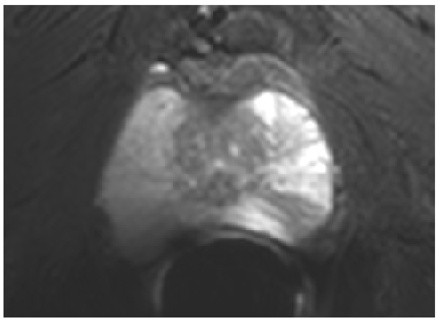

Figure 5: prostate cancer patient. T2w image (array + endorectal coil) TR/TE =6000/70 ms, 1x1x12 mm^3, TSE-factor 9, NSA=2, SPAIR fat suppr. 10 slices, 9m08s