

High-field imaging at low SAR: Tx/Rx prostate coil array using radiative elements for efficient antenna-patient power transfer

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Introduction

Several institutes have presented results on prostate imaging using a surface array of resonant stripline elements [1-3]. In the perspective of antenna theory, resonant stripline elements are near-field antennas with a high magnetic field in the near field zone around their conductors. This is an advantageous concept for MRI as long as the target region can be located in the near field. The near-field, however, decays quickly with distance (near field extends approx. $\lambda/4 = 4 \text{ cm @ } 298 \text{ MHz}$). Since most interesting sites in the abdomen are far beyond near-field regime, a radiative antenna would be the element of choice for a coil array in MR imaging [4]. A radiative antenna is designed to couple an electromagnetic wave effectively into the patient. In this way the power flow to the target region is maximized while reducing peaks in the electric and magnetic fields at the antenna-body interface. We present an antenna design that is known originally from hyperthermia. It generates E- and H-fields in such a way that the Poynting vector is pointing into the patient (figure 1). Extensive simulations and measurements on phantoms (presented elsewhere) show that radiative elements will enable imaging with a lower maximum SAR level and a wider and more homogeneous field of view. In this work we present imaging and simulation results on a volunteer with a prototype coil array of radiative elements. Advantages of this coil array are a lower maximum SAR level and a wider and more homogeneous field of view.

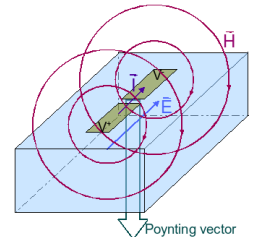


Figure 1: Schematic design of radiative antenna, its E- and H-fields and the resulting Poynting vector

Materials and methods

An array has been constructed using four elements. Each element consists of a dielectric ceramic substrate (Morgan Technical Ceramics) with a permittivity of 37 and low conductivity. A dipole antenna is mounted on each element consisting of two legs of copper tape. The antenna is matched to 50 ohms by adjusting the shape of the legs of the antenna and by placing one tunable capacitor over the feeding point (Figure 4). The antenna is fed by a coax cable passing through a BalUn and connected to home-built Tx/Rx switches. To obtain the maximum power available, two elements were connected to 4 kW amplifiers and the two remaining elements were connected to 2 kW amplifiers. All amplifiers were steered via a home-built vector modulator to enable phase-amplitude shimming. Images were obtained on a Philips Achieva 7 T system (Best, The Netherlands). Image quality was evaluated by measuring a FFE sequence and a TSE sequence. The B_1^+ level at the prostate was measured to determine the coil efficiency. FDTD simulations have been performed using SEMCAD (SPEAG, Zurich, Switzerland) to investigate the SAR distribution. To highlight the improvements of the radiative antenna array, a comparison has been made to a similar four element coil array consisting of stripline elements.

Results

Simulation results are presented in figure 2 and 3. Results show that the B_1^+ level in the prostate with the radiative array is comparable to the level with the stripline array (0.11 vs 0.13 $\mu\text{T @ } 1\text{W}$ delivered power). For both coil arrays, the SAR level at the dorsal elements is higher than at the ventral elements, due to the higher abundance of muscle tissue. For the radiative elements, the SAR level is lower than for the stripline elements (0.8 vs 0.5 W/kg , 10g average, 1W delivered power).

Measurement results are shown in figure 4. These results show that the radiative antenna array is capable of acquiring good and homogeneous T1w images of the pelvic region (figure 5a). In comparison to images obtained with a 8-element stripline array (figure 5c) [3], the images are much more homogeneous. Note the absence of inversion bands near the elements, indicating lower B_1^+ (and SAR) at the surface. T2w images of the prostate have been measured as well (figure 5b). The measured B_1^+ level was 4 μT which is roughly in agreement with the simulations. The strongest coupling between two elements was measured to be -22 dB.

Conclusion

The radiative antenna array is a promising alternative for pelvic imaging at 7 Tesla. Performance is improved in terms of lower local SAR and more homogeneous image intensity. In future, the number of elements will be increased to achieve even higher levels of B_1^+ while maintaining the low SAR level.

References:

- [1] Metzger et al. "Local B1+ shimming for prostate imaging..." MRM 2008
- [2] Orzada et al. "A flexible 8-channel Tx/Rx body coil..." ISMRM 2009 proceedings
- [3] Raaijmakers et al. "Prostate Imaging at 7T..." ISMRM 2009 proceedings
- [4] Raaijmakers et al. "Boosting B1+ efficiency..." ISMRM 2009 proceedings

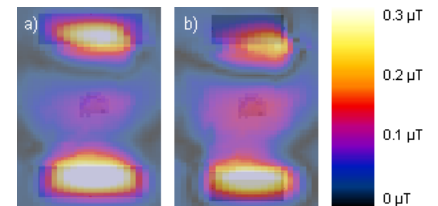


Figure 2: B_1^+ distribution (normalized to 1 W delivered power) in sagittal plane through prostate for radiative antenna array (a) and stripline array (b). B_1^+ levels at prostate (visible in transparent) are comparable.

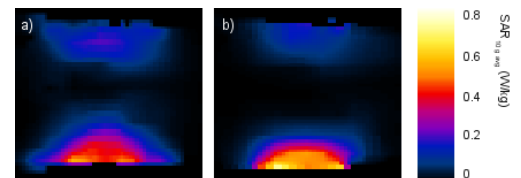


Figure 3: SAR distribution (10g averaged) in the sagittal plane through the right elements of the radiative antenna array (a) and stripline array (b). Radiative antenna elements demonstrate lower maximum SAR.

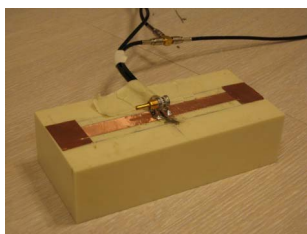


Figure 4: The radiative antenna element, consisting of a ceramic dielectric substrate, two copper strips, a matching capacitor and connection via a BalUn

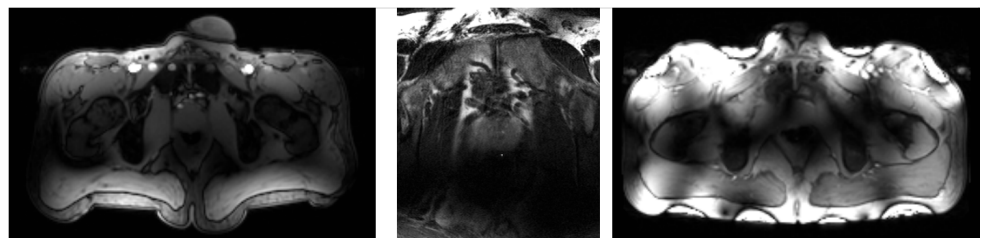


Figure 5: MR images on healthy volunteer obtained with the radiative antenna coil array. (a) T1w FFE, $FA=45^\circ$, $TR/TE=46/1.5$, $2x2x5 \text{ mm}^3$ (b) T2w TSE, $FA=90^\circ$, refocussing= 100° , $TR/TE=4000/104$, $0.5x0.67x3 \text{ mm}^3$ (c) For comparison: T1w FFE obtained with an 8-stripline coil array, $FA=45^\circ$, $TR/TE=150/1.36$, $1.1x1.1x10 \text{ mm}^3$.