How to reach the full potential of the B1+ efficiency for a 7 T body transmit array?

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Introduction: 7 T prostate MR imaging has been shown feasible using multi element transmit coils and RF shimming strategies [1]. However, B_1^+ field strength at depth is limited due to strong RF attenuation and limited power capability of RF amplifiers for 7T MR imaging (298.2 MHz). By designing the array elements as radiative antennas, the B_1^+ field at depth can be augmented [2]. Employing 8 radiative antennas in an array combined with B_1^+ phase shimming to optimize constructive interference in the prostate, we evaluated by FDTD simulations that the B_1^+ field in the prostate should be around 20 µT for maximum 8x500W net input power [3]. This is contrary to our experiences from experiments where in a phase shimmed situation, the B_1^+ field is mostly around 10 µT for 8x500 W net input power [2]. The origin of this discrepancy is the topic of this study.

Methods: An 8 elements radiative antenna array was simulated with the finite difference time domain (FDTD) method in SEMCAD (SPEAG, Zurich, Switzerland). Each of the 8 radiative antennas comprised a dielectric substrate with two conductors forming a dipole antenna. The substrates consist of eight blocks (6.7x4.2x14.3 cm^3) with of a dielectric permittivity of 37. Four blocks are placed respectively on the anterior and posterior side of a male human model member of Virtual Family [4] (Figure 1). For all simulations the 500 W RF input power was assumed per element. Using simulations we evaluated the B_1^+ patterns for three scenarios: In scenario A, the B_1^+ fields of each element were calculated by setting the feeding voltage to 1 V for that specific element while setting the voltages in all other elements of the array to zero. Based on these individual element simulations, the phase shim settings were determined to obtain constructive B_1^+ interference in the prostate. These phase settings were applied when adding the individual B_1^+ fields up to one overall B_1^+ field. In scenario B, a simulation was performed with all elements active and applying the phase shim settings from scenario A to the voltage sources. In scenario C, the coupling admittance matrix was first determined based on the simulations from scenario A. The matrix elements Y_{ij} were calculated by recording the current at non-active element i and dividing it by the voltage of the active element j. As the phase of the transmitted B_1^+ field of an element is proportional to the phase of the total current in an element, we determined in scenario C the voltage source settings that would result in the currents (in scenario C) having the phases of the currents from scenario A minus the B_1^+ phase in the prostate. This procedure was performed by solving a linear system given by:

$$\vec{I}_{phase\ shim} = [Y]\cdot\vec{V}_{phase\ shim}$$

where $I_{phase\ shim}$ and $V_{phase\ shim}$ are vectors carrying the voltages and currents of the elements and **Y** is the admittance matrix characterizing the coupling between all the elements. The phase shim settings entered in $I_{phase\ shim}$ are the phase shim settings determined in scenario A. The calculated $V_{phase\ shim}$ (carrying amplitude and phase information) was subsequently applied in a situation where all elements were active like in scenario B.

Results and discussion: S_{12} evaluation demonstrated that the decoupling was better than -15 dB for all elements. Although the coupling is negligible, the impedances change substantially from scenario A to B (Table 1). The phase shimmed B_1^+ distribution of scenario A is depicted in Figure 2a. The B_1^+ field at the prostate was 19 µT for 8x500 W. Applying these phase setting to scenario B and maintaining same overall power, a substantially lower B_1^+ field of 13.4 µT was observed. Scenario B is identical to what is being performed in the experiments. Following scenario C, the resulting B_1^+ pattern is similar to the shape observed in scenario A. The B_1^+ efficiency is increased to 18.3 µT almost recovering the B_1^+ efficiency of scenario A. These findings explain why in the experiments where no correction is being made for the mutual admittances, a reduced B_1^+ efficiency is found even though S12 decoupling is better than -15 dB. The findings from scenario C indicate the importance of performing such a correction. The incorporation of pickup probes in our radiative antenna array to measure the admittance matrix could easily facilitate this.

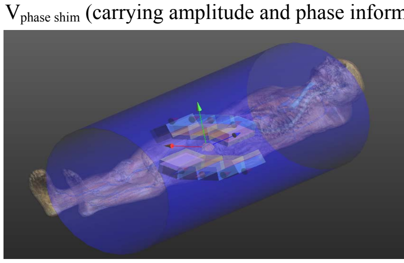

Figure 1: The simulation model of a radiative array located on a male model lying in the bore.

Table 1: Impedances of voltage sources per element of simultaneously-on and individually on simulations

	Element 1	Element 2	Element 3	Element 4	Element 5	Element 6	Element 7	Element 8
Simultaneously on	29.1-j5.7	19.0+j7.4	12.8+j15.3	19.7+j11.7	22.9+j11.6	14.6+j15.8	17.3+j10.8	35.5-j10
Individually on	25.7+3.3	25.2+j6.4	22.9+j7.1	27.7+j4.08	30.1+j4.5	23.8+j5.6	23.6+j7.09	30.6+j6.05

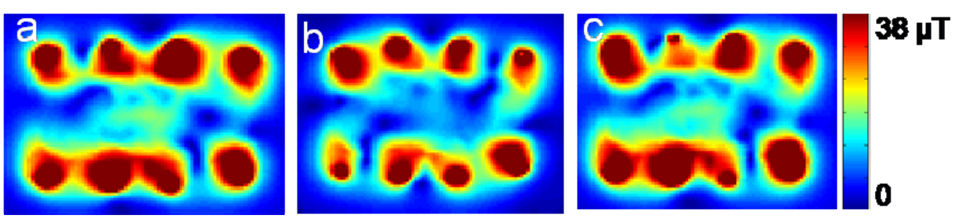

Figure 2: Transverse B_1^+ field slice of a human body excited by a radiative antenna array with individual channels on, combined with phase shimmed value (a), all elements are simultaneously-on with the phase settings (b), and with corrected phase settings calculated from the current and voltage setting of individual channel.

Conclusion: To perform accurate B_1^+ phase shimming for 7T prostate imaging the inclusion of mutual coupling is important even if elements are better decoupled than -15 dB. The voltage phase shim settings found in a single channel calibration method should be corrected for by including the admittance matrix. In this way the full B_1^+ potential for a body transmit array can be harvested. As the elements are placed on the body, the admittance matrix has to be determined in an exam specific manner. In the near future we will explore this experimentally.

References:

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