The inductively decoupled transceiver array: simulations and performance at 7T

J. W. Pan[1], N. Avdievich[1], T. S. Ibrahim[2], and H. P. Hetherington[1]
[1]Neurosurgery, Yale University School of Medicine, New Haven, CT, United States, [2]Bioengineering, University of Pittsburgh, United States

Introduction: The transceiver array has been shown to achieve excellent homogeneity and B1 amplitude at ultra-high field for head studies. However, as a set of decoupled surface coil elements there has been uncertainty as to its performance consistency. Under in vivo conditions, the largest variable between volunteers is the distance between the element(s) and head, with both coil loading and decoupling affected by this gap. We simulate this effect of variable loading and decoupling at 7T and compare it to experimental data.

Methods: Transceiver Array/MR: The transceiver array consists of 8 rectangular inductively decoupled surface coils 9x8cm on an elliptical former. The array used a split design, allowing the vertical dimension of the coil to be varied in 2cm increments to maintain proximity of the coils to the head different head sizes. All data were acquired with a 7T human MR system. Phantom data were acquired from a GE "Braino" phantom. Simulations: Remcom XF7.1.0.5 finite difference electromagnetic wave analysis was used for B, E and SAR calculations. Simulations for RF shimming were performed using individual simulated coil maps in MATLAB, with the calculated phases and amplitudes then implemented in Remcom. Phantom simulations were performed using a 3liter saline sphere (σ 1.17S/m, ε 80); head simulations were performed using a scaled down version of the (large) Hifi Head model.

Results: To evaluate the effect of variable distance (1-4cm) between the sample and coil, simulations were performed using a single coil (one coil of the transceiver array) and 3liter phantom. With increasing distance (Fig 1), the $B1+_{magn}$ falls at the periphery, while remaining relatively constant in the center; however the phase of B1+ remains largely unchanged. To evaluate the effect of distance on the inductive decoupling, a Thevenin circuit equivalent was used to simulate S11, S12 of decoupled adjacent coils (all coils matched to better than -25dB, Table 1) and phantom. For a gap distance of 1-2cm, a fixed 14nH value could maintain S12 at better than -18dB.

Displayed in Fig 2A-D are B1+ magnitude and phase maps for all 8 coils in the array and after RF shimming for the large central brain region (optimized B1+ in "homogeneous mode") from simulated and experimental data (phantom and head). There is an excellent correlation between simulation and experiment, showing the efficiency of the inductive decoupling. In this decoupled array, the magnitude maps from the head and phantom have relatively similar spatial dependencies, with a slower rate of phase variation in the head in comparison to the phantom. The shimmed simulated powers matched the experimental power measurement, at 2.63 vs. 2.55 kW (phantom, simulation vs experiment) and 1.54 vs. 1.51 kW (head, simulation vs experiment) respectively. To show the importance of decoupling on performance of this transceiver design, simulation data from a well vs. poorly decoupled round transceiver (circularly polarized input) and phantom are shown in Fig 2E, showing the increased E fields generated per B1+ in the poorly decoupled case (ratio E/B1+ maps).

Fig. 1Simulations of a single coil element with a variable gap to load. (A) B1+ (magn), (B) B1+ phase, (C) E(magn) and (D) SAR maps.

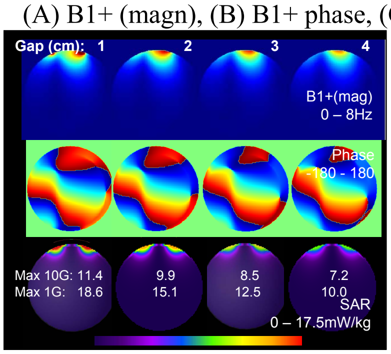


Table: Maintenance of mutual decoupling with variable gap

Gap (cm)	Fixed 14nH decoupling S12	Q
1.2	-18.8	25.5
2.2	-24.9	52
3.2	-16.29	99
4.2	-9	~150

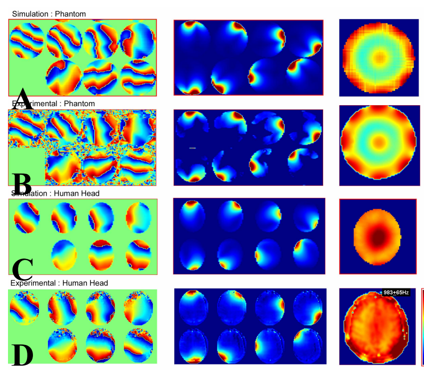
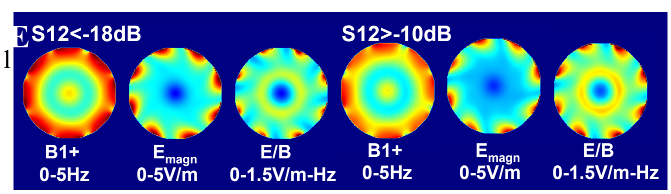


Fig 2: B1+ (magn, phase maps) for 8 coils in transceiver: Simulation (A,C; phantom, head) and experimental (B,D; phantom, head). E: Round transceiver and phantom simulation: $B1^{+}$magn , Emagn and E/B maps.



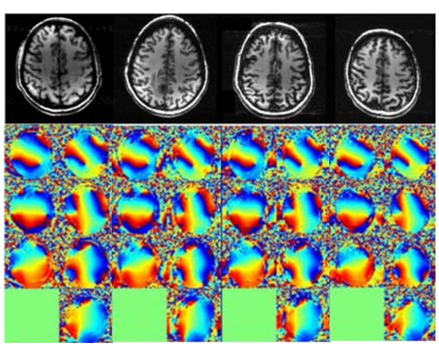


Fig. 3 (left). Experimental B1 phase maps for 4 different volunteers, showing consistency of phase maps.

From 100 in vivo volunteer studies, the transceiver achieves 19.5±0.7 and 17.7+1.6uT at 1kW in SMA brain region with (small, medium head size coils respectively) with ~9% B1 homogeneity. In the thalamic region, 18.3±2.0, 16.0±1.4 and 14.6+2.1 uT (~11% homogeneity) from small, medium and large head sizes.

Conclusions: For single surface coils and surface coil pairs, distance between sample and coil does not dramatically change the phase maps. This property, combined with a well decoupled array that minimizes inter-element interactions, argues that consistent B1+ performance can be achieved over the large central region, which is in excellent agreement with in vivo results.