Parallel transmit excitation at 1.5 T based on the minimization of a driving function for device heating

Natalia Gudino[1,2], Merdim Sonmez[2], Anthony Z Faranesh[2], Robert J Lederman[2], Robert S Balaban[2], Michael S Hansen[2], and Mark A Griswold[1,3]
[1]Department of Biomedical Engineering, Case Western Reserve University, Cleveland, OH, United States, [2]Division of Intramural Research, National Heart Lung and Blood Institute, National Institutes of Health, Bethesda, MD, United States, [3]Department of Radiology, Case Western Reserve University, Cleveland, OH, United States

Target Audience: Those interested in parallel transmission and iMRI safety.

Purpose: It has been shown that induced currents in long conductors can be minimized through parallel transmission (pTx)[1]. In the present work, a planar Tx coil array driven by near-coil current-source amplifiers [2] was built to reduce RF E-field coupling to a long wire/guidewire based on the minimization of a driving function for device heating [3,4].

Methods: For N-channel pTX system the driving function is given by:

$$W(t) = \mathrm{Re}\left\{ j\omega \int_0^L \sum_{n=1}^{N} \vec{a}_n(r) e^{j\theta_n} e^{j\omega t} d\vec{l} \right\} = \mathrm{Re}\left\{ \sum_{n=1}^{N} \vec{w}_n(r) e^{j\theta_n} e^{j\omega t} \right\}$$

Where a_n , θ_n and w_n are the magnetic potential, the phase of the field and the driving function of channel n respectively. Using an in-house MATLAB code based on Bio-Savart and Maxwell's equations *W* was calculated (in a.u.): 1) for different predefined phase configurations, 2) for different phase (**p**) and amplitude (**a**) vectors obtained through a minimization algorithm constrained by B_1 homogeneity at a predefined ROI. A 4-channel planar coil array was driven by CMCD amplifiers with current feedback [2] through $\lambda/2$ equivalent connections. The array was loaded with a saline phantom of similar loading than the human torso made of 20 L of H_2O 10 g of NaCl (Fig. 1). An insulated nitinol wire with tip exposed and lumen to insert a fiber temperature sensor (OTG-M170-10-80F2.5-1.55, Opsens, Canada) was built for the phantom experiments. The wire, aligned in the z-direction, was inserted from foot to head 30 cm (IL) into the phantom at x=9 cm and 1 cm depth. In a 1.5 T MRI (Espree, Siemens) temperature was measured at the tip (hot spot) while transmitting a 90° excitation (confirmed through B_1 mapping for TX array) at 10 % duty cycle with: 1) body coil 2) with the pTx system in phase 3) and with a set of phases for which *W* values were previously simulated**.** Temperature increment (ΔT) was calculated by subtracting average baseline temperature from steady temperature after one-minute scan. ΔT along the wire's IL was also measured by pulling the sensor back from tip in 1 cm steps. Gradient-echo images were acquired with 2 ms RF pulse, 10 ms TE, 50 ms TR, 450 x 450 cm^2 FOV. Phase and amplitude vectors obtained from the B_1 constrained minimization were tested on the benchtop with similar wire-phantom and ΔT measurement setup. Finally, the MRI experiment was repeated with an anesthetized naïve Yorkshire (50 kg). An active guidewire [4] was inserted superficially around pelvis area at 7 cm from femoral vein (approved by NIH animal care committee).

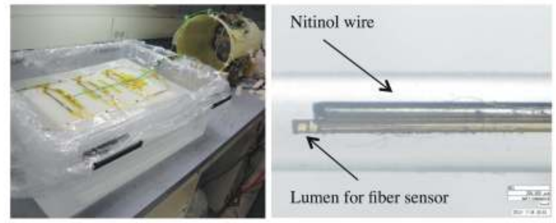

Fig 1: Four-channel planar array driven by near-coil CMCD amplifiers (left) and 128 cm bare nitinol wire with attached lumen for sensor

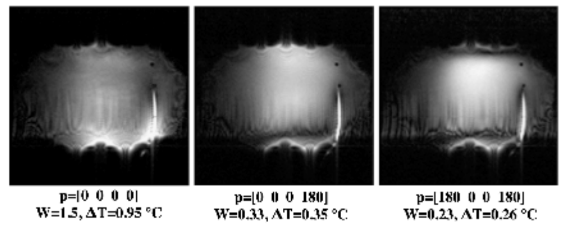

Fig 2: Images of wire immersed in phantom and corresponding phase vector, W and ΔT at the tip of the wire.

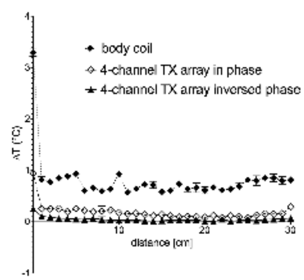

Fig 3: ΔT along the wire from the tip (0 cm) to the phantom exit (30 cm)

Results: Images from simultaneous phased excitation, *W* and measured ΔT at the tip of the wire are shown in Fig. 2. For the 180°out-of-phase excitation [Fig.2 (right)] ΔT at the tip of the wire was reduced up to 72 % from that measured with the TX array in phase and up to 92% from that measured with the body coil TX at same flip angle and duty cycle. Heating was effectively reduced along the wire's IL (Fig. 3). An ROI equivalent to the FOV covered by 3 TX loops but with a ΔT reduction up to 90% was measured on the benchtop by applying the **a** and **p** values obtained through the constrained minimization (Fig. 4). Figure 5 shows sagital images and corresponding ΔT on the tip of the wire (AP location marked by white arrow) for the different TX setups. For the 180° out-of-phase excitation ΔT reduction was up to 32% of that obtained with the in phase excitation and up to 89 % of that obtained with the body coil TX.

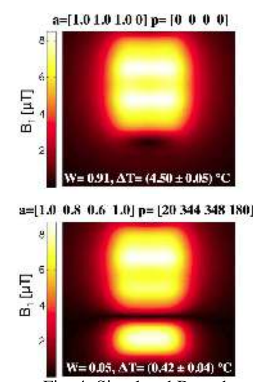

Fig. 4: Simulated B_1 and W and ΔT measured at the tip of the wire.

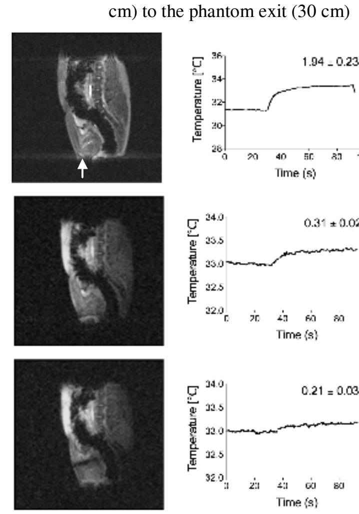

Fig 5: From top to bottom, images and ΔT obtained with BC TX, with pTX in phase and with ch-1 ch-4 180° out-of-phase.

Discussion: Approximately four-fold temperature reduction was possible in the phantom MRI experiments with the 180° out-of-phase excitation while keeping reasonable homogeneity toward the center of the FOV. No considerable in-vivo heating was shown in this setup [5], with ΔT reaching noise levels for the 180° out-of-phase excitation.

Conclusion: Preliminary data shows the advantages of replacing the body coil transmitter with a local TX array in an iMRI setup. Further ΔT reduction was possible by exploiting the additional degrees of freedom of a pTX system. Minimization of E-field coupled to a straight wire was achieved by direct amplitude and phase control of the current/B_1 of the multiple elements. A higher order pTX system will allow E-field control of devices with more complex trajectories in space.

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References: 1-Etezadi-Amoli M, Stang PP, Zanchi MG, et al. ISMRM, 2010. 2- Gudino N, Heilman JA, Riffe MJ, et al. MRM. 2012. 3- Park S-M, Kamondetdacha R, Nyenhuis JA. JMRI, 2007. 4-. Heilman JA. PhD Thesis, 2009. 5- Sonmez M, Saikus CE, Bell JA, et al. JCMR, 2012.