Adiabatic B_1 Shimming Algorithm for Multiple Channel Transmit at 7T

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Introduction: Adiabatic B_1 shimming is a hybrid high-field imaging approach that combines the flexibility offered by multiple transmit RF channels with the B_1-immunity of custom adiabatic RF pulses. In this work, a simulated annealing (SA) optimization algorithm was developed to determine the RF amplitude and phase adjustments to adiabatic RF pulses played on individual transmit channels. The amplitude and phase of the pulses are chosen to maximize the percentage of the final B_1 field over the region of interest (ROI) that exceeds the adiabatic threshold for the applied RF pulses. The adiabatic B_1 shimming algorithm was applied to 2-channel and 8-channel 7T B_1 transmit maps and the resultant shim values were tested in simulation. Greater than 95% uniformity was achieved for the simulated flip angle in phantoms and *in vivo*, when applying the B_1 shim values obtained using our optimization algorithm.

Method: Our objective was to take advantage of the flexibility offered by multi-channel transmit systems to apply adiabatic pulses with varying phase and amplitude on individual channels. B_1 maps of a spherical water phantom and the human head were obtained using the Bloch Siegert method described in [1] on the 7T 2-channel transmit system (GE Healthcare, Waukesha, WI) at Stanford University. A second set of B_1 maps of a spherical doped water phantom were obtained for a 7T 8-channel system at Martinos Center for Biomedical Imaging, Massachusetts General Hospital. B_1 mapping was based on the method used in [2]. We designed an adiabatic SLR pulse with an adiabatic threshold amplitude of 12 μT [3]. We used a simulated annealing algorithm in MATLAB (The Mathworks, Natick, MA, USA) to minimize a loss function which we specified to be the weighted sum of 1) the L2-norm of the input RF amplitudes, indicating the worst-case RF power deposition (i.e. all coils add coherently) as measured by the Specific Absorption Rate (SAR), 2) the amount by which the input RF amplitudes exceed the hardware limit of 35 μT and 3) the number of pixels in the final B_1 map that fail to equal or surpass the adiabatic threshold. The initial values of RF amplitude, set as inputs to the minimization algorithm, were set to be 20% below the adiabatic threshold, and initial values of RF phase were initialized to follow the average phase variation of the acquired B_1 maps, calculated from a small region in the center of the ROI. The final B_1 map was used to scale the amplitude and phase of the adiabatic SLR pulse and the slice profile was simulated for the entire ROI.

Results: Results obtained for a spherical water phantom and an axial slice through the head at 7T with a 2-channel transmit setup are shown in Fig. 1. Figure 2 shows the results for the algorithm applied to an 8-channel transmit setup. When compared to a previous implementation of adiabatic B_1 shimming which maximizes the minimum value in the final B_1 map [4], using the SA algorithm to minimize the loss function specified above achieved the greatest uniformity in the resultant flip angle with the lowest input RF amplitudes for the same worst-case SAR. For the 8-channel case, when the input norm was fixed, the SA algorithm achieved a B_1 field that exceeded adiabatic threshold for the entire ROI with a maximum input RF amplitude of 28 μT while the algorithm in [4] resulted in a B1 field where 10% of the pixels located at the center of the ROI failed to surpass adiabatic threshold and the max RF amplitude was 45 μT, which exceeded hardware limits. Using SA to minimize the objective function in [4] did increase the area exceeding the adiabatic threshold to 100%, however the maximum input RF amplitude of 32 μT was higher than our algorithm.

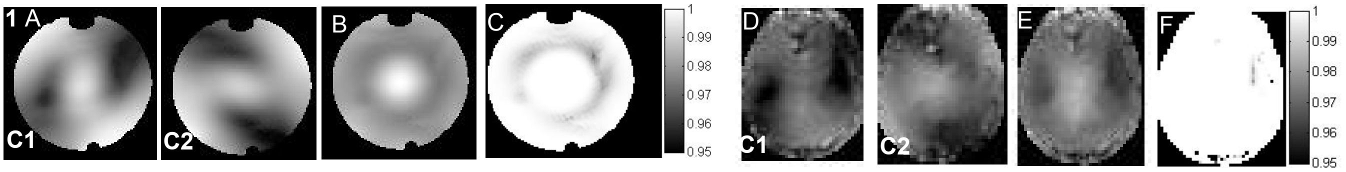

Figure 1: (A) B_1 maps for a spherical water phantom obtained from a 2-channel (C1, C2) 7T transmit setup. (B) RF amplitude achieved when adiabatic B_1 shimming algorithm is applied. (C) Simulated magnitude of slice profile for 180° adiabatic SLR pulse when using B_1 shim values from (B). Results from the same experiment and simulations performed in vivo are shown in (D-F). High uniformity in the flip angle is achieved over the entire slice by ensuring RF amplitudes remain above the adiabatic threshold.

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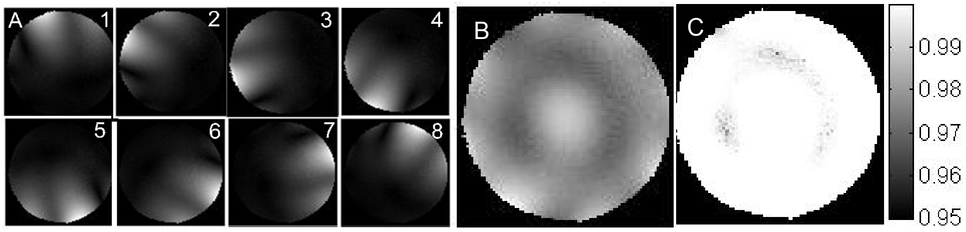

Figure 2: (A) B_1 maps for an 8-channel 7T transmit system. (B) B_1 amplitude achieved with adiabatic shimming algorithm is applied. (C) Simulated magnitude of slice profile for 180° adiabatic SLR pulse when using B_1 shim values from (B). High uniformity of flip angle is successfully achieved for the 8-channel case.

Discussion: Simulations show that a uniform flip angle may be achieved for more than 95% of the ROI in phantom and *in vivo* experiments for a 2-channel and 8-channel system when B_1 shimming is used in conjunction with adiabatic pulses. Input amplitudes are within hardware limits and worst case SAR is lowest when using a simulated annealing approach to minimization. We plan to insert the adiabatic 180° pulse used in simulations into a standard GRE sequence as an inversion pulse and test the efficacy of inversion over the ROI when compared to conventional and adiabatic 180° inversion without B_1 shimming. Values registered on the SAR monitor will also be compared. Future work will be focused on optimizing the loss function for the minimization algorithm to more accurately reflect global SAR. We will investigate the method proposed by Zhu [5] which estimates global SAR given a set of input RF amplitudes and simulated or measured electric field maps. We plan to model the electric field maps for the spherical phantom and our 2-channel head coil. Our ultimate goal is to accurately model or measure the electric fields and use this information to choose input RF amplitude and phase values that minimize local SAR hotspots as well as global SAR while maximizing flip angle homogeneity.

References: [1] Sacolick L, et al. *MRM.* 2010; 63: 1315-1322. [2] Setsompop et al. *MRM.* 2008;60: 1422–1432. [3] Balchandani P. et al. *MRM.* 2010; 64(3): 843-851. [4] Setsompop K, et al. *Proceedings of 15th ISMRM.* 2007; 1687. [5] Zhu Y. *Magn Reson Med.* 2004;51: 775–784.

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