Fast high-flip pTx pulse design to mitigate B1+ inhomogeneity using composite pulses at 7T

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Introduction: Parallel RF transmission (pTx) offers flexible control of magnetization generation and has been successfully applied at 7T for spatially tailored excitations and mitigation of in-plane B1+ inhomogeneity for slice-selection [1,2]. Composite Pulses are known to have favorable robustness properties for large-flip-angle excitations in the presence of B1+ variations and are extendable for parallel transmit [3], but they have not yet been demonstrated on pTx systems. In this work we propose a composite RF pulse design for pTx systems and demonstrate the method for B1+ mitigation in a 90º excitation pulse design.

Methods: The pTx design relies on quantitative B1+ and B0 maps [4] in a Matlab-based optimization over a Bloch simulator with an analytical expression for the Jacobi matrix for improved convergence. The optimization algorithm is a subspace trust region method that is based on the Newton method (Matlab optimization toolbox, fsolve.m). To make the optimization feasible in a high dimensional space, the analytical Jacobi matrix is essential.

Both the Bloch simulation and the Jacobi matrix estimation are computationally intensive tasks, but both of these components can be efficiently implemented on a graphics processor (NVIDIA, CUDA architecture), which yielded two orders of magnitude acceleration over CPU-based designs.

The performance of the pTx composite pulses for volumetric B1+ mitigation at 7T was demonstrated on a phantom with 3:1 variation in peak-to-trough excitation field magnitude. An 8-channel loop coil was driven through a Butler matrix and the pTx pulses consisted of 3 sub-pulses with total pulse length of 3ms and a target flip angle of 90º. The optimization cost function includes a term for pulse power to ensure practical limits on transmit voltage while still achieving excellent mitigation performance.

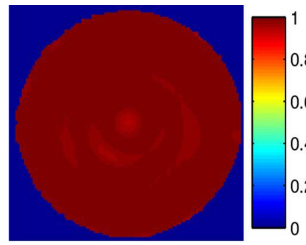

Fig. 1: 90° parallel transmit composite pulse using a water phantom at 7T. Absolute transverse magnetization is plotted.

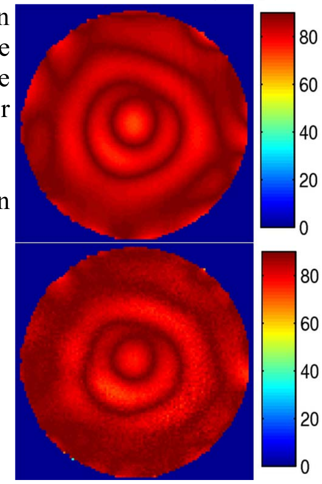

Fig. 2: 90° parallel transmit composite pulse using a water phantom on 7T MRI (top) and simulated (bottom). flipangle from 0° to 90° is plotted.

Results: Numerical simulation of pTx pulse performance and experimental results show excellent agreement (Fig. 2). Min/max values of transverse magnitude magnetization and normalized power required for the pulse are compared to conventional birdcage-mode (BC) excitation, optimized RF-shimming, and single-channel composite pulses (Table 1). Fig 1 displays absolute transverse magnetization and demonstrates very good mitigation of B1+ inhomogeneity as indicated by an RMS deviation of 0.01 around a mean magnetization value of ~1.0.

Designing a pulse for a 4.5 cm volumetric excitation results in a min/max of 1/1.8 compared to 1/3.7 for the birdcage mode excitation using approx. 4 times the power of the BC excitation (Fig. 3).

Computation for the pTx pulse design process took approximately 1 s for the single slice problem, and 2 seconds for the volumetric design (MacBook Pro, 2.2GHz Core 2 Duo and GeForce 8600M GT). The CPU-based MATLAB-only version of the code takes 100 times longer than the CUDA-optimized design.

	min/ max	power (norm.)
Birdcage mode	1/3	~1
RF-Shimming	1/2.2	~1
single channel Composite Pulses	1/2.1	~2.6
8-channel Composite Pulses	1/1.4	~3

Table 1: Peak-to-trough flip-angle (min/max) and power requirements for 90°, 3ms pulse

Discussion and Conclusion: We presented a new method for pTx composite pulse design for large-flip-angle excitation mitigation over large volumes at 7T. pTx pulses that achieve excellent mitigation against a 3:1 magnitude field variation were designed in less than 2 s with the aid of a low-end graphics processor. The proposed design extends readily to slice-selective pulses and is expected to have high utility for large-flip-angle excitations, inversions, and refocusing pulses.

References: [1] Setsompop et al, MRM 59:908-915 (2008), [2]Setsompop et al, MRM 60(6):1422-32 (2008) , [3] Collins et al, MRM 57:470-474 (2007), [4] J. Lee et al, ISMRM 2010

Support: Siemens Medical Solutions, NIH R01EB007942, R01EB006847, NCRR P41RR14075, HST Martinos Catalyst Fund

The concepts and information presented in this paper are based on research and are not commercially available.

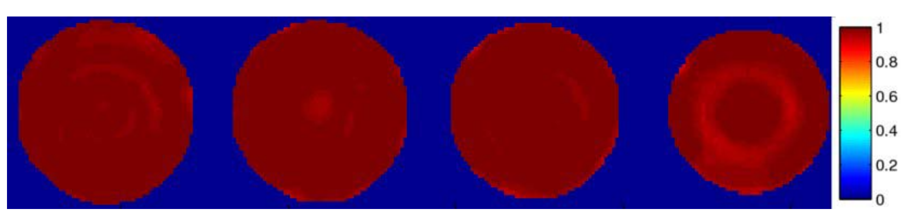

Fig. 3: Multi-channel Composite Pulse for 4.5 cm volumetric excitation. Absolute transverse magnetization is plotted for slices at -1.5cm, isocenter, 1.5cm and 3cm.