RF energy reduction by parallel transmission using large-tip-angle composite pulses

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Introduction: For ultra high field strengths of 7T and above, peak RF power and SAR are dominant limiting factors for high performance human imaging. One way to minimize these quantities, is to prolong the RF pulses. However, long RF pulses are prone to B0 inhomogeneities as the bandwidth of such pulses is reduced. Local frequency offsets consequently lead to signal voids in the image due to reduced excitation flip angle. Parallel RF transmission (pTx) offers flexible control of magnetization generation and has been successfully applied at 7T for spatially tailored excitations and mitigation of B1+ inhomogeneity [1]. Composite pulses are known to have favorable robustness properties for large-flip-angle excitations in the presence of B1+ and B0 variations and their design is extendable to parallel transmission systems [2]. In this work, we investigate the potential of prolonging large-tip-angle composite RF pulses for power and SAR reduction by using pTx pulse design methods that incorporante and account for local B0 field variations.

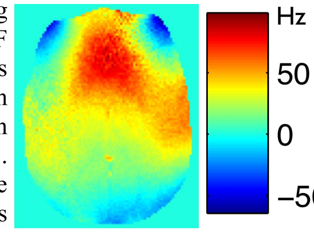

Fig. 1: B0 map in Hz

Methods: The goal of this study is to design a pTx composite pulse for large tip angle excitation or refocusing in the human head at 7T that yields an excitation pattern which is at least as homogeneous as an RF shim optimized excitation. To this end we deploy a fast non-linear optimizer [3] which efficiently solves the Bloch equations while modeling the actual quantitative B1+ and B0 (Fig. 1) maps from in vivo measurements. The pTx RF pulses are designed as non-selective rectangular pulses which are split into several sub-pulses with different amplitudes and phases for each sub-pulse as optimization design parameters for each transmit channel. In the current study, the excitation pulse is split into 3 sub-pulses, while the refocusing pulse is split into 6 sub-pulses. The pulse design is repeated for several different total pulse durations, which range from 4ms to 18ms by increasing the duration of the equally long subpulses. For each pulse design repetition, a regularization factor (trading off magnetization homogeneity vs. forward power) was determined to match at least the above homogeneity criteria based on RF shimming. For each pulse length, the minimum pulse energy was determined as sum over the pulse energy of all channels. Experiments were performed on a 7T Human scanner equipped with an 8 channel transmit array (Siemens Healthcare, Erlangen, Germany). The time needed for the pulse design procedure was less than 70 milliseconds for each pulse.

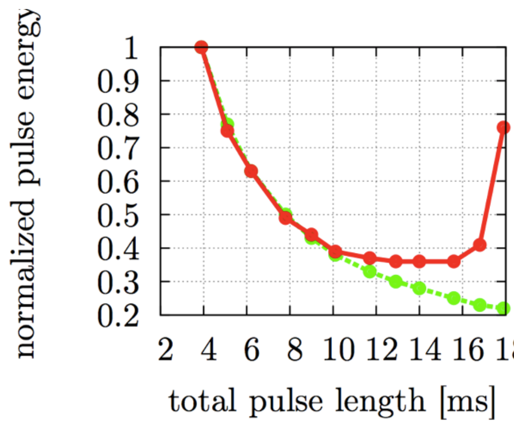

Fig. 2: Forward RF energy for 90° excitation pTx composite pulses (red) and forward RF power for conventional RF pulses (green) versus time.

Results: Figure 2 shows the RF energy of each composite pulse versus the total pulse duration (red) for the excitation pulses. For comparison, the inversely proportional drop of the pulse energy is shown in green, which is expected from simply prolonging the pulses without accounting for B0 offsets.

Up to pulse lengths of 9ms the pulse energies of the pTx composite pulses follow the expected drop based on the pulse prolongation down to a factor of 0.4. In other words, the pTx composite pulses are able to compensate for the B0 inhomogeneity without needing significant amounts of additional power. This is shown in Figure 3: The excitation pattern of the pTx composite pulse (a) basically shows the variation of a short RF shimmed pulse. The conventional RF shimmed (b) pulse of 9ms duration, however, shows significant signal loss in areas of roughly 110Hz frequency offset. Pulses with a length of more than 9ms need significant amount of extra energy to compensate for B0. For approximately 15ms this extra energy is in the same order of magnitude as the energy saved due to the longer pulse length. For pulses longer than 18ms, the pTx composite pulses are not able to maintain the desired flip-angle homogeneity. The designed 180° pulses designed for this study exhibit the same general behavior and tradeoffs as the shown 90° pulses.

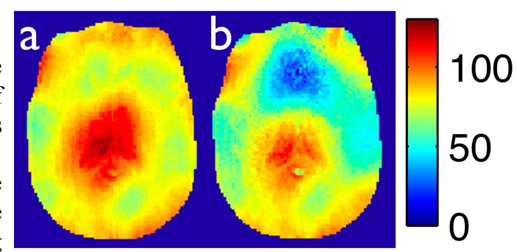

Fig. 3: Simulated flip-angle maps for a 9ms excitation pulse. a) pTx Composite, b) RF-shimming

Discussion and Conclusion: The presented results indicate that pTx can be used to prolong pulses to satisfy power or SAR limitations while maintaining excitation performance in the presence of B0 field variations. For a given slice (i.e. for given B0 and B1 field variations) an optimal pulse length can be found which yields a minimum RF energy. The pTx excitation does have narrow bandwidth but considers the actual local B0 frequency during the design.

In contrast, for conventional RF pulses, the flip-angle homogeneity drops with pulse length due to B0 and cannot be restored. Although these data use non-selective excitation pulses, the same behavior can be demonstrated using slice-selective composite pulses. The focus of this study was to optimize pulse energy while maintaining conventional (RF shimming) excitation homogeneity. However, it is also possible to optimize both excitation performance and efficiency with flexible tradeoffs.

References: [1]Setsompop et al, MRM 60(6):1422-32 (2008) , [2] Collins et al, MRM 57:470-474 (2007), [3] Gumbrecht et al, ISMRM 2010, 101

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