Flexibly shaped saturation band excitation using 7T parallel transmit system

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Introduction: Parallel RF transmission (pTx) offers significant flexibility over single-channel excitations for creating arbitrarily shaped spatial excitation patterns, which can be designed for undersampled spiral-based excitation k-space trajectories played during the pTx RF waveform [1]. In this work we validate the feasibility of using pTx for shaped saturation band that suppresses a user-defined spatial shape in combination with a B_1^+ mitigated pTx slice-selective "spokes" excitation. The feasibility of the proposed excitation is validated in phantom using 7T 8-channel pTx system.

Methods: All experiments were done on a MAGNETOM 7T (Siemens Healthcare, Erlangen, Germany) with an 8-channel prototype pTx system, equipped with head insert gradients (amplitude 80mT/m, slew 400mT/m/ms). A custom-made eight-channel transmit loop coil array was used with a separate 8-channel receive array. Single-slice quantitative B_1^+ and B_1^- mapping was done [2] using a TurboFLASH acquisition (total scan time < 2 minutes). A B_0 map estimate was calculated using a dual-echo (TE_1/TE_2 = 5ms/6ms) FLASH acquisition.

The acquired field maps were then used in the pTx pulse design Matlab engine installed on Linux machine using Intel Xeon® E5520 processor (2.27GHz, 12GB of RAM) to calculate the excitation which consisted of two pulses separated by crusher gradients. The first pulse was used to excite a flexibly shaped target chosen during the exam session. This 90° saturation pulse used a 4 fold accelerated VERSE spiral trajectory in order to excite the drawn target excitation at 1mm^2 spatial resolution. The saturation pulse's maximum voltage was 185V and duration 9.5ms. At the end of this pulse and gradient crusher, the 4-spoke RF excitation pulse [3] was played to create a uniform flip angle slice-selective excitation in the non-saturated region. For slice selection thickness of 1cm and VERSE-ing to 160V (35^0 flip), the total duration of this pulse was 3.5ms. Both excitation designs used maximum gradient and slew rate limits of 40mT/m and 250mT/m/ms, respectively. Fig1 shows the RF (for one TX channel) and gradient shapes of the overall excitation.

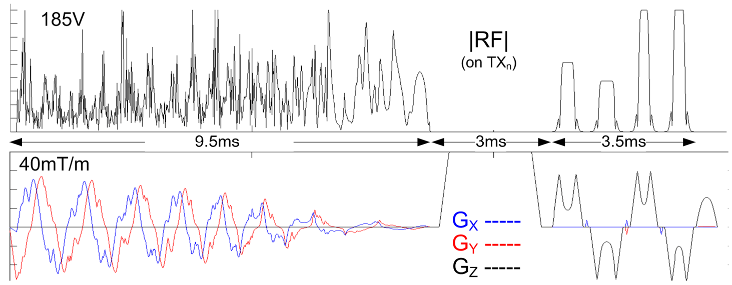

Fig1: Example of the RF and gradient shapes of a saturation band excitation. The spiral RF pulse excites the user defined spatial target to be saturated. This is followed by crusher gradients and slice-selective 4-spokes for uniform B_1^+ mitigation.

Before applying the excitation on the scanner, a full SAR analysis of the designed pulses was performed. We used the FDTD-based software REMCOM® (State College, PA, USA) to model the coil used and simulate the electric (E) fields inside a standardized human head model (Duke, Virtual Family, ITIS, Zurich, Switzerland). Given the E fields and the designed RF pulse, 10g local SAR maps were calculated, and based on the global, and 10g local SAR maximum values, the minimum TR (for the given flip angle) was obtained. In addition, a real-time RF monitoring system using directional couplers was employed in order to quantitatively monitor the RF waveforms. Then, the feasibility of the proposed excitation was tested using single-slice GRE acquisitions performed on a water phantom, doped to approximately match the 2.5-to-1 (maximum-to-minimum) magnitude B_1^+ non-uniformity of the human head. The FOV was set to 20cm and the in-plane voxel size was 1.6mm^2.

Results: After quantitative B_1 and B_0 mapping, the spiral and 4-spokes RF designs calculation took ~2.5 minutes. The pulses were evaluated for global and local SAR at 100% duty cycle, yielding 3.67 W/kg and 31.2 W/kg as the maximum values of the global and 10g-averaged local SAR, respectively. The flip angles and maximum voltages were set to 90^0/185V and 35^0/160V for the spiral and 4-spokes pulse, respectively. Given the IEC approved 10g-average local SAR maximum limit of 10 W/kg and the overall pulse duration of 16ms, the minimum TR calculated was (31.2/10)·16ms = 50ms. In this case, the excitation was local SAR limited. Fig2 shows the quality of the saturation inside the user drawn area, achieving sub 5% suppression related to the uniformly mitigated signals in the rest of the FOV. The acquired single-slice GRE data from each of the 8 RX-coil elements were combined by point wise multiplication of each of the estimated B_1^- profiles' conjugate. The resulting combined data set was then corrected for the spatial receive inhomogeneities by division by the sum of squares of the eight B_1^- profiles.

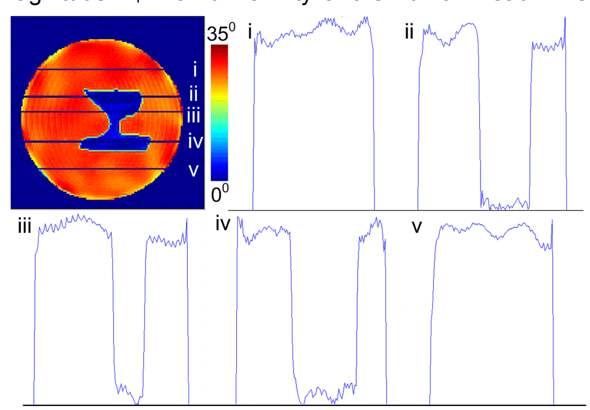

Fig2: User-drawn saturation band pTx excitation applied on a water phantom using single-slice GRE readout, clearly showing the quality of the suppression. The image shown is corrected for B_1^- inhomogeneities.

Conclusion: We implemented and successfully demonstrated a pTx excitation scheme that saturates a flexibly shaped spatial volume with 1mm^2 resolution, which can be specified by user drawing. Such an excitation could be useful for applications where certain spatial regions need to be suppressed in order to improve the image quality in the rest of the VOI. Examples include spine imaging with curved anterior-volume suppression, or skull nulling, for enhanced brain imaging and spectroscopy.

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References: [1] Grissom W., et al. MRM, 56, p.620-9, 2006; [2] Lee, J., et al, Proc. to 18th ISMRM, 2010, p 2835; [3] Setsompop K., et al, MRM, 60, p1422-32, 2010;