Implementation of VERSE Parallel Transmission at 9.4 T

X. Wu[1], J. T. Vaughan[1], K. Ugurbil[1], and P-F. Van de Moortele[1]

[1]Center for Magnetic Resonance Research, University of Minnesota, Minneapolis, MN, United States

Introduction: Parallel Transmission (PT) (1,2) has been suggested as an effective tool for addressing Transmit (Tx) B1 inhomogeneity at high magnetic fields. However shorter selective RF pulses obtained with PT acceleration typically require higher RF amplitudes, resulting in increased levels of Specific Absorption Rate (SAR) which may raise concerns for patient safety. A previous simulation study (3) has shown that an efficient way of reducing SAR in PT is to apply the Variable Rate Selective Excitation (VERSE) principle (4) in RF pulse design, which proves to be more effective in decreasing SAR than just linearly increasing RF pulse duration. In the present study, we verify experimentally the method proposed in (3) by conducting VERSE-PT experiments at 9.4 T.

Materials and Methods: All experiments were performed on a 9.4 T human scanner equipped with an 8-channel RF Tx system (Varian, USA) and a home built 16-channel Receive (Rx) board. The design target for the excitation pattern was a rectangle with uniform flip angle and uniform phase, defined on a 24 x 24 matrix in a 128 x 128mm^2 region. As in (3), an original 2D spiral trajectory was designed in the slew rate limited regime with a reduction factor of 2 (duration 4.6 ms), assuming max gradient slew rate of 80 T/m/s and max amplitude of 28.5 mT/m. This original trajectory was first used to calculate "original" RF pulses for the 8 Tx channels which were used to "adapt" the original gradient waveforms, according to the VERSE principle, always keeping RF magnitudes below a defined threshold (derived from the original RF pulses). New PT RF pulses were then recalculated for the 8 Tx channels, based on those "adapted" gradient waveforms (this step was necessary because "adapted" gradient waveforms brought some k-space trajectory deviations). For comparison, RF power was estimated summing over all channels the time integrals of squared RF amplitudes. Additionally, in order to avoid degradation of excitation patterns due to gradient distortions (eddy current, etc...), it was necessary to utilize the actual *measured* gradient waveforms for RF pulse calculations. Gradient waveforms calibration was obtained using "self-encoding" gradients (5) before the PT experiments. The PT experiments were conducted using an elliptical 8ch Tx/Rx stripline array (6,7) loaded with a 1 L spherical doped water phantom. The Tx B1 maps of individual channels were measured using a multi-channel B1 mapping method introduced in (8). The spatial domain method (9) was used for RF pulse design with B0 inhomogeneity correction based on a B0 map derived from two GRE images at different TE's. Excitation patterns were imaged using a spin echo (SE) pulse sequence where the slice selective excitation module was replaced with our parallel excitation RF pulses. The slice selective refocusing 180° pulse was optimized for B1 homogeneity with a min-max B1 shim algorithm (9). The SE imaging parameters were: slice thickness = 5 mm, FOV = 256 x 256 mm^2, matrix size = 128 x 64; TR/TE = 2000/30 ms.

Results: Fig. 1 shows original and VERSE-PT measured Gx, Gy and k-space trajectories as well as the corresponding sum of the magnitudes (SOM) of the 8 shaped RF pulses. The VERSE-PT gradient waveforms had a weaker amplitude and longer duration than their original counterparts when a high peak occurred in the original RF pulses, resulting in k-space trajectory deviations. Using VERSE-PT adapted gradient waveforms was very effective in suppressing high RF pulse peaks present with the original RF pulses. More quantitative analysis further shows that VERSE-PT RF pulses delivered about 31% less RF power than the original RF pulse linearly stretched to the same duration as VERSE-PT pulse. Fig. 2 displays imaged excitation patterns obtained using original and VERSE-PT RF pulses with and without calibration. Interestingly, excitation quality was significantly improved with VERSE-PT RF pulses compared with the original ones, even when RF pulse calculation did not include measured gradient waveforms (Fig. 2b vs 2d). Using measured, instead of theoretical, Gx and Gy for RF calculations consistently provided much cleaner excitation patterns (Fig. 2c and 2e).

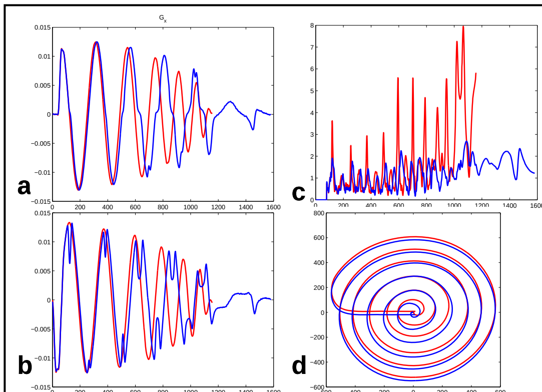

Fig.1. Original (red) vs VERSE-PT (blue) pulse design based on measured trajectories. (a) Gx, (b) Gy, (c) SOM of RFs and (d) kspace trajectory.

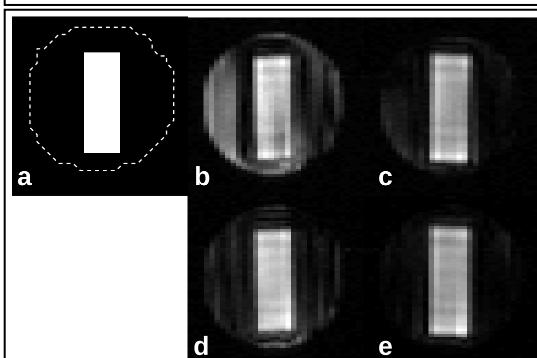

Fig.2. Parallel Transmission of a rectangle target pattern (a) using original uncorrected (b), original corrected (c), VERSE-PT uncorrected (d) and VERSE-PT corrected (e) RF pulses.

Conclusions and Discussion: We report a successful experimental implementation of the VERSE principle with reduced RF power in accelerated Parallel Transmission using an algorithm that had been introduced in a simulation study (3). The VERSE-PT pulses also yielded better pattern accuracy than original non-VERSE-PT, possibly a consequence of less demanding gradient and RF waveforms as well as reduced eddy current. Here, because we started with slew rate limited spiral trajectories for the original gradient waveform, the adaptation algorithm could only translate at any point in equal or reduced k-space traversal rate. Despite of this limitation which imposes an elongation of gradient waveforms by the adaptation algorithm, the resulting duration was still significantly shorter than that of an RF pulse without accelerations (6.3 vs 8.9 ms).

References: **1**. U. Katscher, et al., MRM 49:144-50(2003). **2**. Y. Zhu, MRM 51:775-84(2004). **3**. X. Wu, et al., ISMRM 2007, p. 673. **4.** S. Conolly, et al., JMR 78:440-458(1988). **5**. Takahashi, et al., MRM 34:446-456(1995). **6.** G. Adriany et al., MRM 53:434-45(2005). **7**. Vaughan et al. MRM 56:1274-82(2006). **8**. Van de Moortele et al., ISMRM 2007, p 1676. **9.** Grissom, et al., MRM 56:620-29 (2006). **10.** T.-H. Chang et al. ISMRM 2008, p1088.
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