Correction of Parallel Transmit RF pulses at 9.4 T Using Measured Gradient Waveforms

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Introduction: Parallel Transmission (PT) (1,2) allows for applying accelerated multidimensional spatially selective RF pulses through independent Transmit (Tx) RF channels, a feature especially promising at very high magnetic fields to compensate for B1 field inhomogeneity. However, gradient waveform distortions due to gradient system imperfections and/or eddy current can result in very poor excitation profiles. It has been shown that such degradation of excitation patterns can be effectively reduced by using measured k-space trajectories for RF pulse design (3). In the present work, we conducted PT experiments on a 9.4 T human scanner and measured k-space trajectories to calculate corrected RF pulses, resulting in dramatic excitation accuracy improvement.

Materials and Methods: We used a 9.4T human scanner (Magnex, UK) with 8 Tx RF-Ch (Varian, USA), equipped with home built 16-Ch Receive (Rx) board. Max gradient strength was 28.5 mT/m and max slew rate 180 T/m/s. An ideal 2D slew rate limited spiral trajectory was designed with a reduction factor of 4 (2.2 ms in length). Before PT experiment, gradient waveforms (Gx and Gy) were calibrated using “self-encoding” gradient method (4), with a modified gradient echo (GE) sequence. Signals were sampled in a small doped water tube (~1cm in diameter) with a ring shaped Tx/Rx RF coil providing homogeneous B1 in the phantom. Practically, "reception" spiral k-space trajectories were first measured by temporally locating the echo peaks generated when sequentially increasing self-encoding gradients that immediately preceded the test gradient waveforms. The gradient waveforms were calculated based on the time derivative of the measured reception k-space trajectories. The PT experiments were then conducted using an elliptical 8ch Transceiver stripline array (5,6) loaded with a cylindrical (16 cm in diameter and 25 cm in length) doped saline phantom. The Tx B1 map of individual channels (Fig. 1) was obtained with a multi-channel B1 mapping method (7). The spatial domain method (8) was used for pulse design, including spatial B0 inhomogeneity correction based on a B0 map derived from two GE images at different TE's. The desired excitation pattern was a checkerboard with uniform flip angle and uniform phase within an axial plane. This pattern was defined on a 40 x 40 matrix in a 200 x 200 mm^2 region. Excitation patterns were imaged using a 3D GE pulse sequence where the slice excitation module was replaced with our 2D RF pulses. GE imaging parameters were: orient = sagital, FOV = 400 x 200 x 200 mm^3, matrix = 512 x 64 x 64, TR/TE = 1000/9 ms. The Rx B1 profile of each coil element was also derived from the data in order to compensate for the corresponding intensity variation in the final images.

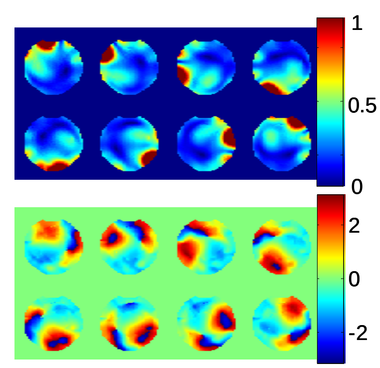

Fig. 1. Transmit B1 magnitude (top) and relative phase (bottom) maps.

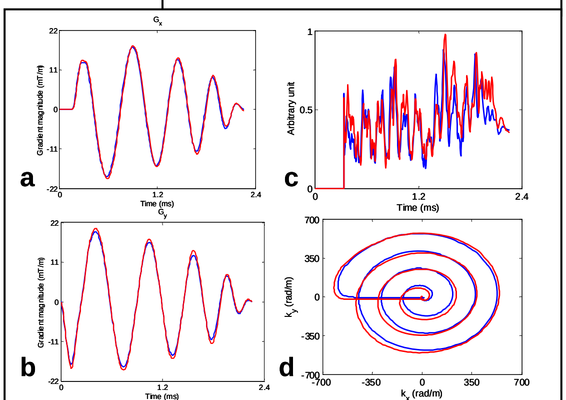

Fig.2. ideal (blue) vs corrected (red) pulse design. (a) Gx, (b) Gy, (c) SOM of RF pulses and (d) kspace trajectory.

Results: Fig. 2 shows ideal and measured Gx, Gy and k-space trajectories as well as the sum of the magnitudes (SOM) of the 8 uncorrected and corrected shaped RF pulses. The ideal and measured gradient waveforms had a similar global shape. However, the peak amplitude was greater in the measured gradient waveform than in the ideal one, resulting in obvious deviation in the k-space trajectories. Fig. 3 displays a comparison between the imaged excitation patterns obtained with uncorrected and corrected RF pulses. Most artifacts observed with uncorrected RF pulses were removed with the corrected RF pulse. Some of the residual errors still visible in the corrected pattern may relate with some eddy current B0 components.

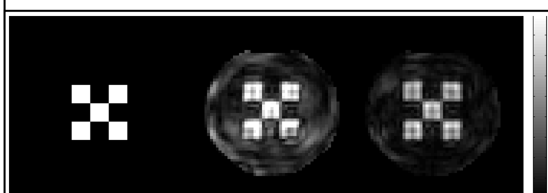

Fig.3. Parallel Transmit of a checkerboard pattern (left) using uncorrected (middle) and corrected (right) RF pulses.

Conclusions and Discussion: In this study, 2D selective RF excitation was achieved with Parallel Transmission on a 9.4 T human MRI system using RF pulses calculated with measured gradient waveforms. Our results indicate the effectiveness of using measured gradient waveforms for PT pulse calculations in order to reduce deterioration of excitation patterns due to gradient errors. The method for k-space trajectory measurement used in this study did not take into account B0 and higher order components of eddy current (only Gx→Gx and Gy→Gy components were measured). Including those components may help reduce further residual errors.

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