

Effect of Trajectory Design on Susceptibility Compensation of Whole Brain Parallel Transmission for UHF fMRI

Hai Zheng¹, Tiejun Zhao², Yongxian Qian³, Tamer Ibrahim^{1,3}, and Fernando Boada^{1,3}

¹Bioengineering, University of Pittsburgh, Pittsburgh, Pennsylvania, United States, ²Siemens Medical Solutions USA, Pittsburgh, Pennsylvania, United States,

³Radiology, University of Pittsburgh, Pittsburgh, Pennsylvania, United States

Introduction: Ultra high field (UHF) MRI has been used to render superior anatomy previously unattainable at lower field. However, many obstacles have to be overcome for its applications. Susceptibility-induced (SI) artifact is one of the major issues. SI artifacts manifest as geometrical distortions and/or signal loss near some important functional regions, such as orbital frontal cortex [1]. Several approaches have been proposed to restore the SI signal loss. The original three-dimensional tailored RF (3DTRF) [2] and its derivative methods [3,4] are very effective but pulse durations are impractically long. Zheng *et al* [5] have successfully demonstrated to combine parallel transmission (PTX) [6] and 3DTRF to design RF pulses for recovering multi-slice SI signal loss at ultra high field. In this study, we extend multi-slice to whole brain excitation and investigate the effect of trajectory design on signal recovery and computational time.

Theory: We use the derivations in Refs. [3, 5] to perform the phase precompensation and parallel transmission RF pulse design. We combine the principle of 3DTRF method and parallel transmission to formulate the RF pulse design for restoring signal loss. To control the excitation at a set of N different slices, we extend the set of equations in Ref [6] and concatenate the modified desired patterns $D_{\text{precom}}\{D_{\text{slice1}}, \dots, D_{\text{sliceN}}\}$ where z_n ($n=1, \dots, N$) is the location of the slice-selective peak, $S_{\text{total}}\{S_{\text{slice1}}, \dots, S_{\text{sliceN}}\}$ is the spatial sensitivity (B_1^+) maps of all slices and the encoding matrix of total slices is $A_{\text{total}}\{A_{\text{slice1}}, \dots, A_{\text{sliceN}}\}$ where frequency offset maps (Δf) are encoded. Finally, we can formulate the following concatenated equation for restoring signal loss,

$$\begin{bmatrix} D_{\text{slice1}} \\ D_{\text{slice2}} \\ \vdots \\ D_{\text{sliceN}} \end{bmatrix}_{z_n} = \begin{bmatrix} S_{\text{slice1}} A_{\text{slice1}} \\ S_{\text{slice2}} A_{\text{slice2}} \\ \vdots \\ S_{\text{sliceN}} A_{\text{sliceN}} \end{bmatrix}_{z_n} \times B_{1,z_n}$$

RF pulses for the signal recovery at the slice location of z_n can be efficiently solved via Conjugate Gradient optimization. Then RF pulses of signal recovery for other slices can be obtained by repeating the same procedure with the location of excited peak (z_n) shifting from slice 1 to slice N .

Methods: Breath holding task is known to produce activations through the whole brain including the regions of susceptibility-induced signal loss. The protocol was an initial resting state of 22 sec followed by the breath holding period of 8 sec. The set of breath holding and normal breathing was repeated six times. All human brain studies were performed on a Siemens (Erlangen, Germany) 7T whole body scanner equipped with PTX extension. B_1^+ maps were acquired with a novel fast B_1^+ mapping method firstly introduced by Zhao *et al* [7]. Flyback fast-kz trajectory is employed to design RF pulses with the following imaging parameters, slice thickness=5mm, flip angle=20°, TE=16ms. We use 1 spoke, 3 spokes and 5 spokes fast-kz trajectories, respectively, to investigate the impact of spoke trajectory. Multiple CPUs are employed for fast parallel computation. RF design was implemented in Matlab R2011b on a Linux computing platform running two 2.33GHz quad-core Intel Xeon processors. In our design, the computational time for 1 spoke, 3 spokes and 5 spokes trajectories are 3.3mins, 9.2mins and 15.8mins. The resulting RF pulse durations are 1.03ms, 3.47ms and 5.91ms, respectively.

Results and Discussion: Figure 1(a) shows 20 axial slices of GRE images excited by PTX 3DTRF with 5 spokes fast-kz trajectory. The comparison of excitations from SINC pulses, 1 spokes, 3 spokes and 5 spokes designed pulses are presented in Fig. 1(b). Significant signal loss can be observed at one representative slice when the SINC pulses are used. With the help of PTX 3DTRF, signal loss is obviously restored for all three different k-space trajectories. Furthermore, the improvement of signal recovery is more evident in 5 spokes fast-kz trajectory design because adding phase-encoding locations can increase the capability to maneuver in-plane excitation variation. However, it is inevitable to increase the pulse duration and computational time. From our experience, the performance would be contaminated at regions with large frequency offset if the pulse duration is longer than 10 ms. The similar results are obtained from EPI BOLD imaging in Figure 2. Visual inspection of increased BOLD activation over the whole brain has demonstrated the effectiveness of the proposed method for the whole brain signal recovery. Figure 3 shows the mean signal intensity within ROI labeled with the yellow squares in Figs 1 and 2. As the number of spokes increases, the performance of signal recovery is improved albeit at the expense of increased computational time.

Conclusions: We have successfully demonstrated that PTX 3DTRF can be used for restoring the lost signal over the whole brain. This is the first time to demonstrate the 3DTRF method in conjunction with PTX can be effective to recover the whole brain signal loss at ultra high field. Future research will be focused on how to find the optimal compromise between the performance of signal recovery and computational time.

Reference: [1] Lipschutz *et al.*, Neuroimage 2001;13:392-398. [2] Stenger *et al.*, MRM 2000;44:525-531. [3] Yip *et al.*, MRM 2006;56:1050-1059. [4] Yip *et al.*, MRM 2009;61:1137-1147. [5] Zheng *et al.*, ISMRM 2011 (Abstract 213). [6] Grissom *et al.*, MRM 2006;56:620-629. [7] Zhao *et al.*, ISMRM 2011 (Abstract 2925)

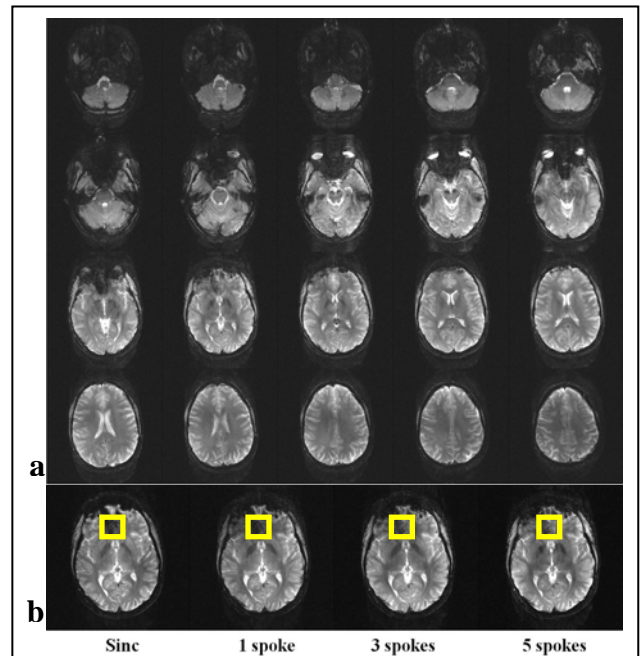


Fig.1 (a) GRE excited by PTX 3DTRF with 5 spokes
(b) Comparison of one slice excited by different pulses

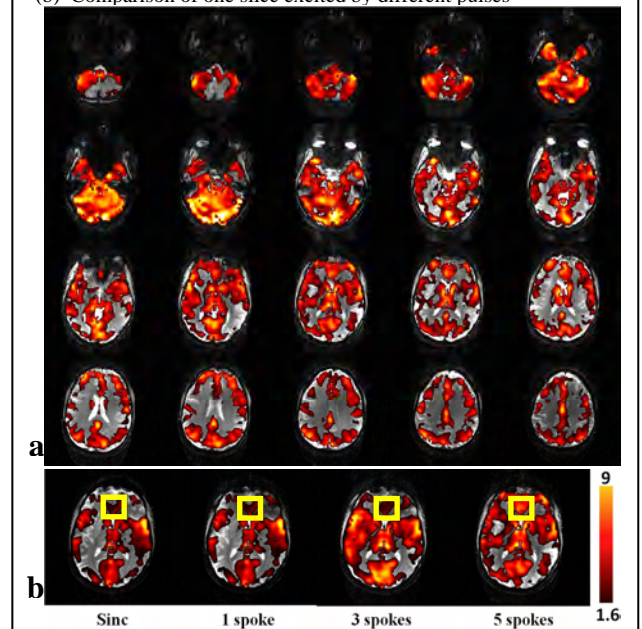


Fig.2 (a) BOLD excited by PTX 3DTRF with 5 spokes
(b) Comparison of one slice excited by different pulses

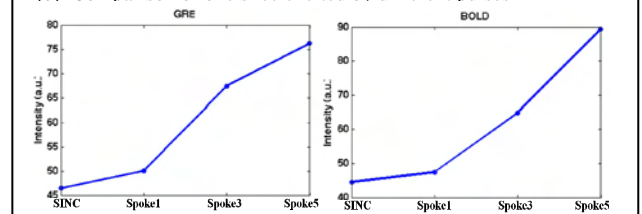


Fig.3 Mean Intensity within ROI labeled with yellow square.