Spectral-spatial pulse design for signal recovery in T2*-weighted BOLD functional MRI

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Introduction

T2*-weighted functional MR images in the inferior human brain are plagued by signal loss artifacts that arise from field inhomogeneity caused by the magnetic susceptibility differences between air cavities and brain tissues. One way to mitigate the signal loss is to precompensate for the through-plane dephasing, using multi-D excitation pulse in lieu of the standard sinc pulse. The three-dimensional tailored RF pulse (3DTRF) method was demonstrated to be effective [1], but with performance limitations and heavy online computational cost. Here, we propose a novel approach to achieve phase precompensation using specially designed spectral-spatial (SPSP) excitation pulses [2]. Compared to 3DTRF pulses, the SPSP pulses are more effective in signal recovery. More importantly, they can be computed and stored offline, and retrieved for deployment during a fMRI study. This feature obviates the burden of online pulse computation during experiments.

Theory

SPSP signal recovery relies on the assumption that magnetic field offset is spatially correlated with through-plane field gradient (which causes dephasing). For signal recovery, we exploit this assumption by using a 2D SPSP pulse that has (1) spatial selectivity for exciting a slice profile, and (2) spectral selectivity for prescribing precompensatory through-plane phase variation whose rate is a function of frequency offset. The pulse is designed with desired SPSP pattern as shown in Fig. 1. If this pattern is excited, magnetization in an on-resonance voxel volume flips down with the same phase, as indicated by the circles (○). Meanwhile, through-plane magnetization within an off-resonance voxel volume flips down with different phases, as shown by the squares (□). When this phase variation matches the negative of that caused by dephasing, signal loss is mitigated. The rate of phase variation in the desired pattern is controlled by a parameter tuned by the pulse designer.
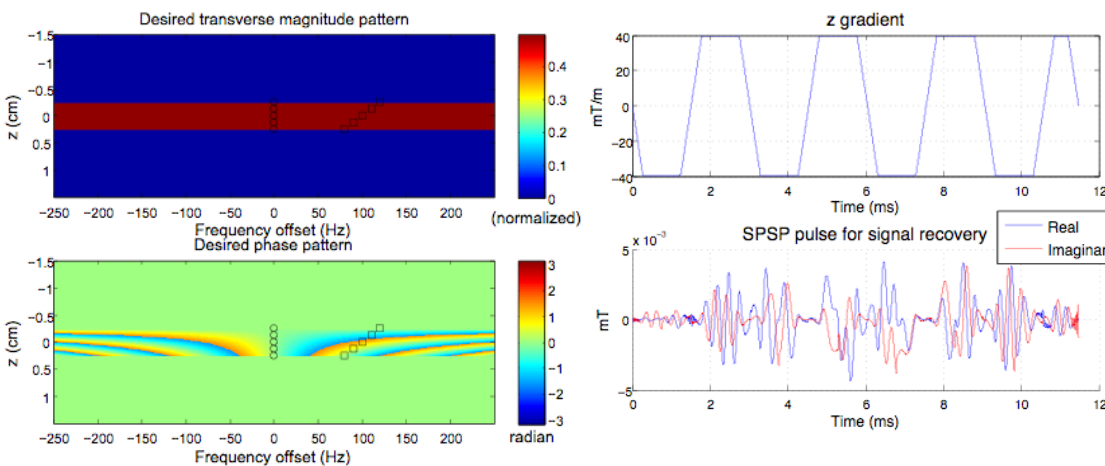

Fig. 1 (Left): SPSP desired pattern for slice selection and precompensation of through-plane dephasing. On- and off-resonance voxel volumes are excited as indicated by the circles and squares.

Fig. 2 (Right): Iteratively designed SPSP pulse for signal recovery (with desired pattern in Fig. 1).

Because of the special desired pattern, the pulse must be designed iteratively using conjugate gradient (CG) [3]. With an oscillatory z gradient (Fig. 2, top), the SPSP pulse generated by CG is shown in Fig. 2 (bottom). A collection of such SPSP pulses, designed with different rates of phase variation, can be computed and stored prior to the fMRI study. Based on field maps acquired from the subject's head, one can select a suitable subset of the pulse collection for deploying at different slice locations.

Experiment

We tested signal recovery in a water phantom imaged in a GE 3T Signa scanner. To emulate the field distortion in the human head, three pieces of metal were attached to the phantom surface inferior to the imaging plane. Field maps revealed that the field was significantly distorted and the resulting through-plane dephasing was severe (Fig. 3a,b). With a spiral-in-out GRE sequence (16-interleaves, matrix size=256x256) using a long TE (30 ms) and a 3.2 ms sinc pulse selective for a 5-mm slice, signal loss was observed at the image regions superior to the metal pieces (Fig. 3c). With all the other sequence parameters unchanged, the sinc pulse was replaced by an SPSP pulse. The signal loss was significantly mitigated (Fig. 3d), suggesting that the SPSP pulse was effective in precompensating the through-plane dephasing. Signal recovery was also demonstrated in phantom with more severe field distortion, and in the human head (results not shown).

Discussion

The SPSP pulses are superior to the 3DTRF pulses, because they are effective in phase precompensation and hence signal recovery, even when there are multiple loss regions or when frequency offset is high. Also, the pulses can be computed offline and retrieved for deployment during a fMRI experiment. A potential problem is that the assumption of correlation between field offset and through-plane gradient may not be valid, especially in inferior brain slices. In that case, x,y field gradients and/or high-order shimming can be used to help "enforce" correlation.
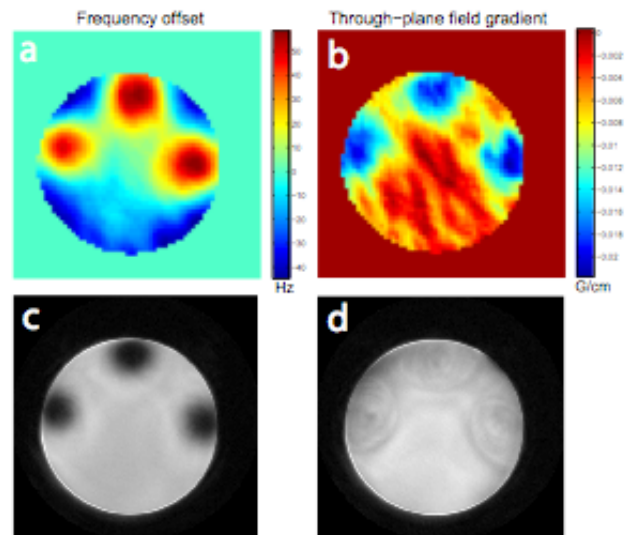

Fig. 3: (a,b) Maps of frequency offset and through-plane gradient, showing strong spatial correlation. (c) Signal loss occurred where through-plane gradient was high. (d) SPSP pulse recovered all the loss regions simultaneously.

References 1. Yip et al., MRM 56(5), 2006   2. Meyer et al., MRM (15)2, 1990   3. Yip et al., Proc. ISMRM 2006, #3001