Parallel Transmission with Spectral-Spatial Pulses for Susceptibility Artifact Correction

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Introduction: Susceptibility induced signal loss is a major limitation in high field T2*-weighted MRI including BOLD fMRI. Spectral-spatial (SPSP) pulses are effective at reducing through-plane signal loss in axial slices using a single excitation (1,2). The SPSP pulse approach assumes that the susceptibility gradient is a linear function of frequency: $G_s(f)$. However, a single SPSP pulse may not applicable for more inferior slices where more than one gradient value may be needed at a given frequency. We propose to address this limitation by using parallel transmitters to apply unique SPSP pulse to different brain regions (3). The method is demonstrated in T2*-weighted brain imaging at 3T with an eight-channel parallel transmission system.

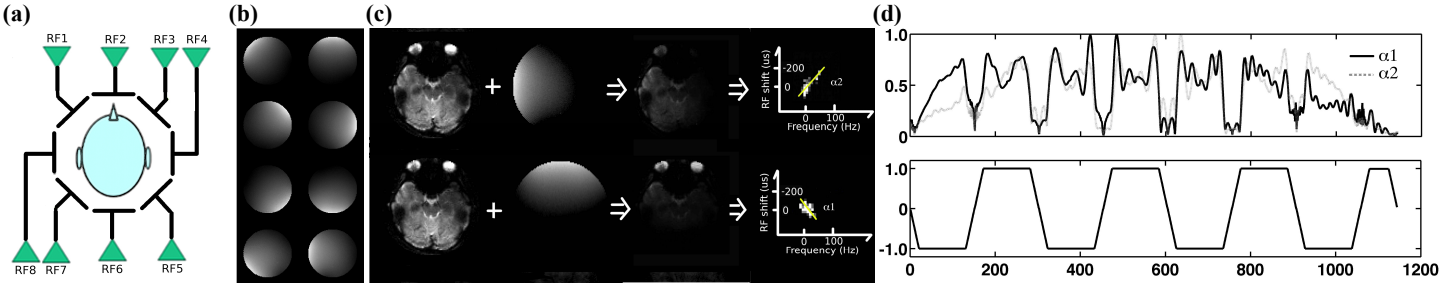

Figure 1. (a) Parallel transmitters can apply unique pulses to different brain regions. **(b)** Transmission sensitivities for eight-channel transmission system. **(c)** The sensitivities provide a coarse spatial localization to different brain regions that require different corrections. **(d)** Example SPSP pulse.

Theory: The SPSP pulse design assumes a linear relationship between off-resonance frequency and through-plane susceptibility gradient $G_s(f)=\alpha f$. SPSP pulses $B_n(t)$ for a transmitter can be designed using an image domain small-tip-angle approach:

$$M_n(z,f) = M_n(z)e^{i\gamma\alpha TEzf} = i\gamma M_0 \int_0^T B_n(t)e^{ik_z(t)z+i2\pi f(t-T)}\,dt \text{ , where } k_z(t) = -\gamma\int_t^T G_z(s)\,ds .$$

$M_n(z)$ the slice profile, γ the gyromagnetic ratio, M_0 the equilibrium magnetization, $G_z(t)$ the z-gradient, and T the pulse length. The approximation $G_s(f)=\alpha f$ holds well for more superior slice locations, where α is on the order of -2.0μT/m/Hz. Inferior slices, however, can have regions that require α of opposing sign. Parallel transmission can be used to apply unique SPSP pulses to different brain regions. The localization introduced by the transmission sensitivities $S_n(x,y)$ compensates for the spatial distribution of the susceptibility gradients. The composite excitation $M(\mathbf{r})$ from N transmitters is:

$$M(\mathbf{r}) = \sum_{n=1}^{N} S_n(x,y)M_n(z,f) .$$

Fig. 1 (a-c) shows how parallel transmitters can apply unique SPSP pulses to the same slice.

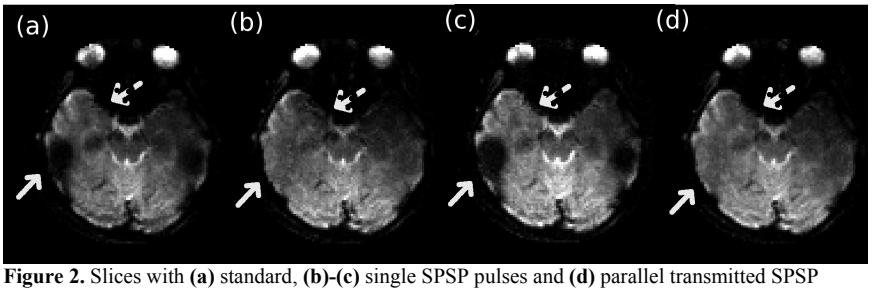

Figure 2. Slices with **(a)** standard, **(b)-(c)** single SPSP pulses and **(d)** parallel transmitted SPSP pulses.

Methods: Studies were performed on a Siemens TIM Trio 3T (Erlangen, Germany) scanner using a 15000G/cm/s gradient slew rate and 3G/cm peak. The parallel transmission system consisted of a Tecmag (Houston, TX) Apollo eight-channel waveform generator, eight RF amplifiers, and a custom eight-channel coil. The RF and gradient waveforms were calculated using Matlab (Natick, MA). Fig. 1 (d) shows example SPSP pulses. The parallel transmission system applied the RF waveforms and was synchronized to the scanner, which applied the gradients and acquired the data with a FLASH sequence (TE/TR=30/1000ms, 22cm FOV, 128x128, 30^0 flip, 5mm slice). The spatial distribution of α was determined by incrementally time-shifting the slice-select RF pulse in a spectroscopic imaging sequence.

Results: Fig. 2 shows an inferior slice acquired using a standard RF pulse (a) and SPSP pulses with $\alpha 2$=-2.0 μT/m/Hz (b) and $\alpha 1$=1.0 μT/m/Hz (c) on all eight transmitters. Fig. 2 (d) shows parallel transmission SPSP pulses with $\alpha 1$ on the top three transmitters near the sinus region and $\alpha 2$ on the remaining five. Notice that the single SPSP pulse in (b) and (c) recovers signal in one region but reduces signal in the other. The parallel transmission SPSP pulse in (d), however, recovers signal in both regions.

Discussion and Conclusions: Parallel transmission using SPSP pulses was demonstrated to improve signal loss recovery in T2* weighted brain images at 3T. The technique is similar to the parallel z-shim method, however, SPSP pulses do not reduce signal in regions that require no correction. Future work will utilize the method to measure recovered BOLD activation using fMRI.

References: (1) C-Y Yip *el al*. MRM 2009 **61** 1137:1147, (2) C. Yang *et al.* MRM 2010 **64** 1:8. (3) W. Deng *et al.* MRM 2009 **61** 255:258.

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