Single-shot z-shim technique using parallel transmitters for reduced suscpetibility artifacts

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Introduction: Susceptibility artifacts are major limitation in T2* weighted MRI applications such as BOLD fMRI. Z-shim techniques (1) and 3D RF pulses (2,3) have been proposed to mitigate the through-plane susceptibility artifact, which is dominant in axial slices above the sinus region. However, z-shim techniques require multiple shots and 3D RF methods are complex with long pulse lengths. Parallel transmission methods (4,5) have been proposed to reduce 3D RF pulse lengths, however, the current implementation of these techniques is computationally very challenging. Below we present a potentially simple parallel transmission method using time-shifted 1D sinc pulses for performing a single-shot z-shim. The method is shown to reduce susceptibility artifacts in T2* weighted images at 3T.

Theory: Z-shim methods reduce susceptibility artifacts by applying an additional phase encode gradient along the slice-select (z) direction. The gradient is incremented using multiple scans such that a series of images are acquired with varying degree of z-shim. The final corrected image is a combination of all of the shimmed images. The drawback is that multiple shots are required, which leads to increased scan time. Parallel transmitters can be used to create a single-shot z-shim. Each transmitter can apply a unique time-shifted 1D sinc pulse to effectively produce a simultaneous sum of z-shims. Figure 1 shows a shifted pulse and a Bloch simulation of the slice profile including the through-plane phase. As long as the transmitter sensitivities overlap enough, many linear combinations of shims are possible.

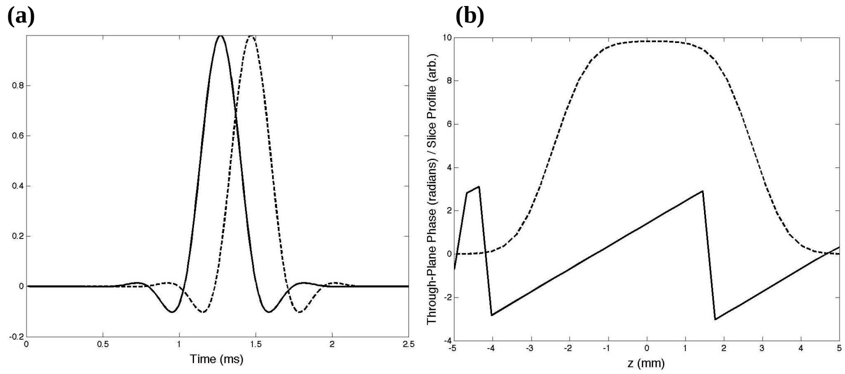

Figure 1 (a) Centered (**Pulse 1**, solid line) and shifted (**Pulse 2**, dashed line) 1D sinc RF pulses. The shifted pulse creates a z-shim. Each transmitter can have a uniquely shifted pulse. **(b)** Bloch simulation of slice profile (dashed) and through-plane phase (solid) of shifted pulse.

Methods and Results: As simple proof-of-concept, the RF pulses were implemented in a standard spiral sequence (TE/TR=30/2000ms, 22cm FOV, 64x64 matrix, FA=60^0, 16 slices, 5mm thickness) on a Siemens 3T whole body scanner. Nine shifted pulses generating through-plane phases ranging from -4π to 4π in increments of π were constructed. Due to a lack of parallel transmission hardware at our facility, a standard receiver array was used to mimic parallel excitation (6). Each of the nine pulses was transmitted in separate scans with the body coil and acquired by four receivers. The best complex sum of the images from the four coils using any of the nine pulses was determined *post hoc*. The complex summation mimics parallel transmission from hypothetical transmitters with sensitivities identical to that of the receivers. This assumes linearity between transmission, reception, and the final images; which has been shown to hold well in real parallel transmission experiments (7). Figure 2 shows example magnitude images from one slice in one of three human volunteers scanned. Slices at different locations showed similar results, but required different combinations of pulses.

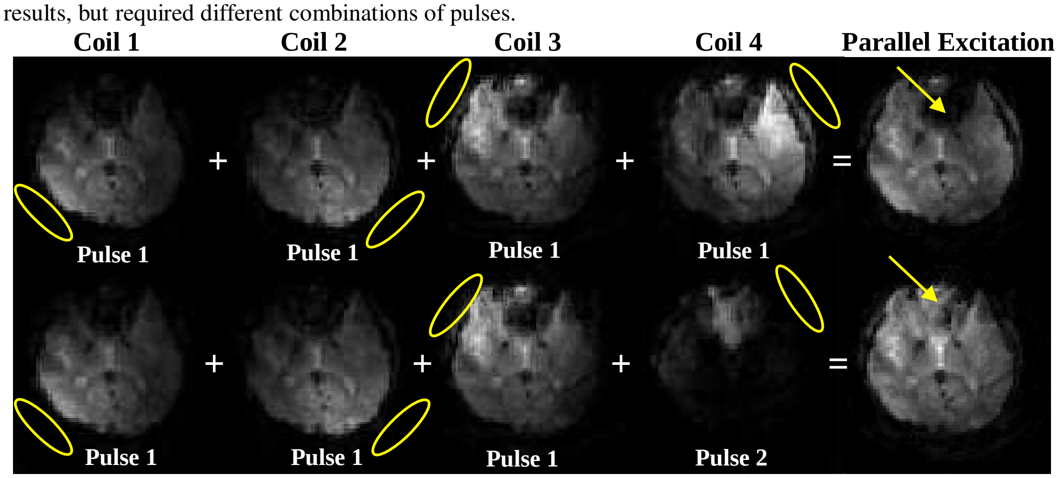

Figure 2 Top Row: Individual coil images (Coils 1-4) using un-shifted pulses (**Pulse 1** in Fig. 1 (a)). The last image shows the complex sum (or parallel excitation). Note the loss of signal in the sinus region as indicated by the yellow arrow. **Bottom Row:** Individual coil images where Coils 1-3 use un-shifted pulses (**Pulse 1**) and Coil 4 uses a shifted pulse (**Pulse 2** in Fig. 1 (b)). The last image shows the parallel excitation with recovered signal in the sinus as indicated by the yellow arrow. The yellow ellipses show the approximate coil locations.

Discussion and Conclusions: We have presented proof-of-concept for a single-shot z-shim technique for reducing susceptibility artifacts using parallel transmitters. This approach is a simplification over 3D RF methods, including those using sensitivity encoding. In essence, the intrinsic susceptibility gradients perform the in-plane spatial localization, allowing for 1D pulses. It also allows for simpler hardware designs because only a unique delay, amplitude, and phase are required on each transmitter. Future work is being done to optimize the pulse combinations as well as to demonstrate the technique on a parallel transmission system.

References: (1) R. T. Constable. JMRI 1995;5:746. (2) V. A. Stenger *et al.* MRM 2000;44:525. (3) C.-Y. Yip *et al.* MRM 2006:56:1050. (4) U. Katscher *et al.* MRM 2003;49:144. (5) Y. Zhu MRM 2004;51:775. (6) W. Grissom *et al.* MRM 2006;56:620. (7) P. Ullmann *et al.* MRM 2005;54:994.

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