Parallel Transmission Method for Susceptibility Artifact and B1+ Inhomogeneity Reduction

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Introduction: Susceptibility artifacts and B1+ inhomogeneity are major limitations in high field MRI. Although 3D RF pulses have been shown to be useful for reducing B1+ inhomogeneity with parallel transmission (1,2), susceptibility artifacts remain a problem. Parallel z-shim is a promising technique for reducing the through-plane signal loss susceptibility artifact (3) without sacrificing temporal resolution and implementation ease that hindered previous z-shim methods (4,5). We present a parallel transmission, z-shim 3D tailored RF pulse for simultaneously reducing susceptibility artifacts and B1+ field inhomogeneity. The method is demonstrated *in vivo* in T2*-weighted human brain imaging at 3T.

Theory: The parallel z-shim method corrects susceptibility artifacts by transmitting with each channel $j = 1,...,N$ unique pulses shifted in time τ_j relative to the z-gradient G_z. This reduces the through-plane susceptibility induced phase at TE, which is problematic in axial slice in the brain. This concept can be extended to 3D using the "fast-k_z" or "spokes" trajectory $\mathbf{k}(t)$ to also compensate for a smooth in-plane B1+ inhomogeneity. The resultant image domain equation can be written as (6):

$$\mathrm{rect}(z/\Delta z) = \sum_{j=1}^{N} s_j(x,y) e^{i\gamma G_z z \tau_j} \int b_j(t) e^{i\mathbf{k}(t)\cdot\mathbf{r}} dt .$$

Here $s_j(x,y)$ is the transmitter sensitivity, Δz is the slice thickness, and $b_j(t)$ is the pulse. This equation can be solved using the conjugate gradient solution to the matrix equation $m = \mathbf{A}b$, where $\mathbf{A}$ is the encoding matrix. The time shifts can then be added to $b_j(t)$ depending on the location the particular channel and the susceptibility artifact. Figure 1 shows an example 3D tailored RF pulse for susceptibility artifact and B1+ reduction.

Methods: Human brain studies were performed on a Siemens 3T (Erlangen, Germany) whole body scanner. The body gradients had a 150 T/m/s slew rate with peak value of 4 mT/m. The parallel transmitter consisted of a Tecmag (Houston, TX) Apollo four-channel waveform generator and four 300W solid-state power amplifiers. The Apollo system was synchronized to the scanner, which applied the gradients and acquired the data. The TR coil was a customized four-channel array that used eight coils configured into a (1, 1, 1, 5) mode optimized to z-shim the orbital frontal brain region. The array and the transmit sensitivity maps of each channel acquired in a phantom is shown in Fig. 2. The RF and gradient pulse profiles were calculated using Matlab (Natick, MA) and were inserted into a FLASH sequence (TE/TR=30/500ms, 22cm FOV, 128x128, 30^0 flip). The shift τ=-100 µs was determined by *post-hoc* visual inspection of corrected brain images and was applied to the top three transmitters.

Results: Figure 3 shows a comparison of brain images acquired by a standard slice-select RF pulse (left column) and the 3D RF pulse with B1+ inhomogeneity and susceptibility artifact reduction (right column). The signal recovery near orbital frontal area can be clearly seen in the right image. Figure 3 (bottom row) shows windowed images to illustrate the degree of B1+ inhomogeneity correction. The image from the 3D RF pulse (right) is more uniform and absent of the bright edges associated with array coils. The standard deviations of the images, as an indication to the B1+ homogeneity, were calculated as 14% and 10%, for the images acquired by a standard pulse and the 3D RF pulse, respectively. A factor of 30% improvement in homogeneity is achieved.

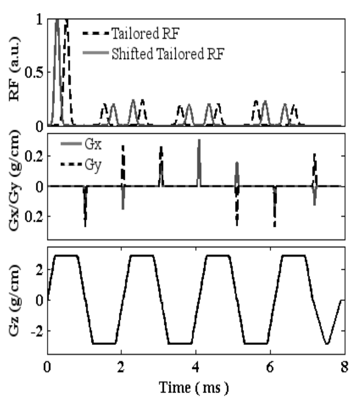

Figure 1. 3D RF pulses and gradients.

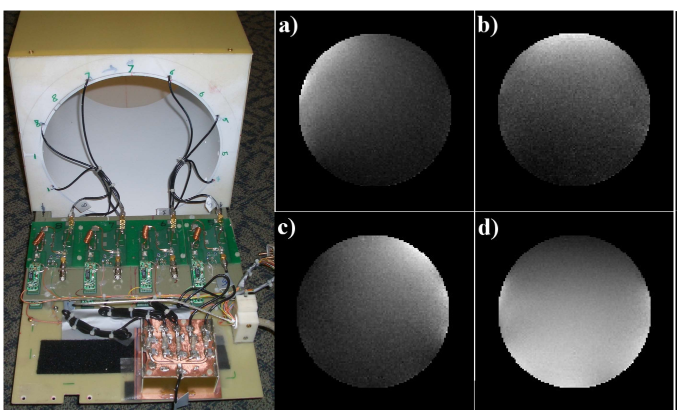

Figure 2. Customized TR eight-coil array configured for four transmitters optimized for imaging the frontal brain. **(a)-(c)** are the sensitivity maps of the single coils and **(d)** is for the five coils.

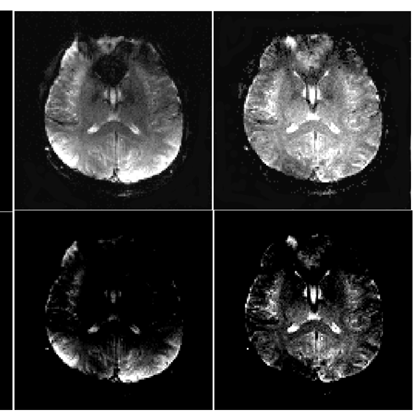

Figure 3. Brain images acquired with standard(left) and 3D pulses(right) showing reduced susceptibility and B1+ artifacts.

Discussion and Conclusions: A parallel transmission 3D RF pulse design was demonstrated to effectively reduce B1+ field inhomogeneity and susceptibility artifacts in T2* weighted brain images at 3T. Reasonable pulse lengths were obtained, however future work will examine the use of reduction factors to either improve B1+ homogeneity or reduce pulse length. Although the empirical time-shift values were determined *post-hoc*, more optimal shift values are also being explored.

References: (1) Z. Zhang *et al.* MRM 2007;57(5):842. (2) K. Setsompop *et al.* MRM 2006;56(5):1163. (3) Deng W. *et al.* ISMRM 16 p622, 2008. (4) R. T. Constable. JMRI 1995;5:746. (5) V. A. Stenger *et al.* MRM 2000;44:525. (6) W. Grissom *et al.* MRM 2006:56:620.

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