Multiband Spokes Pulses and Design Algorithm for B_1^+ Inhomogeneity-Compensated Multislice Excitation at 7T

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Introduction Simultaneous multislice/multiband acquisitions are of significant interest for scan time reduction, especially in functional MRI and diffusion-weighted imaging[1,2]. However, multiband acquisitions at ultra-high field strength will suffer from spatially-varying contrast and SNR due to flip angle inhomogeneity resulting from B_1^+ inhomogeneity. We introduce an approach to designing multiband 3D tailored RF (3DTRF) excitation spokes (MB-spokes) pulses that compensate B_1^+ inhomogeneity encountered at 7T, while simultaneously exciting multiple slices.

Theory Spokes pulses for B_1^+ inhomogeneity-compensated multiband (MB-spokes) excitations can be designed by extending a previously-described parallel transmit spokes pulse design algorithm[3] to multiband excitation. That algorithm is a combination of greedy and local optimization approaches to spokes pulse design. The modifications comprise construction of the slice-selective subpulses using cosine-modulation and addition, and stacking the slices' B_1^+ maps so that the RF weights, excitation k-space locations (k_x, k_y), and target phase patterns are optimized to produce a uniform excitation on all slices simultaneously. The steps of the new algorithm are illustrated in Fig. 1.

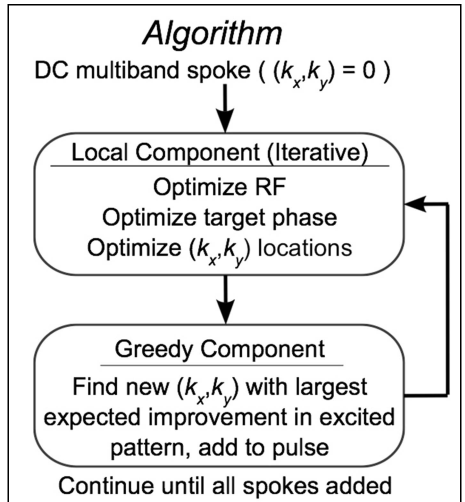

Figure 1: Illustration of the proposed multiband spokes pulse design algorithm.

Methods In-vivo experiments were performed using a single-channel head volume coil on Philips Achieva 7T scanner (Philips Healthcare, Cleveland, OH). $|B_1^+|$ and B_0 field maps were measured for 3 slices spaced 30 mm apart, over a 20 cm FOV with a 64x64 matrix size. The proposed algorithm was then used to design MB-spokes pulses with 5 spokes that excited those slices with thickness 4 mm and 10 degree flip angles. The subpulses had a time-bandwidth product of 2 and duration 1.43 ms. The total pulse duration was 7.85 ms, and the approximate pulse design time was 5 seconds. The MB-spokes pulses were compared to conventional (1-spoke) multiband pulses with the same time-bandwidth, slice thickness and duration as the slice-selective subpulses in the MB-spokes pulse. The excitation patterns were imaged using 3D gradient-echo scans with 20x20x8 cm FOV, 224x224 matrix size and TE/TR of 7.2/50 ms. The acquired images were normalized by an estimate of the volume coil's receive sensitivity in each slice, obtained by fitting 2D polynomials to conventional low-flip-angle gradient-echo images, after dividing out the $|B_1^+|$ maps.

Results Figure 2 shows a comparison of conventional multiband and MB-spokes pulses. Compared to conventional multiband, the MB-spokes pulse deposits energy at a handful of locations in the k_x-k_y plane. Figure 3 shows the results from the in vivo experiments. The MB-spokes pulses significantly reduce center brightening in the middle of the brain, without reducing signal elsewhere. Averaged across slices and subjects, the 5-spoke pulses achieved a 27% decrease in relative maximum signal intensity in ROIs drawn in the center and periphery of the brain.

Discussion and Conclusion We have presented an algorithm for designing multiband spokes pulses, and initial results showing that the pulses significantly reduce center brightening in vivo at 7T. Though single-channel experimental results were presented here, the algorithm is capable of parallel transmit pulse design. Future work will include extension of the algorithm to jointly optimize the weights of the slice-selective subpulses for each slice explicitly, so as to better correct $|B_1^+|$ variations between slices.

References [1] D. A. Feinberg et al, PLoS ONE, Volume 5, Issue 12, 2010. [2] Larkman et al, MRM, 13:313-317, 2001 [3] W. A. Grissom et al, MRM, 68:1553-1562, 2012.

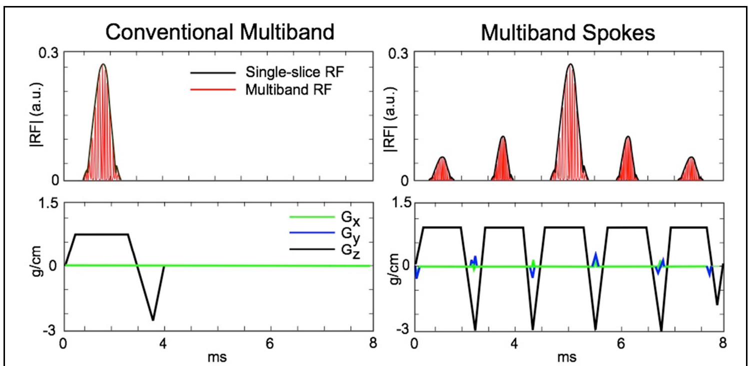

Figure 2: Illustration of conventional multiband and multiband spokes excitation RF and gradient waveforms. Also plotted are single-slice waveforms for comparison.

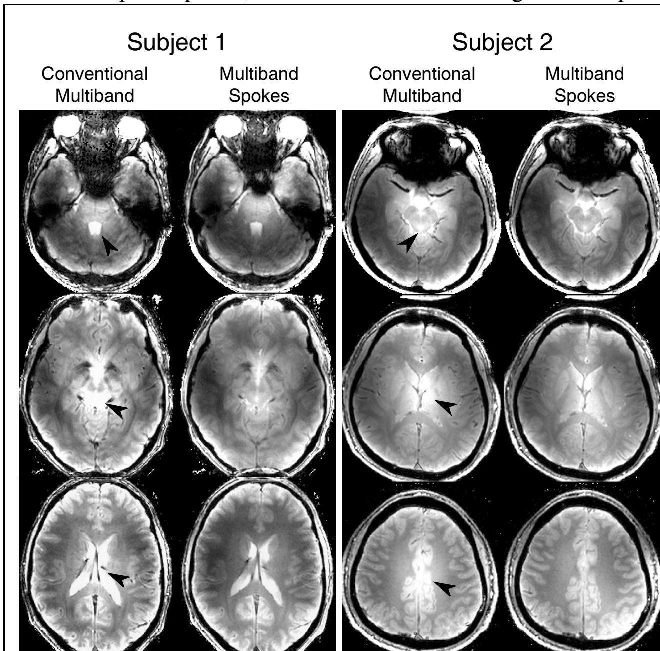

Figure 3: 7T in vivo results. The arrows indicate regions where central brightening was reduced by the multiband spokes pulse.