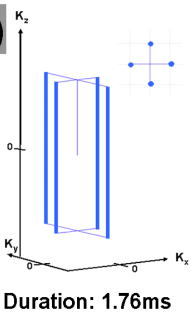
Uniform Wideband Slab Selection with B1+ Mitigation at 7T via Parallel Spectral-Spatial Excitation

K. Setsompop[1], V. Alagappan[2], B. Gagoski[1], L. Wald[3], and E. Adalsteinsson[1]
[1]EECS, Massachusetts Institute of Technology, Cambridge, ma, United States, [2]A. A. Martinos Center for Biomedical Imaging, MGH, Charlestown, ma, United States, [3]A. A. Martinos Center for Biomedical Imaging, Department of Radiology, MGH, Charlestown, MA, United States

Introduction Parallel RF (pTx) designs based on small-flip-angle excitations with "spoke"-based trajectories can efficiently mitigate large B_1^+ inhomogeneities at high field using relatively short slice-selective excitation pulses [1-2]. Unfortunately, such pulses often exhibit a narrow-band off-resonance response and may not be suitable for applications that require B_1^+ mitigation over a large bandwidth. Proton chemical shift imaging gains SNR and chemical shift dispersion benefits from higher B_0, but requires B_1^+ mitigation over both a specified spectral bandwidth and a spatial FOV. This additional bandwidth constraint presents a challenge for past methods on water-only B_1^+ mitigations. In this work, we describe a method for general pTx spectral-spatial excitations, and demonstrate the technique on a wideband slice-selective spoke excitation, which is then validated on a water phantom using an 8-channel TX array system on a 7T human MRI scanner.

1)



Theory and Methods

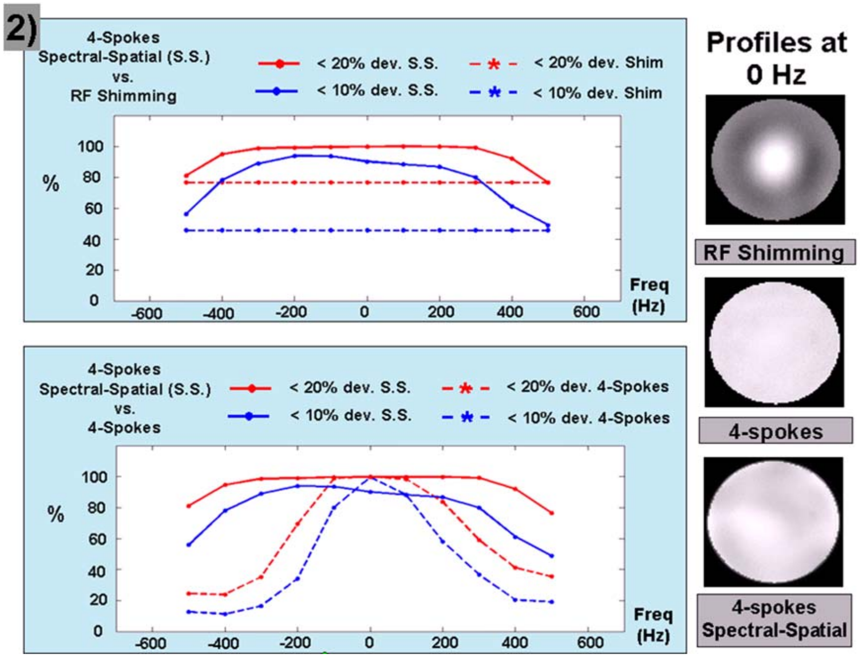
RF design: The spectral-spatial excitation design is formulated by directly extending the spatial-domain parallel excitation formulation by Grissom [3], in which the RF pulses (***b***) are solved via least-squares (LS) solution of $\boldsymbol{m} = \boldsymbol{Ab}$. To design for spatial profile (***m***) at a set of frequencies, we extend the set of equations and concatenate the ***m*** and ***A*** matrix of the different frequencies to form:

$$\begin{bmatrix}\overline{m}_{Freq1}\\ \overline{m}_{Freq2}\\ \overline{m}_{Freq3}\end{bmatrix} = \begin{bmatrix}[A_{Freq1}]\\ [A_{Freq2}]\\ [A_{Freq2}]\end{bmatrix}\times\overline{b}$$

However, generally the excitation profile at different frequencies will have different spatial phase and the design is ill-posed as a LS optimization with a fixed, uniform target phase. To solve this issue, magnitude least square optimization (MLS) [5] is used. This optimization, posed as $b = \arg_b \min\{\| |Ab| - m \|_w^2 + \beta \|b\|_2^2\}$ only optimize over the magnitude profile, allowing for phase profile variation, and resulting in substantial gains in magnitude performance. In addition, B_0 inhomogeneity correction (B_0 tracking) is also incorporated into the MLS RF design by modifying the individual A_{Freq} matrix to include a measured field map using a procedure similar to [3, 5].

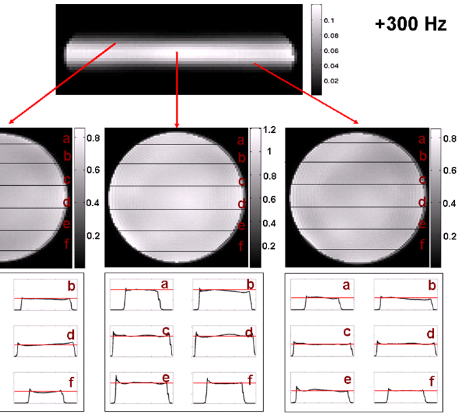
Experimental verification: The above design method was used along with a 4-spoke trajectory (shown in fig 1) to obtain parallel RF pulses that uniformly excite a 5-cm thick slab over a bandwidth of 600 Hz (2 ppm at 7T), in a 17-cm diameter water phantom. Experimental verification was performed on a 7T human scanner equipped with a 16-channel degenerate birdcage coil coupled with a butler matrix to excite 8 optimal birdcage modes. Flat target excitation profiles were specified at 3 spatial locations in z (0, ±1.75 cm), to account for the z-variation in the coil transmit profiles. A set of 5 frequency points, at [-300 150 0 150 300] Hz, were used as part of the design to adequately create the 600 Hz excitation bandwidth for B_1^+ mitigation. To evaluate the performance of the pTx design, the RF pulses were transmitted at a set of B_0 offset frequencies ranging from -500 to +500 Hz in steps of 100 Hz. The uniformity of the resulting excitation profiles are then quantified by the fraction of pixels in the field-of-excitation that falls within a 10% and a 20% bracket around the mean in-slice signal value. To illustrate the benefit of the spectral-spatial design, the 10% and 20% statistics obtained for this new design are plotted against the ones obtained using either RF shimming or a standard 4-spoke parallel excitation.

2)



Results and discussion: Fig. 2 (right) shows the in-plane excitation profiles at the center frequency for RF shimming, standard spoke and spectral-spatial spoke excitations. RF shimming provided an improvement over the standard birdcage excitation (not shown), but still resulted in significant flip-angle inhomogeneity. The standard 4-spoke excitation mitigated essentially all of the B_1^+ inhomogeneity, while the spectral-spatial excitation resulted in a very minor non-uniformity. Shown on the left of Fig. 2 are the 10% and 20% threshold plots comparing the three excitations. The metrics for RF shimming are low, but remain almost constant with frequency, demonstrating the wide bandwidth behavior of the standard sinc pulse. The performance metrics of the standard 4-spoke excitation are excellent at the center frequency but deteriorate rapidly with off-resonance, e.g. the 10% threshold drops from ~100% at 0 Hz to less than 40% at –200 Hz. The spectral-spatial pulse trades off the highly uniform excitation at the center frequency for a good uniformity over a much wider bandwidth, where the 10% threshold value remain above 80% over the 600 Hz design bandwidth. Fig 3 shows the excitation of this pulse at +300 Hz off resonance, with excellent slice selection and good uniformity in the in-plane profile at 3 different z-positions along the excited slab.

3)



Conclusion: A method for parallel spectral-spatial excitation was proposed and demonstrated with a wideband slab selective excitation in a water phantom of severe B_1^+ inhomogeneity, using an 8-channel transmit system on a 7T MRI scanner. Results demonstrate good performance of the design with good excitation uniformity over the 600 Hz design bandwidth. Future work includes extensions to other spectral-spatial excitation specifications, extension to large flip angles, and optimizing the k-space trajectory for enhanced spectral selectivity.

Support: NIH R01EB006847, R01EB007942, R01EB000790, and NCRR grant P41RR14075, Siemens Medical Solutions, R.J.Shillman Career Development Award, and the MIND Institute. **References: 1.** Setsompop K. et al, MRM 2006:56:1163. **2.** Zhang Z. et al, MRM 2006:57:842. **3.** Grissom W. et al., MRM 2006:56:620. **4.** Setsompop K. et al, submitted MRM **5.** Setsompop K. et al, ISMRM p.671, 2007.