Spectral-spatial excitation and refocusing for reduced volume mis-registration at 7 Tesla

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INTRODUCTION For localized MR spectroscopy (MRS) at high field (>= 3 T), chemical shift mis-registration of the excited/refocused volume is a major concern. This is because the peak achievable RF amplitude is typically similar to lower field systems (with the same sized transmit coil), but the range of chemical shifts to be imaged is proportionally larger. This problem is usually mitigated by using high bandwidth saturation pulses to trim the mis-registered edges of the volume of interest, but the resulting RF heating is problematic. In this abstract, the use of spectral-spatial pulses as a means to excite/refocus volumes without mis-registration is investigated for application at 7 T.

THEORY Conventional slice-selective excitation and refocusing pulses are transmitted along with a constant slice-select gradient. Invoking the excitation k-space formalism [1], this gradient results in a single, angled line through k_z vs. time. The Fourier transform of this pattern is tilted by the same angle. This tilt is the source of chemical-shift mis-registration. With the oscillating gradient used with spectral-spatial pulses [2,3], which gives a zig-zag trajectory through k_z vs. time, this tilt can be entirely removed over the bandwidth defined by the oscillation frequency.

METHODS Two spectral-spatial pulses were designed for 7 T applications using Matlab software (TM). For the pulse shown in Fig.1, the goal was to achieve the full spectral bandwidth possible with the specified gradient oscillation frequency (1 kHz). For the pulse shown in Fig.2, adiabaticity was introduced by using a hyperbolic secant function to define the RF sub-lobe amplitudes and phases [4]. For testing, the pulse of Fig. 2 was substituted for the 180-degree pulses in a spectral-spatial PRESS sequence for testing. Images of the excited/refocused volume and localized spectra were acquired in a phantom on a General Electric 7 T whole body scanner using a birdcage head coil (USA Instruments Inc.).

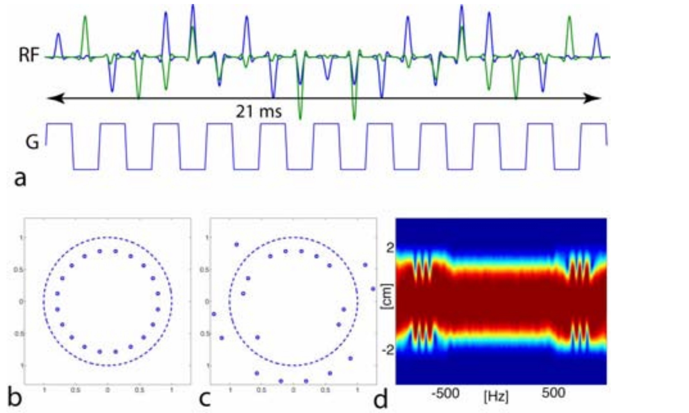

Figure 1. (a) A wide-band spectral-spatial pulse was designed using the 2D SLR transform [3]. As in [5], the filter corresponding to the pulse envelope was created by factoring the roots of B = T + P*z^(1-N), where N is 21 in this case, shown in (b). (c) A subset of these roots were flipped as specified in [5]. (d) The spectral vs. spatial profile (90-degree flip angle) shows that the full possible bandwidth is achieved (1 kHz) without chemical-shift mis-registration.

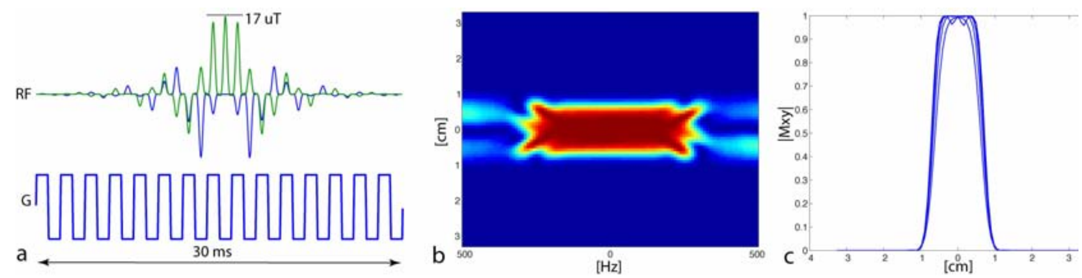

Figure 2. (a) A partially adiabatic spectral-spatial refocusing pulse was designed, with the 1D SLR transform used to craft the individual sub-lobes as in [4]. (b) The spectral vs. spatial profile (180-degree flip angle) shows an absence of chemical-shift mis-registration. (c) The spatial profile plotted for RF amplitude +/- 33% shows adiabatic behavior, with only slight changes in the profiles (overlapping plots).

CONCLUSIONS Spectral-spatial pulses that completely eliminate chemical-shift mis-registration over the full bandwidth defined by the gradient oscillation frequency can be designed. Difficulties designing the "alpha polynomial" within the 2D SLR transform currently limit these pulses to excitations rather than refocusing pulses, but this was not deemed a fundamental limitation. In a tradeoff of spectral bandwidth for robustness, a partially adiabatic spectral-spatial pulse was designed. Experimental tests showed feasibility for long echo-time spectroscopy without chemical-shift mis-registration and insensitivity to RF inhomogeneity over a range of +/- 30%.

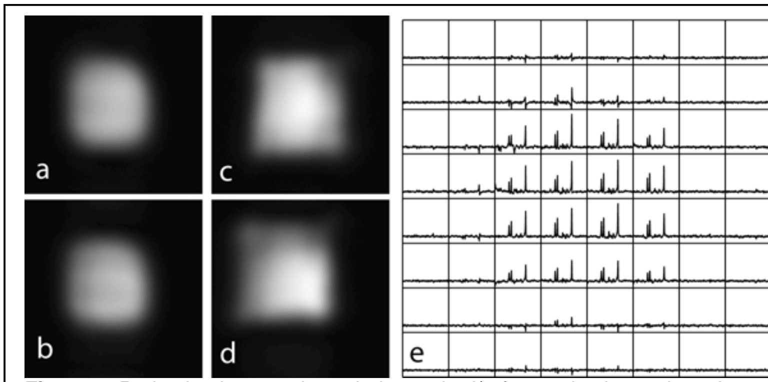

Figure 3. Projection images through the excited/refocused volume show that the volume selected with the pulse of Fig.2 remains in the same location when the center frequency is moved by 200 Hz (a and b), whereas conventional refocusing pulses (800 Hz bandwidth) display significant mis-registration (c and d). (e) An array of 1 cm^3 voxels from an 8x8x8 chemical-shift imaging (CSI) acquisition of a phantom containing brain metabolites (TR = 2s, TE = 144 ms) demonstrates that the profile for the range of metabolites is the same.

[1] Pauly et al. JMR 81: 43-56 1989, [2] Meyer et al. MRM 15: 287-304 1990, [3] Pauly et al. MRM 29: 776-782 1993, [4]Conolly et al. MRM 24: 302-313 1992, [5] Heid. MRM 38:585-590 1997.