Constant Time VERSE for RF Amplitude Reduction in Spectral-Spatial Pulses with Improved Timing Robustness

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Introduction: Spectral-spatial RF pulses often must contend with limits on RF power and amplitude, particularly for highly spatially selective pulses, high-field applications, and hyperpolarized ^{13}C. We present a new method for reducing the peak amplitude in spectral-spatial RF pulses without introducing significant gradient delay sensitivity.

Methods: This method begins with a desired spatial RF sublobe which has a fixed duration, as well as gradient and RF limitations. First, violations of the RF limits were corrected by scaling and stretching the waveforms according to the variable-rate selective excitation (VERSE) relationship [1]. Next, all slew-rate violations were corrected [2]. Finally, any portion of the waveform that has yet to be adjusted was scaled to maintain a constant duration. This entire process was repeated until the waveforms are no longer scaled or the algorithm fails to achieve the desired specifications.

In setting the slew-rate, the maximum slew rate was scaled such that it is reduced for larger RF amplitudes. This is beneficial because larger RF amplitudes in regions of high slew-rates result in larger errors when there are delays between the waveforms.

Results: Figure 1 shows a water-only slab-selective excitation with a spatial time-bandwidth of 10, resulting in a very sharp spatial profile. The 5.4 ms pulses are for a 90º flip angle, 4 cm slab, and use a flyback design that has a fat null around -460 Hz. The spectral-spatial responses of the pulses are nearly identical, but the constant time VERSE pulse requires a peak amplitude of 0.18 G, as compared to 0.36 G without VERSE.

The benefits of varying the maximum allowable slew rate are demonstrated in Fig. 2. The pulses are identical in duration, and so are their spatial profiles with perfect timing alignment. With gradient delays, the pulse with a variable maximum slew rate has significantly less distortion.

Phantom images in Fig. 3 demonstrate the spectral, spatial, and resulting image performance of the pulse in Fig. 1b.

Discussion: This new VERSE algorithm is a useful technique to reduce peak RF amplitude in spectral-spatial pulse designs. Furthermore, we have addressed the inherent sensitivity to gradient delays in VERSE pulse designs, which is useful to apply or consider in any VERSE RF pulse designs.

References: [1] Conolly SM, et al. JMR 78: 440-458 (1988).
[2] Hargreaves BA, et al. MRM 52(3): 590-597 (2004).

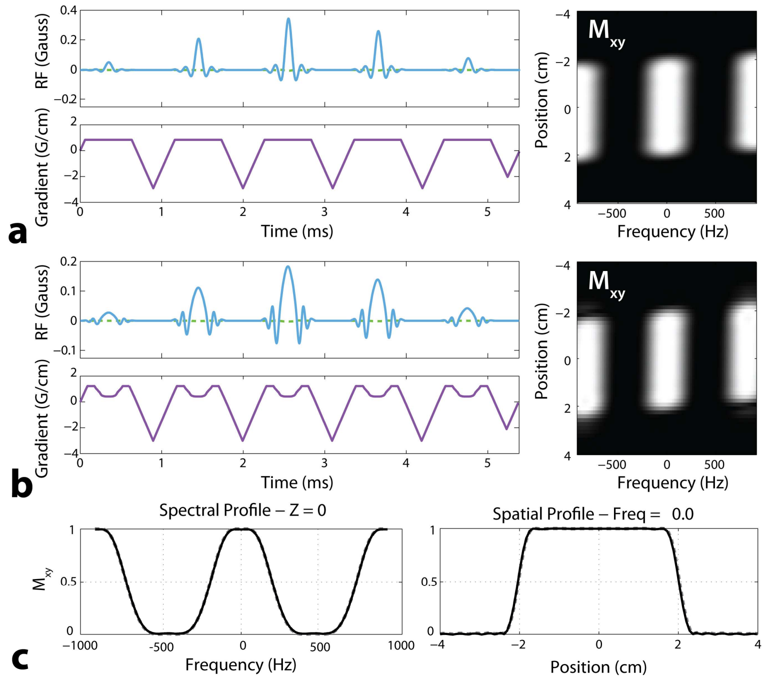

Figure 1: Water-only spectral-spatial RF pulse and simulated profile (a) without VERSE and (b) using constant-time VERSE. The profiles are nearly identical (c), while the amplitude is halved by using VERSE.

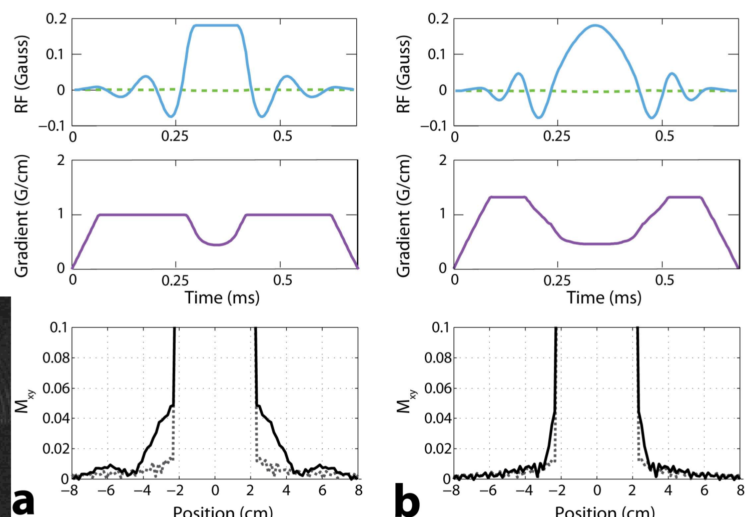

Figure 2: Constant time VERSE pulse design (a) without and (b) with slew rate reductions for large RF amplitudes. The zoomed spatial profile simulations show the response with no delays (dashed gray line) and for a 2 μs delay between the RF and gradient (solid black line).

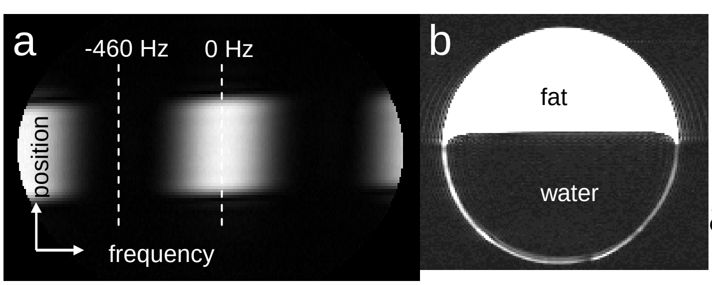

Figure 3: Phantom images using the pulse in Fig. 1b: (a) spectral-spatial profile, (b) fat-only image (windowed to show noise).