Variable-rate design of quieter slice-select pulses

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Purpose: To use the variable-rate principle to create quieter slice-select pulses.

Introduction: Variable-rate selective excitation was developed by Conolly, et al. to reduce the RF power of slice-select pulses[1], and was later used to increase the bandwidth of 2D selective-excitation pulses under gradient slew-rate or amplitude constraints[2]. We here employ the variable-rate principle to design slice-select pulses with more rounded gradient waveforms and thus improved acoustic signatures ("QVERSE" pulses) while maintaining identical on-resonance slice profiles.

Slice-select pulses can also be made quieter by derating them, i.e. by reducing gradient slew rate and/or amplitude (along with RF bandwidth), but both of these measures increase minimum echo time. In variable-rate design, the RF and gradient waveforms are reshaped together in such a way that the magnetization vector on-resonance follows the same trajectory (but at varying rates) over the course of the excitation.

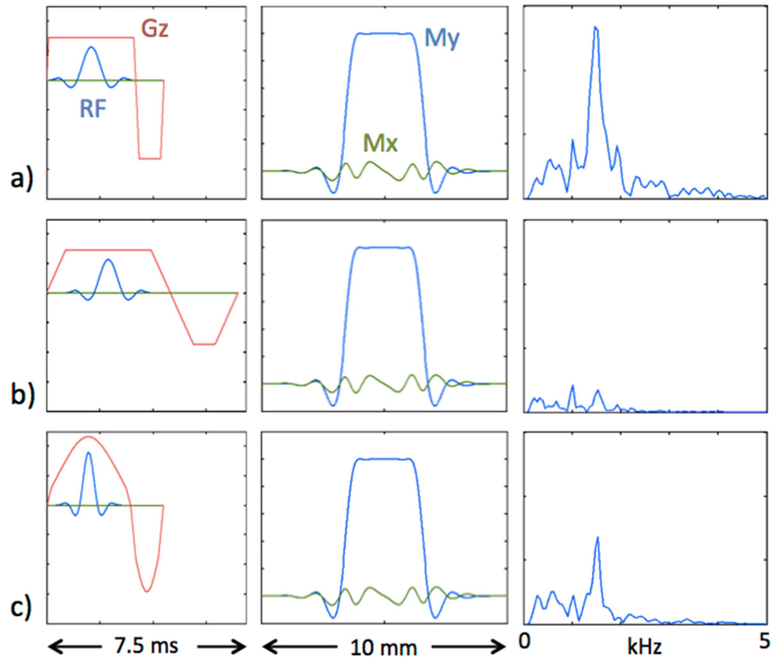

Figure 1. Slice-select waveforms (left), slice profiles (center), and linear-scale acoustic noise spectra (right) for standard pulse a), slew-rate derated pulse b) and a QVERSE pulse c). Rows a), b), and c) use identical scales

Methods: A "standard" 3-mm slice-select pulse was defined as a 3.2-ms Fermi-smoothed sinc $\pi/2$ RF pulse in the presence of a 14.5 mT/m gradient, followed by a -26.5 mT/m gradient refocusing lobe. A maximum slew rate of 200 T/m/s was followed on the ramps. A derated pulse was created with 10-fold reduced slew rate and a refocusing lobe of -17.5 mT/m. QVERSE pulses were designed using various pulse remapping schedules to simultaneously vary gradient and RF amplitudes and time increments while keeping overall slice-select durations constant. Slice profiles were mapped using a Bloch simulator. To predict acoustic behavior, each gradient pulse was Fourier transformed and the magnitude multiplied by a measured gradient acoustic response function to yield relative sound level vs frequency. Relative overall sound levels were calculated by integrating over frequency the square of the sound-level curves. For simplicity, other gradient pulses such as crushers, spoilers, readout and phase-encode were omitted.

Results: Figure 1 shows various slice-select waveforms and corresponding slice profiles and acoustic noise spectra. The standard pulse is shown in row a), the derated pulse in b), and an example of a QVERSE pulse in c). The schedule for the QVERSE pulse is shown in Fig. 2 – This was derived by mapping a half-cycle sqrt(sin) for both the slice-select and refocusing periods. All pulses had identical slice profiles on-resonance. The derated pulse was 64% longer than the other two pulses. For the QVERSE excitation, the peaks of the RF pulse, slice-select gradient lobe, and refocusing lobe were 60%, 60%, and 10% higher, respectively, than for the standard pulse. Compared to the standard pulse, the derated pulse and the QVERSE pulse had overall relative sound levels of -16 dB and -7 dB, respectively. In audio files generated from pulse trains, both derated and QVERSE pulses had more pleasing acoustic texture than standard pulses.

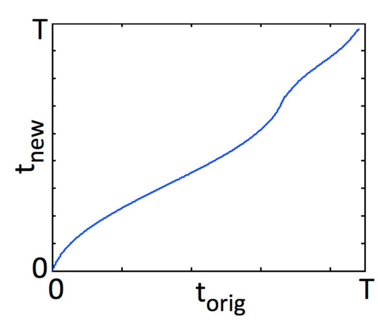

Figure 2. Variable-rate schedule for pulse of Fig. 1c.

Discussion: At 300 Hz off-resonance, the QVERSE pulse experienced broadening of the slice profile by ~50%. This method should also be applicable to minimum-phase excitation pulses, as well as to inversion pulses and refocusing pulses. In practice, sound levels will be determined by the overall pulse sequence. QVERSE pulses could play a role in a collection of noise reduction measures. Additional noise measurements and imaging experiments are planned.

References: [1] S Conolly, et al. J Magn Reson 1988;78:440–458. [2] CJ Hardy, et al. J Appl Phys 1989;66:1513-1516.