B_1^+-selective RF pulses and their design using a rotated Shinnar-Le Roux algorithm

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Target Audience Scientists and engineers interested in new approaches to selective excitation.

Purpose We present a new class of B_1^+-selective excitation pulses, and a rotated Shinnar-Le Roux (SLR) algorithm[1] to design them. Compared to adiabatic pulses that produce uniform rotations independent of B_1^+, B_1^+-selective pulses generate a uniform excitation across only a desired B_1^+ range, and zero excitation outside that range. Here we describe the algorithm, compare a B_1^+-selective pulse to a BIR-4 pulse[2] in simulation, and present experimental measurements of a B_1^+-selective pulse's excitation profile.

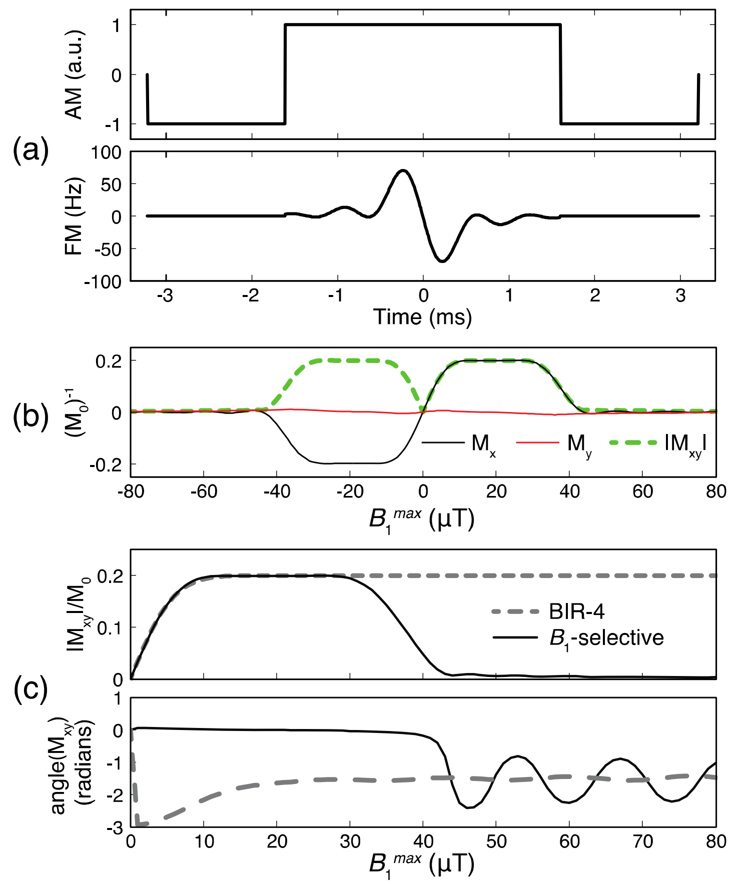

Figure 1: a) AM and FM waveforms of the 11°, 6.4 ms B_1^+-selective pulse. b) Transverse magnetization profiles excited by the pulse. The excited phase is flat across the slice. c) Excitation profile comparison to a BIR-4 pulse with the same duration. The two pulses have about the same transition width (10 µT) from 0-11°, but the B_1^+-selective pulse excites a flat phase across its transition and passbands.

Theory SLR is adapted to design B_1^+-selective pulses by rotating the coordinate axes of the spin system and magnetic fields 90°, so the z-components of the magnetization and magnetic field lie along the –x axis, the x-components lie along the z-axis, and the y-components are unmoved. The AM waveform is further assumed to be a constant function of time (like the gradient waveform in conventional SLR), so the FM waveform (equivalent to $-B_{1,x}$ in the rotated coordinate system) is designed to selectively excite magnetization as a function of $|B_1^+|$. We specify the target excitation profile in terms of $M_z/M_0 = \Re\{(\alpha^*)^2 - \beta^2\}$, and a purely real FM waveform is obtained by designing a dual-band pulse.

Methods A 6.4 ms time-bandwidth 4 pulse was designed to excite 11° between 10-30 µT, with pass/stopband ripples of 0.01°/0.5°. A 6.4 ms 11° BIR-4 pulse was designed for comparison in simulations ($\beta = 5$, $\kappa = \tan^{-1}(10)$). The B_1^+-selective pulse was implemented in a 3D GRE sequence (TE/TR 5/30 ms) on a 31 cm 4.7T Varian spectrometer (Varian Inc., Palo Alto, CA) with a birdcage coil that was used to acquire images of a vial of $CuSO_4$ solution, across a range of nominal B_1^{max} values. The images were normalized by an image acquired using the same 3D sequence but with a 5° Gaussian excitation.

Results Figure 1a plots the pulse's amplitude and frequency modulation waveforms. The AM waveform resembles a balanced gradient trapezoid, while the FM waveform resembles a sine-modulated slice-selective pulse. Note that the FM waveform's peak amplitude will increase with flip angle. Figure 1b plots the simulated transverse magnetization excited by the pulse. Figure 1c compares the pulse to a BIR-4 pulse. Figure 2 shows the experimental results.

Discussion and Conclusion We presented a new class of B_1^+-selective excitation pulses that are designed using a rotated SLR algorithm. They excite a target flip angle over a prescribed B_1^+ range with minimum pulse duration. They therefore may be a compelling alternative to non-selective adiabatic pulses such as BIR-4. The pulses may also be useful for reduced-FOV excitations based on $|B_1^+|$; for this application we note that, like frequency-selective pulses, the excited slice can be shifted anywhere along the $|B_1^+|$ axis.

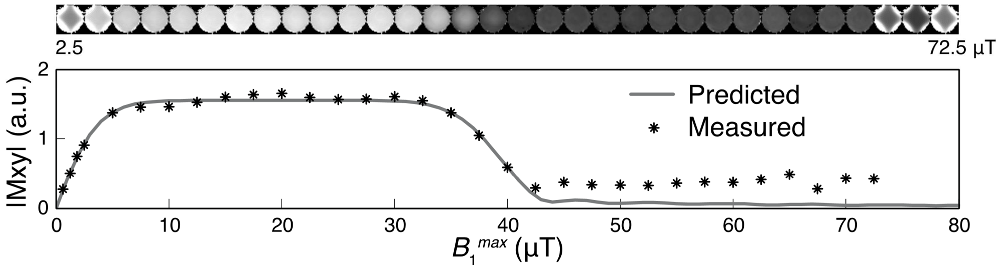

Figure 2: Experimental results. (Top) Central axial phantom images across a nominal B_1^{max} range. The bright corners at the lowest and highest $|B_1^+|$ values are due to large off-resonance (< -100 Hz). (Bottom) Predicted and measured profiles. The two are very close for low B_1^{max}; deviation of measured values at high B_1^{max} is likely due to RF amplifier droop at those high powers.

References 1. J M Pauly et al, IEEE TMI, 10:53-65, 1991. 2. M Garwood and Y Ke. JMR, 94:511-25, 1991.