

BIR-4 based B1 and B0 insensitive velocity selective pulse trains

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Introduction

The BIR-4 pulse (1) was recently shown in (2) to be useful for B₁ insensitive T₂ preparation. In (2), two equal delays were added to the BIR-4 pulse at the zero points of the RF amplitude, and the resulting pulse was demonstrated to be both B₁ and B₀ insensitive. We report here an extension of this concept that includes the use of symmetrical gradient pulses during the delay periods to impart velocity selectivity to the pulse. Application to velocity selective arterial spin labeling is demonstrated.

Methods

The BIR pulse was modified to include two delays, during which equal gradient pulses were applied, as shown in **Figure 1**. For the pulse shown, BIR-4 parameters were: $\omega_{max}=39.8\text{KHz}$; $\zeta=15.2$; $\tan(\kappa)=63.6$. The response of the pulse was simulated by numerical integration of the Bloch equations, including relaxation and constant flow in the direction of the gradient. T₁ and T₂ were assumed to be 1s and 100ms, respectively. The pulse was used in a velocity selective ASL experiment (3), with cutoff velocity 2cm/s. The response was compared to that of a velocity selective pulse train using an adiabatic double spin echo (4) with sech refocusing pulses and linear tip down / tip up pulses (3).

Results

The calculated response of M_z to the pulse is shown in **Figure 2** as a function of B₁ and velocity, demonstrating B₁ insensitivity above a threshold and the expected cosinusoidal velocity dependence. For B₁=[0.15 0.20 0.25]G (dotted lines in Figure 2), M_z vs velocity is shown in Figure 3 for both the BIR-4 and dual sech pulses. At B₁=0.2G where the linear pulses in the dual sech pulse train have the correct flip angle, the slightly higher amplitude of the cosine for the BIR-4 pulse is due to the shorter total pulse duration, resulting in less T₂ decay. At other values of B₁, the double sech is further degraded, while the amplitude of the response to the BIR-4 pulse is higher and indistinguishable across this B₁ range. In **Figure 4**, the raw ASL signal is shown on the same scale for BIR-4 and double sech velocity selective labeling pulses. The average signal in the gray matter is 18% higher for the BIR-4 pulse.

Discussion

The BIR-4 based velocity sensitive pulse train was found to be superior to the double sech based pulse train in terms of T₂ and B₁ insensitivity. This is demonstrated using velocity selective ASL, but may also be useful for diffusion prepared pulse sequences or velocity based suppression of flowing spins. In one of our target applications, direct imaging of blood volume, the desired profile of M_z is proportional to sin(v) rather than cos(v), with the goal of suppressing static tissue. $M_z \propto \sin(v)$ may also be useful for angiography.

This profile can be achieved using either pulse train with a 90° phase shift applied to the final sub-pulse. For this application, the advantage of the BIR-4 pulse is even more pronounced. For the cos(v) pulse, the double sech is accurately transparent at v=0 because the two sech pulses return magnetization to the same position as immediately following the tip down pulse, and the tip up pulse therefore returns magnetization accurately to the +Z axis, despite B₁ inhomogeneity. For the double sech sin(v) pulse train, the suppression at v=0 is proportional to cos²(α), where α is the nominal 90° linear pulse flip angle, while the BIR-4 based pulse train is inherently B₁ insensitive.

References

1. Garwood et al, JMR 94:511, 1991.
2. Rezafat et al, MRM 61:1326, 2009.
3. Wong et al, MRM 55:1334, 2006.
4. Conolly et al, MRM 18:28, 1991.

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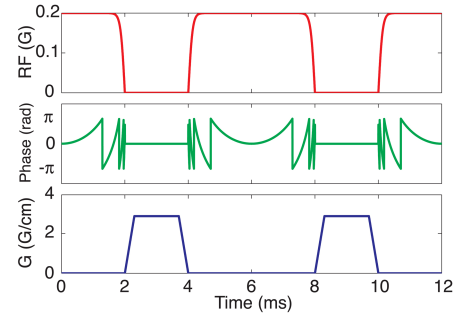


Figure 1: Velocity Selective BIR-4 pulse

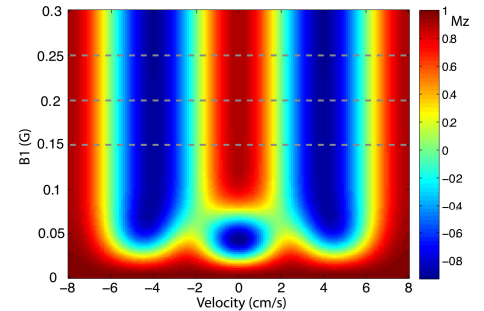


Figure 2: Simulated response of VS-BIR-4 pulse across velocity and B₁

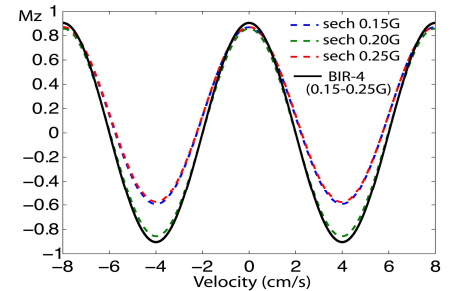


Figure 3: Comparison of VS-BIR-4 and double sech pulse (3,4).

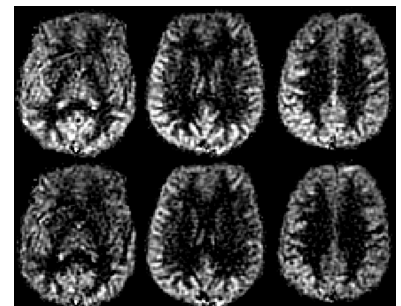


Figure 4: VS-ASL images using BIR-4 (top) and double sech (bottom) pulses.