Design of a Variable-Rate Selective Dual-Band FOCI Pulse for Spin Labeling

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Introduction: For pulsed arterial spin labeling (pASL) the quality of the spatially selective inversion is decisive to minimize errors and maximize contrast. This comprises the homogeneity and the degree of the inversion as well as the steepness of the transition zones of the inversion. Commonly, adiabatic pulses like the hyperbolic secant (HS) [1] or the frequency offset corrected inversion (FOCI) pulse [2] are used. For a complete inversion, the adiabatic condition has to be met. Therefore, a compromise between the pulse parameters and the maximum available B1, i.e. coil voltage, has to be found. Especially, when using dual-band adiabatic inversion pulses, such parameters can no longer be found without sacrificing the quality of the inversion profile. In this work, we present a variable-rate selective excitation (VERSE) [3, 4] - transformed FOCI pulse that conserves the advantageous properties of a FOCI pulse, however reduces the maximum required RF power. This way, it is possible to meet the adiabatic condition even when using it as a dual-band inversion pulse.

Material and Methods: We created a HS inversion pulse with standard B1 envelope and frequency offset $\Delta \omega$. Given bandwidth BW = $\mu \beta$/2, length $T_p$ and B1-truncation of the pulse, the parameters $\mu$ and $\beta$ were calculated such that $\mu$ had been maximized. For calculating the generated FOCI pulse we used a HS pulse with an in-house MATLAB (The MathWorks, Natick, MA, USA) script. Thereby, a rotation matrix based on the Cayley-Klein parameters [7] is recalculated for every time step. For a fair comparison the simulation of both FOCI and VERSE pulse were carried out with the same B1max.

Results: The pulses calculated for the measurements are shown in Figure 1. The VERSE scaling function depicted an incomplete inversion. The HS inversion and the VERSE-transformed FOCI pulse are compared in Figure 2. The simulated and the measured slice profiles show a very good agreement. Despite the maximum coil voltage, the profiles of the FOCI pulse fulfill the adiabatic condition leading to a complete inversion of the magnetization at the center of the slices. The inversion efficiencies are plotted in Table 1.

Conclusion/Discussion: The presented pulse allows for the simultaneous inversion of two slices while conserving the high inversion profile quality and the low sensitivity to chemical shift displacements of a single-band FOCI pulse. Although the scaling function can generally be chosen to minimize B1 limitations due to the maximum available gradient strength and slew rate, in practice, lead to a trade-off between both. Due to its properties, the presented dual-band pulse can be beneficial for the acquisition of ASL perfusion data of paired organs when a 3D readout is used. Especially for the 3D measurement of renal perfusion with pulsed ASL, the kidneys can be labelled without labelling the aorta which leads to shorter bolus arrival times and a higher perfusion contrast.

References:

Fig. 1: B1 envelope, gradient waveform and frequency sweep of the HS, FOCI and dual-band VERSE pulse as calculated for the measurement. The B1 envelope of the dual-band pulse as used for the measurement is not shown.

Fig. 2: Simulated (blue) and measured (yellow) slice profiles of the dual-band FOCI pulse (upper panel) and its VERSE-transformed pendant (lower panel). The longitudinal magnetization is plotted against the position.

Tab.1: Mean longitudinal magnetization of both slices in their centers, i.e. 0.88 slice thicknesses.

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<tr>
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<th>measurement</th>
<th>simulation</th>
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<tr>
<td>FOCI pulse</td>
<td>(-0.75±0.10) a.u.</td>
<td>(-0.75±0.10) a.u.</td>
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<td>VERSE pulse</td>
<td>(-0.99±0.01) a.u.</td>
<td>(-0.98±0.01) a.u.</td>
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