B_1^+-insensitive slice-selective pulses constructed from optimized non-selective composite waveforms

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Introduction

Although parallel RF transmission has proven to be an effective method for achieving uniform flip angles in the presence of inhomogeneous RF fields common to high field MRI, there exist scenarios (e.g., clinical and small animal MRI, surface coil applications) in which the expense of additional hardware or the complication of subject-specific RF calibrations may be prohibitive. RF pulses with intrinsic B_1^+-insensitivity are desirable alternatives to parallel transmission in these contexts, but many such previously reported pulses either (1) are not spatially selective, (2) are not capable of producing arbitrary flip angles, (3) have nonlinear through-slice phase, or (4) function adiabatically and thus require durations resulting in high SAR and T_2-related signal loss. In this work, we present a protocol for the design of short (<10 ms), slice-selective, B_1^+-insensitive pulses for arbitrary flip-angle excitation with linear phase. Under the given hardware limitations, such pulses allow for an imaging slice thickness of ≤2 mm and improve signal relative to sinc pulses in GRE imaging at 7 T.

Methods

The pulse design protocol consists of three main steps: **I.** According to methods described in [1], a non-selective, amplitude and phase modulated, composite pulse is generated such that near-uniform flip angles are achievable over the range of ΔB_0 and B_1^+ variations expected in the human brain at 7 T. **II.** The spectral composition and bandwidth of the composite RF waveform are transformed by replacing the individual block-shaped sub-pulses with Gaussian amplitude modulations that have equivalent time-integrated areas. **III.** The train of Gaussian sub-pulses is executed in the presence of an oscillating slice-selection gradient as in [2] and [3]. This three step process results in spatially selective pulses that produce uniform flip angles comparable to the original non-selective composite pulse while having slice profiles that are stable over the prescribed ΔB_0 range. The example pulses presented here are 8-part composites of 1.1 ms Gaussian sub-pulses (2.9 kHz bandwidth). Magnetization responses were simulated (Fig. 1), slice profiles were measured in an oil phantom (Fig. 2), and GRE images were acquired in an axial slice of the human brain with a Philips 7 T scanner (Fig. 3).

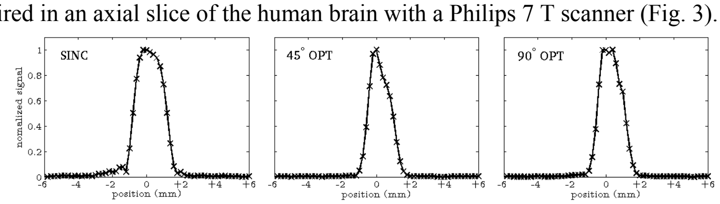

Fig. 2: Slice profiles as measured in a mineral oil phantom for a Gaussian-modulated sinc pulse (left), and the 45° (middle) and 90° (right) optimized pulses from Fig. 1.

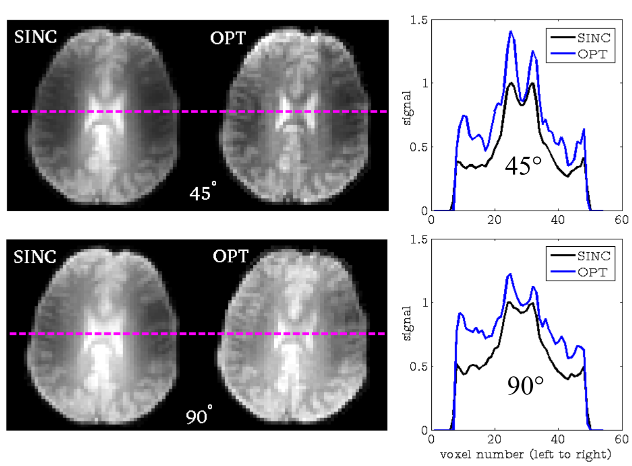

Fig. 3: Images acquired at 7 T with a GRE sequence (T_R = 5s) using sinc excitations (left) and the composite pulse excitations from Fig. 2 (middle). Line profiles (right) reflect signals from the two pulse types after adjustment for the slice profile differences reported in Fig. 2. Results for both 45° (top row) and 90° (bottom row) pulses are included.

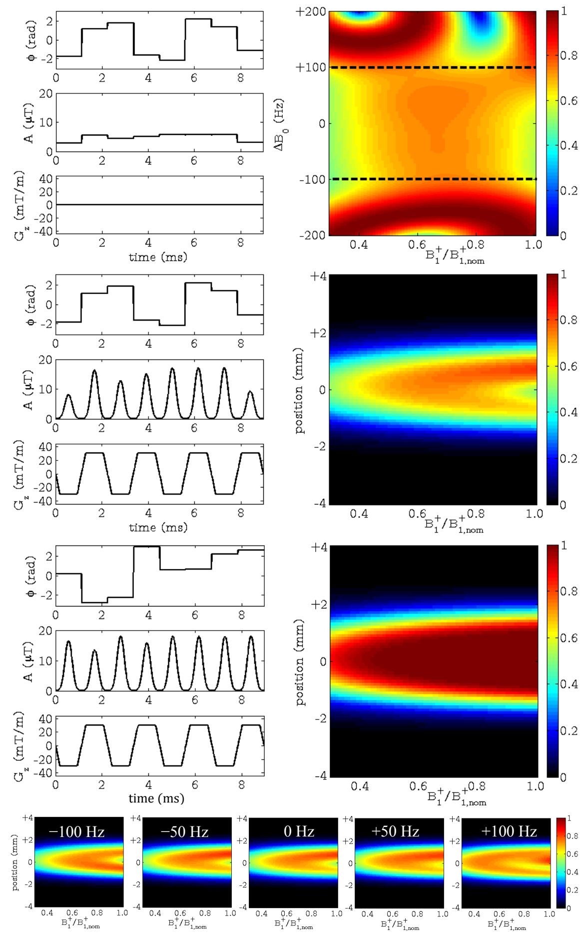

Fig. 1: RF and G_z waveforms (left side) and simulated M_z/M_0 values (right side) for a non-selective 45° composite pulse (top, with dashed lines indicating the ΔB_0 optimization range), a slice-selective 45° pulse (middle), and a slice-selective 90° pulse designed in the same manner (bottom). The final row illustrates slice profile stability of the 45° pulse over the given range of ΔB_0.

Results and Conclusions

Simulated performances of a non-selective 45° pulse along with slice-selective 45° and 90° pulses are highlighted in Fig. 1 and indicate the B_1^+-insensitivity possible with this class of pulses. The measured slice profiles reported in Fig. 2 are consistent with the simulations of Fig. 1 and show composite pulses to result in spatial selectivity comparable to that of sinc pulses. Moreover, slice thicknesses relevant to high-resolution imaging are shown to be achievable given the maximum gradient strengths and slew rates of 33 mT/m and 166 T/m/s, respectively. While large signal variations still exist due to B_1^- inhomogeneities, the 7 T brain images in Fig. 3 reflect the more uniform excitation possible with optimized composite pulses as compared to sinc pulses of the same nominal flip angle. Line profiles, having been adjusted to correct for slice profile differences, reveal that significant signal gains can be realized with optimized pulses. Given their established performance, the pulse designs reported here have much potential in a variety of high-field applications, from excitation and refocusing for imaging to volume localization and spectroscopy.

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References: [1] Moore et al. JMR 205:50-62 (2010). [2] Rieseberg et al., MRM 47:1186-1193 (2002). [3] Balchandani et al. MRM 59:1072-1078 (2008)