Frequency Selective RF Pulses for Multislice MRI with Modest Immunity to B1 Inhomogeneity and to Resonance Offset

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Introduction: For MRI of the human head at high field (4 Tesla or greater), the B_1 field is necessarily inhomogeneous, due to RF penetration and dielectric effects (1). Additional B_1 field inhomogeneity may also be created when array coils are used for both transmission and reception. The non-uniform B_1 field results in non-uniform tipping, and non-uniform image intensity. While a number of methods have been suggested for correction of the resulting non-uniform image intensity, the non-uniform tipping also produces non-uniform contrast, for which there is no correction. One way to avoid the non-uniform tipping is to use adiabatic pulses, which produce uniform tipping even in the presence of inhomogeneous B_1 fields. However, only one adiabatic excitation pulse suitable for multislice MRI has been shown in the literature (2), and its length and complexity probably render unsuitable for conventional MRI. On the other hand, rectangular composite pulse sequences that perform uniform excitation over a range of B_1 inhomogeneity have been previously demonstrated. Moreover, we (3) and others (4, 5) have shown that rectangular composite pulse sequences can be used as the basis for frequency selective pulses. A weakness of the modified Levitt 90^0 pulse (6) we showed for uniform tipping in the presence of B_1 inhomogeneity (3) was its sensitivity to resonance offset. However, when we tested other slice selective pulses (4, 5), we found them to be even more sensitive to resonance offset (results not shown). Thus, our goal was to develop excitation pulses, including shallow tip angle pulses, suitable for multislice MRI with immunity to both B_1 inhomogeneity and resonance offset.

Methods: We have developed computer optimization methods to seek out new three and four pulse rectangular composite pulse sequences that have immunity to both B_1 inhomogeneity and resonance offset. These sequences then form an improved basis for generation of slice selective pulses that confer both immunity to B_1 inhomogeneity and immunity to resonance offset to their slice selective counterparts. The optimization programs run in Mathematica (Wolfram Research), and make use of an application package from an independent developer (Global Optimization 4.2 by Loehle Enterprises). The optimization uses the GlobalMinima program that utilizes an adaptive grid algorithm to find multiple solutions if they exist. Solutions have been obtained for tip angles from 15^0 to 90^0 in increments of 15^0. These rectangular composite pulse sequences were then used as the basis for frequency selective pulses with immunity to both B_1 inhomogeneity and resonance offset. The frequency selective pulses were generated with MATPULSE (7).

Results: As an example, Fig. 1 shows Mz for a four pulse 90^0 sequence as a function of B_1 strength (arbitrary units). A graph tracing the paths on the unit sphere for the isochromats experiencing differing B_1 field strengths is shown in Fig. 2. The direction of the B_1 field for the final tip is indicated in the figure. Figures 3 and 4 show the RF and gradient waveforms for a 10 mm slice selected with 20 mT/m gradients, with a slew rate of 200 mT/m/ms, while Fig. 5 shows magnitude profiles for total rotation tips of from 400^0 to 600^0. The RF waveforms are standard SLR pulses generated with MATPULSE (7). This sequence has approximately double the immunity to resonance offset as does the modified Levitt sequence (3). Shortening of the sequence, for example by remapping (7), would improve the immunity to resonance offset.

Discussion: Our computer optimization methods have uncovered new, three and four pulse rectangular pulse composite sequences that can form the basis for new, frequency selective pulses with immunity to both B_1 inhomogeneity and resonance offset. While the goal is the generation of frequency selective pulses suitable for multislice MRI, the rectangular pulse sequences are still be useful for certain MRI sequences, such as MP_RAGE experiments, which do not use frequency selective pulses. While the three pulses sequences yield shorter duration composite pulses and produce less SAR than their four pulse counterparts, the four pulse sequences appear to provide improved immunity to resonance offset. Finally, it is possible that optimization of the frequency selective sequence could further improve its performance.

References:

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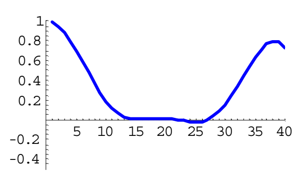

Fig. 1. Mz as a function of B_1.

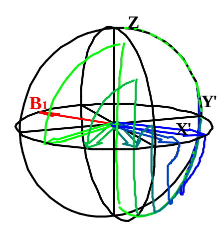

Fig. 2. Traces over the unit sphere.

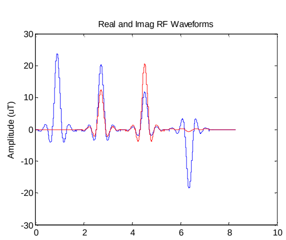

Fig. 3. RF waveform.

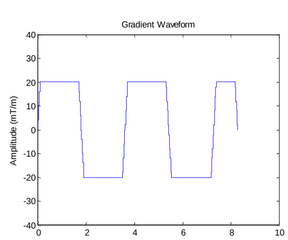

Fig. 4. Gradient waveform.

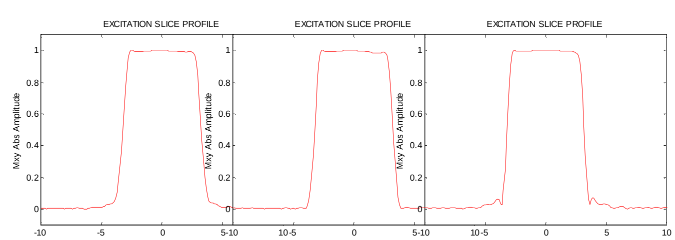

Fig. 5. Magnitude profiles for tips from 400^0 to 600^0.