Multi-Band Adiabatic Pulses

R. Ouwerkerk[1], R. A. Edden[2]

[1]Russell H. Morgan Dept. of Radiology and Radiological Science, Johns Hopkins University, SOM, Baltimore, MD, United States, [2]FM Kirby Center for Functional MRI, Kennedy Krieger Institute, Baltimore, MD, United States

INTRODUCTION: A disadvantage of higher field strength magnets is that it is more difficult to create RF coils with homogeneous B1 fields. Therefore, porting pulse sequences with selective pulses from 1.5T magnets to higher fields often requires a redesign of the RF pulse shapes in the sequence to handle B1 inhomogeneity. To achieve this, inversion pulses can be replaced by adiabatic inversion pulses (1,2). However, problems with SAR limitations also increase with higher fields (3). Combining multiple pulses into one pulse can counter SAR-imposed sequence limitations Although adding phase-shifted amplitude pulses to achieve multi-band excitation is an established method, some problems arise when the excitation bands are close together (4) and very few attempts have been made to create multi-band adiabatic pulses.

METHODS: By adding a frequency-shifted asymmetric hyperpulse (5) to a time-reversed and frequency-shifted copy (4), a dual-band pulse can be created with two very sharp transitions, which can be a used as a selective inversion pulse with a sharply defined pass-band. One such waveform is shown in Fig.1. A wide variety of multi-band adiabatic pulses were calculated by adding phase-shifted versions of two or more adiabatic pulses, and all were tested for response as a function of B1 field and offset using the Bloch equations (6) in Matlab (Mathworks, Natick, MA). The pulse responses of selected pulses were also measured on a Bruker Avance 4.7T MR scanner using a 1cm diameter tube with $CuSO_4$-doped water in a 30 mm volume coil. The 10 ms inversion pulses preceded a crusher gradient and a BIR4 90-180 spin echo pulse sequence (TE30ms) with a soft readout gradient on all pulses and 10kHz BW that collected 2048 points. The B1 for the BIR4 pulses was kept constant at about 235 μT, while the B1 for the dual-band inversion pulse was varied from 0 to 30 dB lower in 3dB steps.

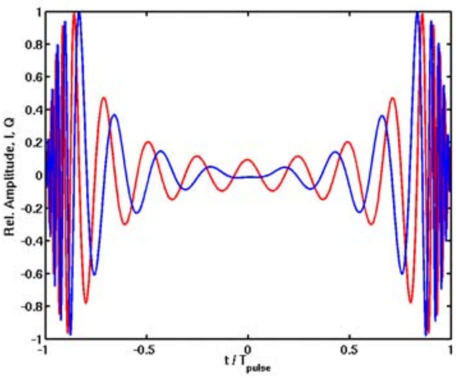

Figure 1 *Real (red) and imaginary (blue) parts of the waveforms of a dual hyperpulse.*

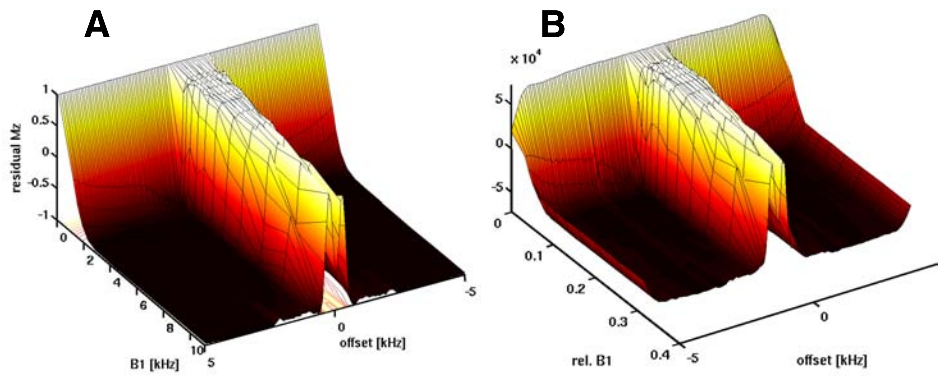

Figure 2 *3D plot of the simulated (A) and measured (B) response of the waveform shown in Fig1. as a function of offset and B1 (rel. B1 0.3 ≈ 235 μT).*

RESULTS:. The extent of the B1 range in which the pulses function as desired depends on the inversion and pass-band widths. Fig. 1 shows the real and imaginary components of the RF waveform for a dual-band pulse, resulting in a wide inversion with a narrow (500Hz) pass-band. Fig. 2 shows the pulses simulated and measured Mz. The wide bands are inverted at a B1> 2.2 kHz, leaving Mz a good pass-band up to 5 kHz. At higher B1, some distortions appear in the pass-band. Similar results were obtained with pulses created from two symmetric SECHN pulses, but the best results were obtained when pulses were not equal in shape and amplitude.

CONCLUSION: We have shown that adiabatic pulses can be combined to form multi-band selective pulses, some with an adequate B1 insensitivity even for surface coil experiments. These pulses are widely applicable to MRI and MRS for simultaneous inversion, suppression of spectral components, or outer volume suppression.

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