A Dual Fly-back Spectral-Spatial RF Pulse for Lipid Suppression and Reduced Susceptibility Artifacts

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Introduction: Numerically generated spectral-spatial RF pulses have been proposed for decreasing the through-plane signal loss susceptibility artifact in T2*-weighted imaging applications such as BOLD fMRI (1,2). We present the same pulse concept designed using a simple, analytic, fly-back dual-band approach (3). The pulse is constructed for the simultaneous reduction of through-plane signal loss artifact and lipid suppression. The pulse performance is demonstrated in phantoms and humans undergoing breath holding fMRI scans at 3T.

Theory: The through-plane variation is the dominant contribution to susceptibility induced signal loss in axial slices above air cavities in the brain. Pre-phasing the slice with minus the induced phase $\phi(z)$ can reduce the signal loss. Spectral-spatial pulses achieve this using the assumption that regions with signal loss will also be off-resonance by Δf. This was demonstrated in Ref. (2) using numerically generated pulses. A similar pulse can be designed using an analytic fly-back design written as the sum of two unique RF pulses on the positive and negative gradient lobes respectively:

$$RF(t) = RF_1(t-\tau)e^{i2\pi\Delta f t} + RF_2(t)$$

The through-plane phase $\phi(z) = \gamma G_z z \tau$ is created by time shifting RF_1 by τ, which is also frequency modulated by Δf creating a dual-band excitation. Fig. 1 (a) shows a spectral-spatial pulse and gradient G_z. Each sub-pulse is Gaussian with a 5mm slice-thickness and τ=150us and Δf=125Hz. The overall pulse is Gaussian weighted with a frequency pass band of 125Hz. The sub-pulse duration 1.44ms, which sets the stop band to 700 Hz (lipid is off-resonance by 440Hz at 3T). Fig. 1 (b) shows the magnitude and phase of the slice in spectral-spatial domain from a Bloch equation simulation.

Methods: The pulses were implemented in a 2D spiral in-out sequence (TE/TR=30/2000ms, 22cm FOV, 16 slices, 5mm thickness, 90° flip angle, 64x64 matrix, two interleaves) on a 3T Siemens scanner (150 mT/m/s slew rate, 30 mT/m gradient) with a twelve-channel head array. The pulse was compared to a standard non-spectrally selective pulse with the same slice profile in a water/lipid phantom and human scans. The humans underwent two four-minute breath-holding fMRI experiments to compare BOLD activation. The four-minute fMRI paradigm used a block design that required the subject to repeatedly breathe for 20 seconds and hold for 20 seconds. Values for τ and Δf were the same as in Fig. 1 (a) and were determined post-hoc from visual inspection of the images.

(a) **(b)**

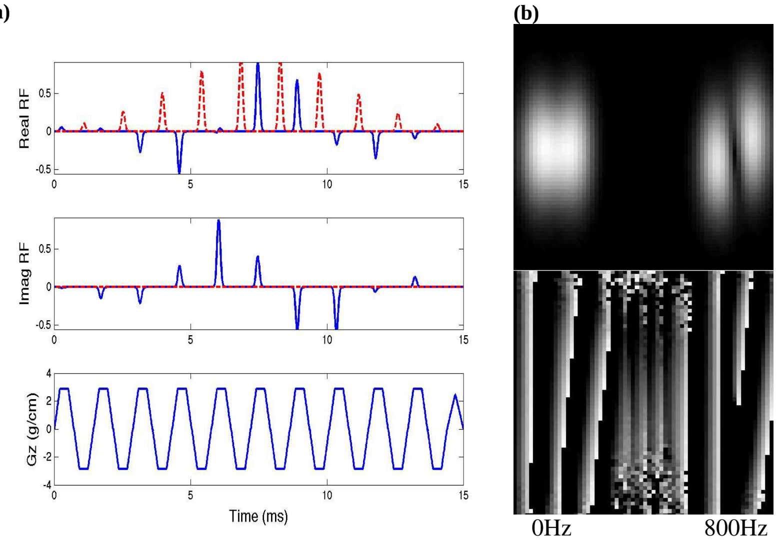

Figure 1 (a) Dual-band fly-back spectral spatial RF pulse for simultaneous fat suppression and signal loss recovery. **(b)** Magnitude and phase of the slice profile in the spectral and spatial directions from a Bloch equation simulation.

Results: Fig. 2 shows images of the water/lipid phantom using (a) standard and (b) spectral-spatial pulses. Suppression of lipid signal can be clearly noticed in (b). Figure 2 also shows functional images (c-d) overlaid with activation maps (Z-value from 3 to 10). Figure 2 (c) show spiral-in images acquired with standard (top row) and spectral-spatial (bottom row) pulses, respectively. Figure 2 (d) were acquired with the spiral-out readout gradient using standard (top row) and spectral-spatial (bottom row) pulses, respectively. Recovered signal in orbitofrontal and auditory regions is clearly noticeable with the spectral-spatial pulse. Improved activation from the breath-holding fMRI experiment is also observed in regions with recovered signal.

(a) **(b)** **(c)Spiral-in** **(d)Spiral-out**

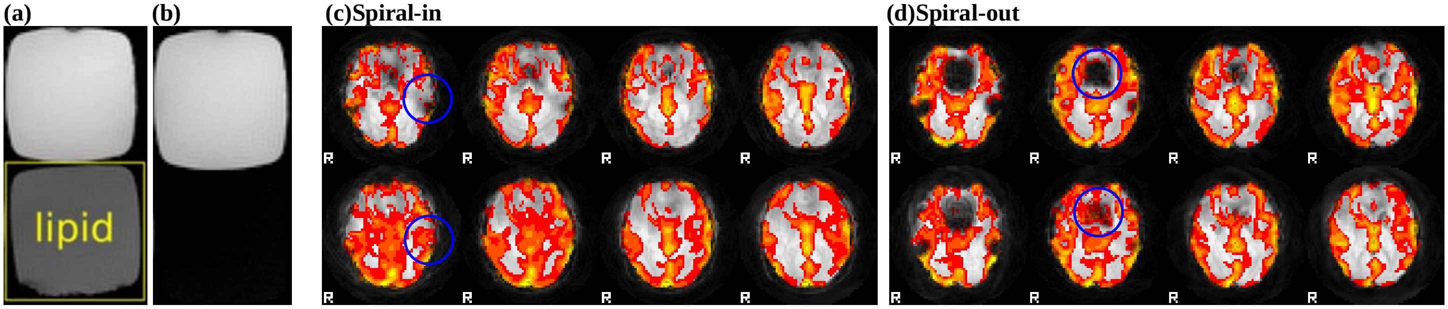

Figure 2 Water-lipid phantom image using **(a)** standard and **(b)** spectral spatial pulse. **(c)** Spiral-in images overlaid with BOLD activation maps acquired with standard pulse (top row) and spectral-spatial (bottom row) pulse. **(d)** Spiral-out images acquired with standard (top row) and spectral-spatial (bottom row) pulse. Improvement in activations is clearly seen as exemplified in the circled regions.

Discussion and Conclusions: A fly-back dual-band spatial-spectral pulse is presented for simultaneous lipid suppression and susceptibility induced signal loss recovery. The performance is comparable to the previously proposed numerical design and offers a simpler analytic alternative.

References: (1) C. M. Meyer et al. MRM 1990;15:287-304. (2) C-Y Yip *et al.* Proc of 16th ISMRM 2008, p. 2453. (3) J. M. Pauly et al. Proc of 11th ISMRM 2003 p. 966.

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