A Simultaneous Multi-Slice Fast-k_z RF Pulse for Reduced B1+ Inhomogeneity

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Target Audience: MR physicists and others interested in multi-dimensional RF pulses and B1+ compensation.

Purpose: There is recent interest in Simultaneous Multi-Slice (SMS) imaging because of reduced imaging times [1-4]. SMS excitation is typically achieved with a single-slice pulse modulated to excite N simultaneous identical slices. However, there has been little work done on extending SMS excitations to multi-dimensional RF pulses. For example, the "Fast-k_z" or "spokes" 3D RF pulse has been shown to excite thin slices with in-plane B1+ inhomogeneity reduction [5]. We present a simple, analytical "proof-of-concept" SMS Fast-k_z pulse for correcting the central brightening associated with B1+ inhomogeneity from a volume transmitter. We demonstrate the pulse with excitation of multiple B1+ inhomogeneity compensated brain slices at 3T.

Methods: A Fast-k_z pulse is a series of slice-select (z) sub-pulses separated by in-plane (x-y) gradient blips. Each blip effectively weights an excitation k_x-k_y point within a slice. Modulation of the sub-pulses will enable the excitation of multiple slices. An analytical slice profile $m(x,y,z)$ for N slices of thickness z_0, separation Δz, and quadratic curvature in x-y can be written as:

$$m(x,y,z) = \mathrm{rect}(z/z_0)\left[1+\varepsilon(x/x_0)^2+\varepsilon(y/y_0)^2\right] * \sum_{n=-N/2}^{N/2-1}\delta(z-n\Delta z).$$

The quadratic curvature can be used to compensate for the central brightening from a volume transmitter and can be adjusted with ε, x_0, and y_0. The corresponding RF weighting of excitation k-space $b(k_x,k_y,k_z)$ will then be given by:

$$b(k_x,k_y,k_z) = \mathrm{sinc}(2\pi k_z z_0)\mathrm{Diric}(N\pi k_z \Delta z)\left\{\delta(0,0) - A\left[\delta(k_x-1/x_0,0)+\delta(k_x+1/x_0,0)\right] - A\left[\delta(0,k_y-1/y_0)+\delta(0,k_y+1/y_0)\right]\right\}.$$

"Diric" is the Dirichlet function from sampling theory. Note that $m(x,y,z)$ is just the Fourier transformation of $b(k_x,k_y,k_z)$ assuming x_0,y_0>FOV of the excitation. The degree of B1+ correction can be adjusted in an *ad hoc* manner by the relationship $\varepsilon=2A\pi^2/(1-2A)$. Figure 1 shows an example of an N=3 MB Fast-k_z pulse.

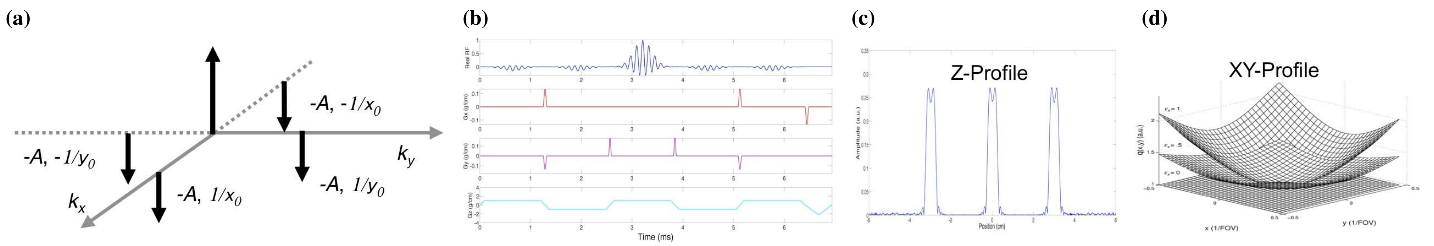

Figure 1. **(a)** The in-plane k-space weighting will produce a quadratic excitation profile. Each point is weighted by a MB slice-select pulse along z. **(b)** MB Fast-k_z pulse with corresponding gradients for N=3. Simulated slice profiles in **(c)** z and **(d)** x-y. The value ε controls the degree of B1+ compensation.

Three prototype pulses (N=3, Δz=3cm, z_0=5mm, 150mT/m slew rate, 20mT/m peak) with ε=0, 0.5 and 1.0 and x_0,y_0=2FOV were generated in MATLAB. Human brain images were acquired with a Siemens 3T scanner using the body coil for both transmitting and receiving. A fully sampled 3D FLASH sequence (128x128, 40ms TR, 10ms TE, 30° FA, 2.5mm slices) was used for acquisition. Individual slices were extracted from the reconstructed 3D volume.

Results And Discussion: Fig. 2 shows proof-of-concept 3T brain slices. The images from left to right were acquired with increasing values of correction ε. Note that ε =0.5 and 1.0 have reduced B1+ inhomogeneity compared to ε=0 (no correction). These results demonstrate that the Fast-k_z pulse design can be used for SMS excitations for B1+ control. The pulse design can be extended to include more accurate models for B1+ as well as to parallel transmission applications and correcting through-plane signal loss artifact [6-8].

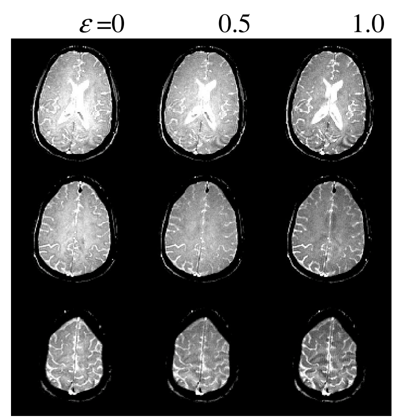

Figure 2. Three slices simultaneously compenesated for 3T B1+ inhomogeneity .

References: [1] Larkman JMRI **14** p.329 2001; [2] Moeller MRM **63** p.1144 2010; [3] Feinberg PlosOne **5** p. e15710 2010; [4] Setsompop MRM, **67** p. 1210 2012; [5] Saekho MRM **55** p.719 2006; [6] Setsompop MRM **56** p.1163 2006; [7] Zhang MRM **57** p.842 2007; [8] Yip MRM **56** p.1050 2006.

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