## Exploring 3D RF shimming for slice selective imaging

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### Introduction

Slice excitation at higher field (>1.5T) shows a non-uniform transverse magnetization profile (in-plane) that leads to mixed contrast images. This is caused principally by B1 homogeneity limitations at very high frequencies [1]. At moderate high field (e.g. 3T) these inhomogeneities are slowly varying across the field of view. Correction schemes have been proposed by designing 2D [2] and 3D [3] RF pulses that compensate for inhomogeneity (RF shimming). However, 2D pulses do not provide full 3D correction and 3D pulses require a long time and can lead to high power deposition. Recently, [4,5] defined a parallel transmission concept that promises to significantly reduce the duration of 3D RF pulses [6]. In this work, we explore pulse design for RF shimming to achieve uniform flip angle in the image plane (xy) for multi-slice imaging applications.

### Methods

The required excitation profile for RF shimming is the reciprocal of the actual excitation profile achieved by an enveloping transmit coil with the subject in place. For this work we have used a Gaussian modulation with width approximately equal to the field of view (Fig 1a) as a simple model of the field inhomogeneity (based on experience of body imaging at 3T). In the small tip angle approximation [7], the RF pulse is the Fourier transform (k-space) of the desired profile weighted by the speed of the k-space path. In the current application the required coverage of k-space is highly anisotropic (Figs. 1b), with large extent in the slice select direction ($k_z$) to achieve an apodised rect profile, but only limited excursions in the transverse ($k_x$, $k_y$) directions. The sampling density of this excitation k-space determines the minimum un-aliased field of view (FoV). We explored the properties of pulses produced by different trajectories that cover the required region at the required density. A critical consideration is the effect of the continuous excitation that occurs along the trajectory, as well as the limitations imposed by gradient switching. The trajectories examined included stacked spiral and EPI paths in planes either containing or perpendicular to $k_z$, as well as $k_z$ directed paths arranged in a square spiral pattern in $k_x$, $k_y$.

### Results

All trajectories that did not have the continuous excitation along $k_z$ resulted in aliasing (N/2 ghost) [8] in the slice direction and distortion of the shimming profile (Fig. 1f). These trajectories are also very inefficient because they require many gradient reversals. Having placed the fast axis along $k_z$, there is then the option to use stacked EPI trajectories or a spiral-in pattern of samples in $k_x$, ky. We found that the spiral-in trajectory has the benefits of being efficient (it is possible to omit corner points in $k_x$,$k_y$) and has the desirable property of finishing the $k_z$ path at $k_x$=$k_y$=0, so effectively making a self-refocused pulse [7] that will be robust against off-resonance and T2 relaxation effects, both of which will simply cause blurring of the shim profile. Figure 1e shows a simulated response of this pulse design with 21 $k_z$ passes that would take approximately 21.5 ms for a typical equivalent conventional slice excitation profile taking 1 ms.

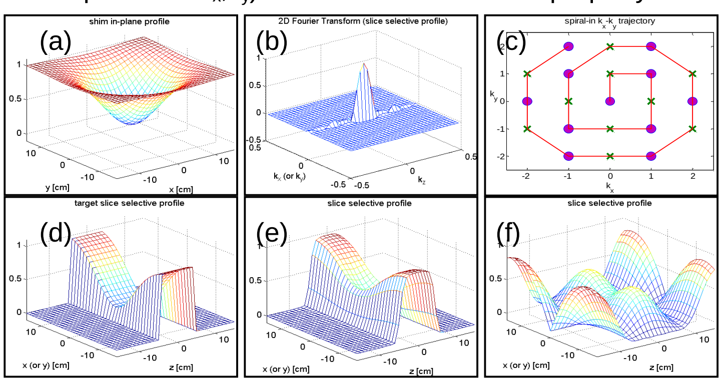


Figure 1:(a) in-plane shim profile.(b) Central of the 3D Fourier Transform of the profile. (c) kx-ky trajectory, with kz lines entering (X) and leaving (O). (d) Target slice selective profile.(e) Simulated profile fast gradient collinear to kz. (f) Simulated profile, fast gradient perpendicular to kz.

### Discussion and Future Work

We have explored the feasibility of applying 3D RF pulse shimming ideas to slice selective imaging. Unlike conventional multi-dimensional pulses, this application only requires extensive coverage in the slice select direction of excitation k-space. The resulting pulse has the desirable property of being substantially self-refocused, rendering it tolerant to relaxation and off-resonance effects. This RF shimming approach is well suited to combination with the parallel transmit concept. We will explore this in future work as well as extending the design beyond the small tip angle approximation with explicit inclusion of relaxation and off-resonance effects. Application of the method will require direct measurement of the RF inhomogeneity for each subject as part of the RF calibration process. With the increasing use of 3T and higher field systems for both clinical and research work, practical solutions for RF shimming are likely to become a routine requirement for many studies.

### References

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