High flip angle slice selective Parallel RF Excitation on an 8-channel system at 3T

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Introduction At high magnetic field strength, B1 inhomogeneity causes undesired non-uniformity in SNR and contrast. Parallel RF design methods based on small flip angle approximation with "spoke"-based trajectories have been shown to correct this problem and produce highly uniform slice selective excitation with relatively short excitation durations [1,2]. However, at large flip angles this design method fails. To solve this issue, Ulloa et al [3] proposed a large flip angle excitation design based on optimization and numerical solution of the Bloch equation. In this work we present an extension to this method, where Powell-based non-linear optimization with local cost function based on partial Bloch simulations are used to improve the speed and convergence of the design. The method is then used in the design of 90º and spin echo excitation on a Siemens Tim Trio scanner, equipped with an 8-channel transmit array.

Theory and Methods

B1 maps: Quantitative coil profile maps (in units of Gauss per Volt of RF) are needed in order to create flip angle specific RF pulses. The method used for estimating these maps is based on exciting individual coils at several voltages (using uniform coil for receive) and fitting the resulting maps to the appropriate image intensity, $I(x,y) = Kp(x,y) \times \frac{[1-e^{-TR/T_1(x,y)}]\sin\theta}{1-e^{-TR/T_1(x,y)}\cos\theta}$ [4], using a nonlinear search algorithm in Matlab.

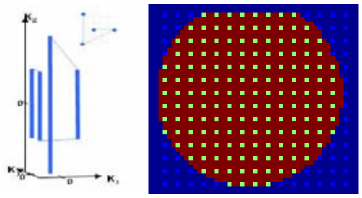

Fig1. 4 spokes design and points used for iterative optimization

RF design: As an initial step, the parallel RF pulses are designed based on the low flip angle approach [5] using the spokes k-space trajectory [1] shown in Fig. 1 (left). Using the qualitative B1 map acquired, the resulting RF pulses are then scaled to produce the appropriate high flip angle. The resulting pulse is then used as an initial guess in the optimization process. To simplify the design, sinc pulses are used for each of the kz spokes. With this simplification, only the complex amplitude of the sinc sub-pulses needs to be iteratively optimized. The optimization problem can then be stated as: $\min \left\| m_{desired} - m_{actual} \right\|_2$, where the minimization is over the complex amplitude of all the sub-pulses in all excitation coils. The Powell method [6] was chosen as the iterative method for this optimization over gradient-based optimization methods (deemed less desirable for this problem because the gradient evaluation time can be long). To calculate the actual excitation (m_{actual}) during each iteration step, the Bloch equation is solved in the spinor domain [7]. Since not all of the spokes' complex amplitudes change at each iteration step, we only need to recalculate the spinor matrix for the updated spokes. The new spinor matrices are then multiplied with the spinor matrices of the unchanged spokes. With the Powell method and the partial Bloch simulation, we found a reduction on computation time of more than 14-fold over standard optimization method in Matlab. With this speed improvement, it is possible to specify a relatively high in-plane sampling of the desired profile (Fig. 1 right) rather than, e.g. a single point at the object center [3]. The improved sampling allows for a better in-plane uniformity of the resulting profile, especially in the case where many non-uniform transmit coils are used.

We implemented the high flip angle parallel RF design for 90º and spin echo excitation sequences. Experiments were conducted on a Siemens Magnetom TRIO, A TIM system, equipped with an 8-channel transmit array. An 8-channel loop array coil was used for excitation, and a uniform body coil for receive. RF pulse versing [8] was used to limit the maximum RF voltage to 100 V.

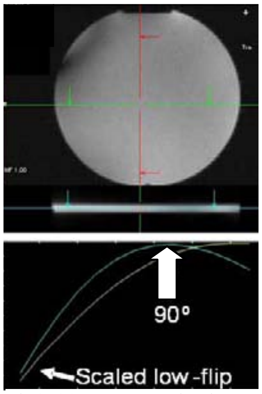

Fig2. 90 degree excitation results

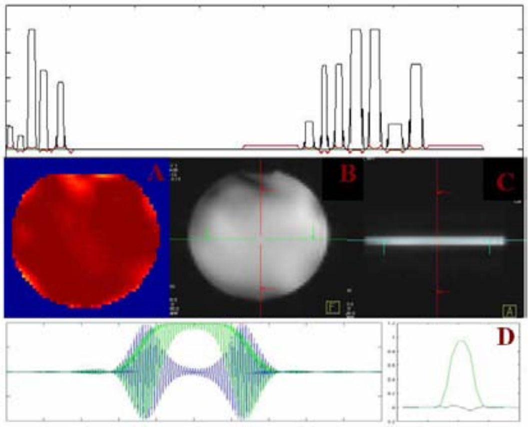

Fig3. Spin Echo sequence (top), simulated profiles (a,d) and experimental results (b,c)

Results and discussion **90 degree** excitation was performed using a 4-spoke design with pulse duration of 3.5 ms. Fig 2. shows a good in-plane profile (top) with excellent slice selection (middle). Also, the in-plane signal peaked at the voltage predicted by the design (bottom, blue-curve). This is in contrast with the yellow curve on the same graph, which resulted from simply scaling up a non-optimized low flip design. The artifact in the slice profile in the upper-left section may be due to error in B_1 mapping for this particular coil in the array. **Spin Echo**: The pulse sequence used for the spin echo (TE = 55 ms) is shown in Fig3. (top), where a 5-spoke design with duration of 4.9 ms and a 7-spoke design with duration of 9.4 ms was used for the 90 º excitation and the 180 º refocusing pulse, respectively. Shown in red is the Gz gradient, and in black is the RF pulse used in one of the excitation coils. Gradient crushers for the 180 pulse can be seen, along with the effect of the versing on the gradient and RF. Also shown in the figure are the simulated and experimental results: in-plane (A,B) and though-slice profile (D,C). The slice profile simulation (bottom-left) shows the effect of the gradient crusher in causing rapid variation in phase across the slice. This rapid phase variation averages out to give the profile shown in (D). From the figure, it can be seen that the experimental results match well with the simulation. The experimental result shows some in-plane non-uniformity which was predicted by the simulation. The likely cause of this is in the inaccuracy in B_1 phase maps. The phantom used for the experiment contain a large air bubble at the top, which causes abrupt local B_0 inhomogeneity, leading to significant phase change in the B_1 map obtained with the current method. This phase change makes it considerably harder to obtain a uniform magnitude and phase excitation profile in the design. In future work we aim to incorporate B_0 inhomogeneity correction into the design for both the phase map calculation and RF pulse design.

Conclusion: Extension of the design method for high flip parallel slice selective excitation has been described and implemented on an 8-channel parallel excitation system at 3T. Powell non-linear optimization and local cost function were used for 14-fold improvement in computation time, compare to standard method. Successful implementation of 8-channel Parallel RF Excitation for 90 º and spin echo sequence based on this method has been realized.

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