Sparse spokes slice selective design for B1 inhomogeneity correction at 7T

K. Setsompop[1], A. C. Zelinski[1], V. K. Goyal[1], L. L. Wald[2,3], and E. Adalsteinsson[1,3]
[1]EECS, Massachusetts Institute of Technology, Cambridge, MA, United States, [2]A. A. Martinos Center for Biomedical Imaging, MGH, Harvard Medical School, Charlestown, MA, United States, [3]Harvard-MIT Division of Health Sciences and Technology, Cambridge, MA, United States

Introduction: At high magnetic field strength, B_1 inhomogeneity causes undesired effects of non-uniformity in SNR and contrast. For slice selective excitation, 3D RF pulse design proposed in [1,2,3], can be used to mitigate this B_1 inhomogeneity effect. These designs are based on playing k_z sinc "spokes" of different amplitude at a number of (k_x,k_y) locations around the k-space origin. The sinc spokes in k_z create slice selective excitation in z, while the amplitude weighted placement of these spokes in k_xk_y provides modulation in excitation in xy plane. This modulation is designed so that it cancels the effect of the B_1 inhomogeneity. Such designs require the use of relatively few kz-spokes to correct for the mild B_1 inhomogeneity observed in the brain at 3T. At 7T however, B_1 inhomogeneity can be very large and many spokes are required for the correction, causing long RF pulse to be used. With the goal being a reduction of the number of k_z spokes, in this work we propose a novel method to optimally select (k_x,k_y) locations for the placement of the spokes.

Methods and Results: In the small tip-angle approximation [4], the RF pulse played out in k-space (weighted by the trajectory's velocity) is the Fourier Transform of the excitation profile. Amplitude modulated k_z sinc spokes placed at a number of (k_x,k_y) locations is a suitable trajectory for creating slice-selective excitation with in-plane modulation to counteract B_1 inhomogeneity. To correct for the inhomogeneity, the desired in-plane modulation is the inverse of the in-plane inhomogeneity. As shown in Fig. 1 (right), at 7T this desired modulation can contain rapid spatial variation when B_1 is highly inhomogeneous. The location and the number of spokes used in the design will determine the possible modulation that can be achieved. Conventionally, based on the sampling theorem, the spokes are placed with a separation of 1/FOV from each other around the origin so that aliasing is avoided. With this method, large number of spokes is required to create the desired modulation. Fig. 2 shows the result when 61 spokes placed in a spiral pattern around the origin are used for the excitation. The resulting RF pulse is far too long to be considered practical and the correction is sub-optimal. Keeping in mind that the main goal is to achieve a good in-plane modulation using a small number of spokes, a new design method for spoke placement is formulated as: $\min_{\Phi}(1-\lambda)\|m - F\Phi\|_2 + \lambda\|\Phi\|_1$ where: the m vector is the desired modulation at various x-y locations; the Φ vector is the spokes' complex amplitude at various (k_x,k_y) locations; the F matrix consists of $Ae^{j2\pi(k_x x+k_y y)}$ terms that transform the spokes' complex amplitudes into modulation in the in-plane excitation; and λ is a weighting factor. The first term is used to keep the resulting modulation from deviating from the desired one, while the second term is used to keep the number of spokes down. The weighting factor λ is used to control the relative importance of these two terms. The objective function of the above optimization problem is convex and can be solved using Second-Order Cone program. Refer to [5] for more details on the algorithm.

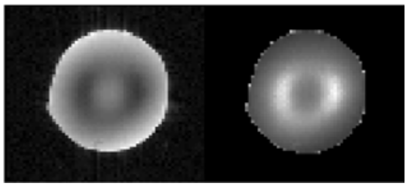

Fig1. B1 inhomogeneity in an agar phantom at 7T (left), and its inverse profile (right)

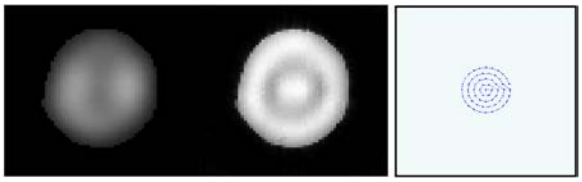

Fig2. Simulated results for spiral spokes placement (right), in-plane modulation (left), and corrected profile (center)

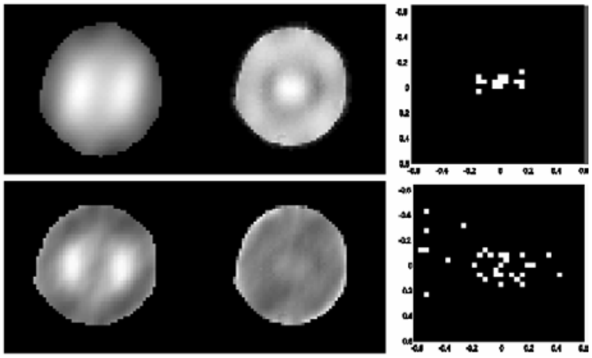

Fig3. Simulated result for sparse spokes placement with 15 (top) and 30 (bottom) spokes: in-plane modulation (left), corrected profile (center), spoke locations (right)

By varying the weighting factor λ, the number of spokes used can be controlled. Fig.3 shows the results when 15 and 30 spokes are used. First, note that in both cases, more spokes are placed at high frequency positions in kx rather than in ky. This makes intuitive sense, as the desired modulation profile contains higher frequency components in the x direction (i.e. the 2-peaks). It can be seen that the correction resulting from the 15 sparse spokes design already outperforms the correction from the 61 spiral spokes design. The modulation profile models the desired modulation better (especially at the 2 peaks), and as a consequence the corrected excitation profile is more uniform. With 30 spokes, the resulting profile is very uniform even in region where there were large dips in the B_1 profile. In Fig. 4 we explore why sparse spoke placement performs so well. In the conventional placement, spokes are placed at 1/FOV distance from each other so that aliasing does not occur (Fig. 4 left). This is not the case for sparse placement where aliasing is allowed (Fig. 4 right). The algorithm only cares about the modulation inside the phantom and allows for large artifacts in the region outside the phantom (which does not matter to us). With fast insert gradient hardware at 7T (max gradient amp of 70 mT/m and max slew of 700 T/m/s), the pulse duration for the 15 and 30 spokes design with 0.5 mm slice selective excitation (TBW = 4) would be ~ 6.5 ms and ~ 13 ms. These durations could be further reduced if short sinc pulses are used for the low amplitude spokes. **Conclusion:** A novel algorithm is proposed for the design of k_z spoke placement in 3D RF pulse for slice selective excitation with B1 inhomogeneity correction. Simulation results show that the algorithm outperform currently available design method, and could play an important role in correcting B1 inhomogeneity at very high field.

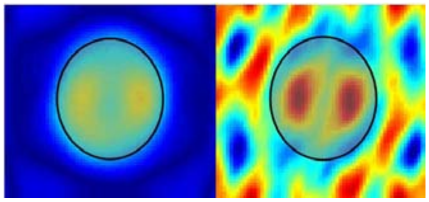

Fig4. Comparison between modulation profile from spiral and 30 spokes sparse placement

Support: Siemens Medical Solutions, P41RR14075, MIND Institute, US DoD NDSEG Fellowship, R.J. Shillman Career Development Award.

References: **1.** Ulloa J. et al, ISMRM, p. 21, 2005. **2**. Saekho S. et al, ISMRM, p.22, 2005. **3.** Setsompop K. et al, ISMRM, p.574, 2006 **4.** Pauly J. et al JMR 81:43-56 (1981) **5.** Zelinski A.C. et al "Designing fast 3-D RF Excitations by optimizing the number, placement and weighting of spokes in k-space via a sparsity-enforcement algorithm", submitted, ISMRM 2007.