An approach to 3-dimensional multi-band acquisition

Bruno Riemenschneider[1], Jakob Assländer[1], and Jürgen Hennig[1]
[1]*Dept. of Radiology, Medical Physics, University Medical Center Freiburg, Freiburg, Germany*

Introduction: The temporal resolution of fMRI measurements has increased significantly over the last years. Non-Cartesian single-shot trajectories permit a TR of only 100 ms for whole-brain acquisition [1], but are susceptible to strong off-resonance artifacts, and have not been realized for voxel sizes of less than $(3\text{ mm})^3$ because of the limitations in read-out time. Higher resolution can be achieved using 3D-acquisition in smaller sub-volumes [2,3] but lead to inhomogeneities at the interface between adjacent slabs if used in multi-slab mode for full brain coverage. Multi-shot sequences with multi-band excitation in conjunction with 2-dimensional EPI read-outs have shown to be feasible at TRs as low as 400 ms [4]. However, the latter method is restricted by the number of slices that can be resolved with parallel imaging techniques at an acceptable signal-to-noise ratio. In order to take the best of both approaches we suggest a method which combines multi-band excitation with a 3-dimensional read-out**.** This helps to overcome the limitations in number of excited slices, and still exploits the information of the coil sensitivities in all three dimensions. Furthermore, in comparison with slab-wise excitation and read-out, saturation effects influence each voxel in an identical manner and regional inhomogeneities in image intensity/contrast are avoided.

Approach: Using multi-band excitation pulses the volume of interest is excited as a stack of 2D planes along the slice direction. The thickness of each plane corresponds to the desired voxel size; the distance between planes is an integer multiple N_{seg}. The resulting non-contiguous volume covers only a fraction of $1/N_{seg}$ of the original volume. Consequently, data needs only to be sampled up to that fraction of the corresponding k-space of the original volume (Fig. 1). The measurement of the target volume in full resolution is achieved by repeating the process N_{seg} times with a shifted excitation until all voxels of interest have been excited. The full image then results from interleaving the reconstructed slices using the knowledge of their spatial position.

Methods: Sample measurements were performed on a 3T Tim Trio scanner using a 32 channel head coil array (Siemens, Erlangen, Germany) for signal reception. Coil sensitivities and off-resonance map were derived from a 2D multi-slice, multi-gradient echo image with $TR = 1\,s, TE_1 = 2.46\,ms$, $TE_2 = 4.92\,ms$. A full image of 64^3 voxels with a field of view of $(0.192\,m)^3$ was assembled from the reconstructions of 4 shots. During each shot 16 slices of 3 mm thickness and 12 mm distance between the centers of two neighboring slices were excited with a flip angle of 25 degree by algebraically superimposed pulses of shifted slices. For the 3-dimensional read-out we used a stack-of-spirals trajectory (fig. 2) with a linear varying reduction factor [1], $R_r \in [3, 6], R_z \in [3, 3.75]$, increasing from the k-space center, echo time $TE = 20.6\,ms$, and a dwell time of $5\,\mu s$. TR was chosen to be 400 ms, but could be optimized to below values below 300 ms. The data was reconstructed with MATLAB using a regularized reconstruction. The image x is found by using a conjugate gradient method to minimize the cost function $f(x) = \|Ax - S\|^2 + \lambda\|x\|^2$, where A is the forward operator implemented as a non-uniform FFT [5] including the coil sensitivities, and S is the signal of all coils. Off-resonance correction was applied in a time-segmented approach [6].

Results: Fig. 2 shows 30 adjoining slices from a reconstruction of 64 slices with a thickness of 3 mm. Every fourth slice results from the same shot. The reconstructed image shows susceptibility induced signal drop-out and distortions that are typical in sequences with long read-outs.

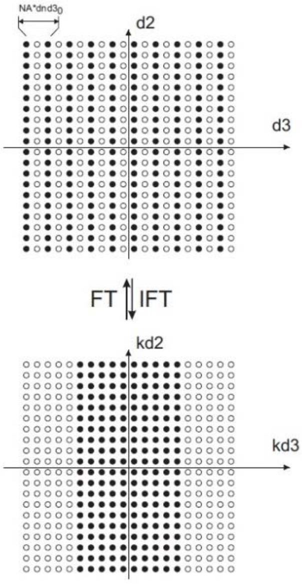

Fig. 1: Schematic view of the fourier relation between the multi-band excitation in image space (top) and k-space (bottom). The d1-direction is not shown; each vertical column of grid points therefore corresponds to one 2D-plane.

Discussion and conclusion: The feasibility of the new approach to multi-band 3D acquisition has been demonstrated. Further analysis has to be carried out to find the best compromise in order to achieve whole-brain acquisition with high spatial resolution at low TRs. Multi-band 3D-acquisition is not limited to ultrafast fMRI but can also be applied for methods like 3D-TSE(SPACE), MPRAGE and others.

References: [1] Assländer, J. et al, ISMRM 328 (2012) [2] Posse, S. et al., NeuroImage 61(1): 115-130 [3] Testud, F. et al., ISMRM 215 (2012) [4] Feinberg, D. et al., PLoS ONE 5(12): e15710 [5] Fessler, J., et al. IEEE T-SP, 51(2): 560-74 [6] Sutton, B., et al., IEEE Trans. Med. Imaging 22(2): 178-188

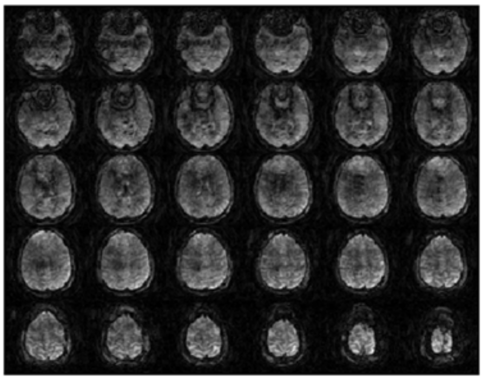

Fig. 3: 30 adjoining slices from the reconstruction of 64 slices with a thickness of 3 mm

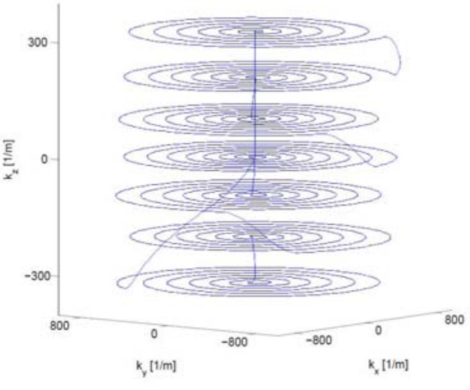

Fig. 2: Trajectory that was used for sample measurement. Note the different scaling of the k_z-axis.