Partial Fourier accelerated selective excitation improves pattern fidelity at 9.4 Tesla

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Introduction

Accelerating the process of k-space encoding has proven to be one of the major driving forces behind development of new methods for MRI signal acquisition and, subsequently, excitation. Nevertheless, acceleration techniques remain bound to obeying the Nyquist sampling theorem to prevent formation of artefacts. Localised excitation encoding has progressed with the development of Transmit SENSE [1,2], which transported receive SENSE [3] acceleration methodology to the transmit side of the MRI. Transmit SENSE, however, necessitates specialised and expensive hardware and brings with it a numerically challenging framework for pulse calculation and SAR considerations. A much discussed method of encoding acceleration, the partial Fourier paradigm (PF), has remained investigated only in 1 dimension in the shape of asymmetric slice excitation. This work presents new findings with adopted trajectories in 2 dimensions.

Materials and Methods

Note that the positions (x,y) and the spatial frequency (kx,ky) form a Fourier pair with both residing on identically sized matrices. Under this assumption, the relation between different opposite positions in k-space can be formulated as $S(\mathbf{k})=S^*(-\mathbf{k})$. If the excitation pattern is chosen to be real, i.e. all excited isochromats are aligned parallel to each other, one may exploit this symmetric property for excitation encoding. According to the small tip angle approximation [5], the excitation of magnetisation corresponds to depositing energy packets at k-space positions. If the excitation trajectory does not cross itself one, may formulate the resulting transverse magnetisation as

$$\mathbf{m}_{xy} = \gamma|\mathbf{m}_0| \int_{\mathbf{k}} \mathbf{p}(\mathbf{k}) e^{-i\mathbf{kr}} d\mathbf{k} \quad \text{where} \quad \mathbf{p}(\mathbf{k}) = \int_0^T \frac{\mathbf{b}_1}{|\gamma \mathbf{g}(\mathbf{t})|} ({}^3\delta(\mathbf{k}(t) - \mathbf{k}|\dot{\mathbf{k}}(t)|))dt$$

If one chooses $\mathbf{m}_{xy}$ to be real by design, conjugate symmetry applies. A spiral trajectory was designed with nearly constant speed along the trajectory over the excitation window [6] (Fig 1). It encodes a field-of-excitation of 256mm covered by a 64x64 excitation matrix to excite a pattern with different flip angles (Fig 2/3). Two applications were investigated which are expected to be beneficial from encoding optimisation techniques: i) gaining pattern fidelity within an identical encoding time and ii) gaining excitation acceleration with identical pattern fidelity. An oil phantom was used for experiments in a 9.4T human MRI scanner with a single channel birdcage coil to demonstrate, in particular, the advantages of PF under low T_2* regime.

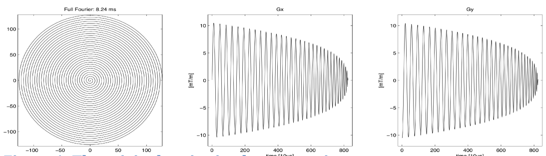

Figure 1: The original excitation k-space trajectory

Results

Pattern-fidelity gain achieved by only shifting the excitation window to the top left corner of the k-space is clearly visible (Fig 2). One can hardly make out a difference to excitations with higher pattern matrices. The higher pattern fidelity comes at the price of higher RF amplitude integrals. The amplitude integrals climb for each shift of 1/8 of k_{max} to 1.1, 1.2, 1.3 and 2 fold before the coverage of the k-space centre is not effective enough to excite the pattern. Excitation acceleration could be gained decreasing the excitation window towards one corner of k-space (Fig 3). For 4/5, 3/4, 2/3, 1/2 and 2/5 Fourier coverage, acceleration shortens the excitation from 8.24 ms to 6.95, 6.66, 6.09, 4.93 and 4.16 ms. Once again, whilst the amplitude integrals of the excitations increase as a function of shorter excitation k-space walks by factors of 1.1, 1.3, 1.6, 2.0 and 2.5 times of the conventional full Fourier excitation.

Discussion

Partial Fourier, spatially-selective excitation is a potential which has thus far remained neglected. This work has shown that PF works very well for the excitation module in MRI sequences. Investigation of its potential for 3 dimensional patterns remains to be investigated together with transmit SENSE. This excitation technique will gain importance with lower T_2* as some patterns, especially high resolution, might be the only doable ones. It was demonstrated that under a short T_2* regime selective excitations gain considerably from partial Fourier excitations.

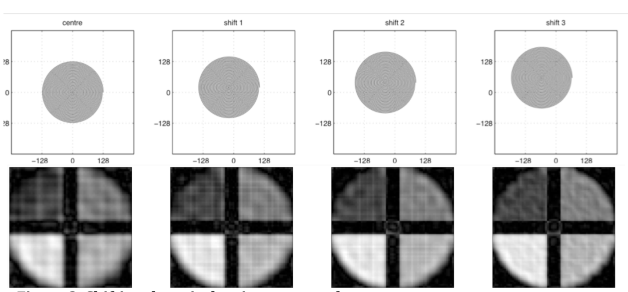

Figure 2: Shifting the spiral trajectory out of centre

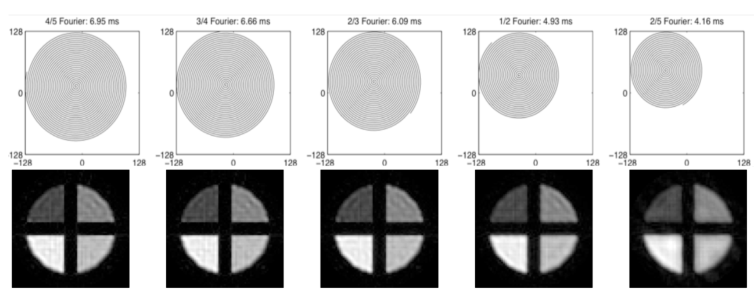

Figure 3: Pushing the limits of acceleration

[1] Pauly et al, JMR 81(1), 1989, pp42-53 [2] Katscher et al, MRM 49(1), 2003, pp144-50 [3] Zhu, MRM 51(4), 2004, pp775-84 [4] Block et al, JMRI 21(6), 2005, pp657-68