Parallel Excitation Experiments Using Measured k-Space Trajectories for Pulse Calculation

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Introduction

The excitation accuracy in many applications of spatially selective excitation is limited by experimental imperfections such as B_0 inhomogeneity, relaxation effects or deviations of the excitation k-space trajectory due to non-ideal gradient coils or eddy currents. For the first two mentioned problems the concept of Parallel Excitation (PEX) [1,2] provides excellent means to reduce their impact by shortening the duration of the excitation pulses [3]. However, deterioration of the excitation pattern related to k-space trajectory deviations persists when moving from conventional spatially selective excitation to PEX. One possible method to cope with such trajectory deviations for small-tip-angle pulses was presented in [4]. In the present study it is shown for PEX experiments that experimentally measuring the k-space trajectory, as it is actually played out by the MRI system, and calculating the PEX pulses based on the measured trajectory is a very effective and convenient way of removing trajectory deviation related degradation of the excitation pattern without the need to perform tedious prospective trajectory calibration and subsequent correction steps.

Methods

This study was performed on a 4-TX-channel 9.4 T, 20 cm bore BioSpec system (Bruker BioSpin MRI, Ettlingen, Germany) in combination with a 4-element TX/RX volume array and a cylindrical bottle-phantom with T_1-doped saline water solution. As a *k*-space trajectory, a constant density constant angular velocity spiral was chosen. The trajectory measurement was carried out using a variant of the method described by Zhang et al. [5]. In this approach each spatial component of the *k*-space trajectory (e. g. the *x*-component) is measured by subsequently exciting thin slices at two positions +*x* and -*x* and by acquiring the FID signals generated by the spins when the corresponding component of the *k*-space trajectory is simultaneously played out by the gradients. The phase evolutions $\Phi_{+x}(t)$ and $\Phi_{-x}(t)$ of these two FID signals can be approximated by an expansion up to the second spatial order: $\Phi_{\pm x}(t) = \Phi_0(t) \pm k_x(t)\cdot x + \Phi_2(t)\cdot x^2 + O(x^3)$. The second term in this expansion is the desired phase generated by gradient action. The other terms account for experimental imperfections such as eddy currents which can also affect the gradient term. By means of these two expressions the course of the *k*-space trajectory can be approximately calculated from the unwrapped phases of the FID signals as follows:

$$k_x(t) \approx \frac{\Phi_{+x}(t) - \Phi_{-x}(t)}{2x}$$

The PEX pulses in this study were then generated using the direct inversion technique by Grissom et al. [6] where the measured *k*-space trajectory values were used to set up the transition matrix between the RF pulse shapes and the excitation pattern. Signal acquisition was performed with a RARE sequence with a PEX module for excitation and B_1-shimmed refocusing pulses.

Results

Figure 1 shows a comparison between two PEX experiments (acceleration factor 2) where in the first case the pulse calculation was based on the theoretically expected course of the *k*-space trajectory and in the second case on its experimentally measured course. The deviations between the theoretical and the measured *k*-space trajectory are depicted in Figure 2. It is clearly visible that due to non-ideal gradient behaviour the experimentally measured trajectory has a reduced extent and an increased radial density in *k*-space which leads to a decreased spatial resolution and an enlarged field of excitation. This results in an incorrectly increased scale of the excitation pattern (Fig. 1b) generated with a PEX pulse based on the theoretical trajectory. Furthermore, the trajectory shows some slight distortions which in turn lead to distortions of the excitation pattern. As demonstrated by Figure 1c, these imperfections of the excitation pattern can be effectively avoided by basing the pulse calculation on the measured trajectory. The excitation pattern generated by such a pulse features significantly better congruence with the target pattern.

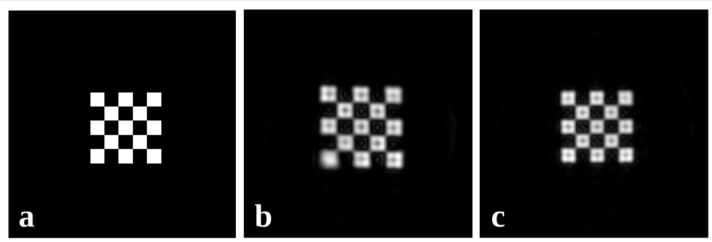
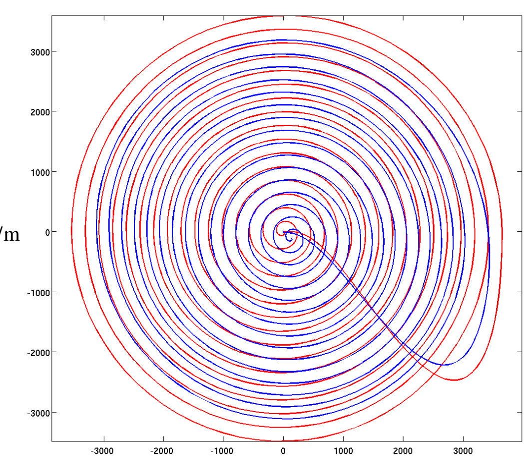


Fig. 1: Parallel Excitation of a chequerboard target pattern (a) by using a PEX pulse based on the theoretical (b) and the actually measured (c) course of the k-space trajectory.



k_y / 1/m

k_x / 1/m

Fig. 2: Theoretical (red) and experimentally measured (blue) course of the k-space trajectory

Discussion and Conclusions

This study shows that using measured *k*-space trajectories for the calculation of PEX pulses is an effective tool for avoiding degradations of the excitation patterns due to gradient imperfections and consequential *k*-space trajectory deviations. The measured course of the *k*-space trajectory can be easily integrated into the PEX pulse generation by using Grissom's et al. calculation algorithm. However, the trajectory measurement approach presented above is only an approximation which neglects the additional B_0 phase component generated by gradient action and components of higher spatial order. The determination of these additional contributions and their integration into the pulse calculation could help to further increase excitation accuracy.

References

[1] Katscher et al., MRM 49:144-150 (2003)
[2] Zhu et al., MRM 51:775-784 (2004)
[3] Ullmann et al., MRM 54:994-1001 (2005)
[4] Ullmann et al., Proc. ISMRM 2007, p. 672
[5] Zhang et al., MRM 39:999-1004 (1998)
[6] Grissom et al., MRM 56:620-629 (2006)

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