Novel 2DRF optimization framework for spatially selective rf pulses incorporating B1, B0 and variable-density trajectory design

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Introduction: Spatially selective pulses based on a rectilinear EPI trajectory (2DRF) have been recently widely used for reducing the total acquisition time in functional imaging und thus, reducing the impact of susceptibility effects and motion artifacts. At the same time, high resolution images are achievable with a reduced-FOV due to the decreased number of phase encoding steps (1-3). To date 2DRF pulses are - in the majority of studies - analytically calculated based on the low tip angle approximation (4) resulting in a sinc-shaped magnitude modulation of the 2DRF sub-pulses. However, 2DRF pulses are still known to be sensitive to off-resonance and B1 effects resulting in strong geometric distortions and inhomogeneous excitation.

The aim of this work is firstly to introduce a 2DRF pulse optimization framework, which significantly improves the excitation accuracy by taking B1 and B0 information into account. Secondly, a novel k-space trajectory design is proposed to further improve the geometric distortion correction due to off-resonance. The proposed methods are evaluated with simulated and experimental data.

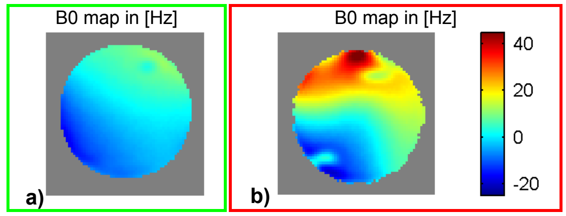

Figure 1: B0 maps in phantom experiments with *a)* **weak and** *b)* **strong off-resonance.**

Methods: The 2DRF pulse optimization scheme follows the spatial domain design approach of ref. (5,6) assuming the low flip angle regime. The resulting minimization problem, i.e. a system of linear complex equations, holds information about the prevailing B0 and B1 maps, k-space trajectory and spatial properties and has to be numerically solved for a desired magnetization pattern for designing the appropriate rf pulse. Within the 2DRF pulses, optimization was done in the PE excitation direction, scaling the sub-pulses in the fast direction (SS) within the optimization. For long 2DRF pulses in presence of strong off-resonance it is however still challenging to correct the accrued phase errors. To further tackle this effect, a rectilinear k-space trajectory with variable density in PE direction is introduced, which allows an additional compensation of off-resonance based geometric distortions by incorporating the B0 map information into the k-line density distribution.

All phantom experiments were conducted on a 3T MAGNETOM Skyra system (Siemens, Erlangen, Germany). By imaging near an air bubble, strong off-resonance effects are introduced. B0 maps were estimated from two GRE images (**Fig. 1**). B1 maps were obtained according ref. (7). Reduced FOV EPI images were acquired using a single-shot gradient echo EPI sequence with FA = 15°, resolution = 3x3x5 mm^3, FOV = 192x38 mm^2, TR = 1000 ms, TE = 46 ms. 2DRF pulses with a total pulse duration of 54 ms and field of excitation of 300 mm were designed in an EPI flyback scheme in order to avoid side-lobes and transmit ghosts within the FOV. The excitation performance of analytically designed and optimized 2DRF pulses was assessed via the root mean square error (RMSE) between the target magnetization pattern and Bloch simulations. In case of the experimental data the mean signal intensity of the ROI was matched to that of the simulation prior to the RMSE calculation.

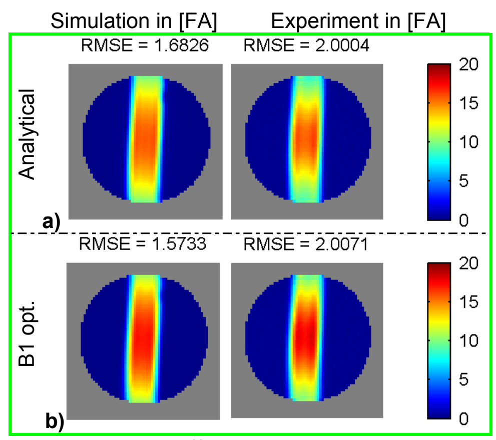

Figure 2: Weak off-resonance with *a)* **analytical design to** *b)* **B1 optimized 2DRF.**

Results: The simulated and experimental results of different 2DRF optimization schemes are shown in **Fig. 2** and **Fig. 3**. For the weak off-resonance experiment (**Fig. 2**), the B1 optimized 2DRF pulse (bottom) shows in practice quite improved excitation homogeneity compared to the analytical one (top). In case of strong off-resonance (**Fig. 3**) severe geometric distortions from the rectilinear shape can be observed due to the accrued phase error during the pulse. An incorporation of the B0 map improves the excitation by 7% lower RMSE, but is only partially able to compensate the deformation (**Fig. 3b**). However, if the B1/B0 optimization is further combined with the novel EPI excitation trajectory design (incorporating the off-resonance into a variable density) an *additional gain of 24%* lower RMSE in excitation accuracy can be observed (**Fig. 3c**).

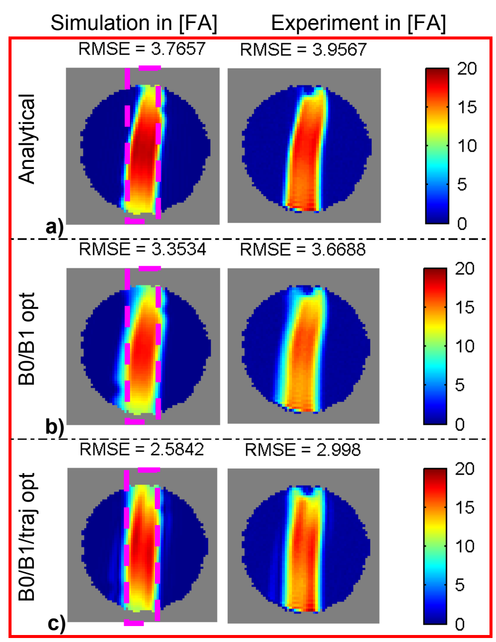

Figure 3: 2DRF excitation with strong off-resonance *a)* **analytical,** *b)* **B1/B0 optimized** *c)* **B1/B0/k-space trajectory optimized design.**

Conclusions: In this work, a new optimization framework for 2DRF pulses was introduced. The B1 and B0 optimized 2DRF pulses outperform analytically calculated pulses with respect to accuracy. In case of strong off-resonance the geometric distortion can be only partially corrected. We found that a variable density k-space trajectory design driven by the B0 information can achieve significant gains. In total, additional improvements of up to 24% were observed in simulation and actual experiments, which is significant for MR applications.

References:

1. Rieseberg et al., MRM 47:1186-1193, 2002. **2.** Ellingson et al., Proc of 19th ISMRM:404, 2011. **3.** Zaharchuk et al., AJNR 32:813-820, 2011. **4.** Pauly et al., JMR 81:43-56, 1989. **5.** Grissom et al., MRM 56:620-9, 2006. **6.** Setsompop et al., MRM 59:908-915, 2008. **7.** Fautz et al., ISMRM:1247, 2008.