

Shaped Saturation with RF Power Efficient 2D Spatially Selective Spiral Design in Parallel Transmission

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Target Audience: RF engineers and MR physicists. **Purpose:** Localized suppression of signals in clinical imaging is often required to avoid motion and aliasing artifacts along the phase-encoding direction, e.g. the suppression of inner organs in sagittal spine imaging. A suitable solution is the application of multidimensional spatially selective saturation radiofrequency pulses in combination with parallel transmission (pTX). This combination can enable anatomically shaped saturations with shortened and off-resonance compensated RF pulses. However, the proper design in human in-vivo experiments is still challenging due to practical RF hardware and SAR constraints and has not been realized, yet.

In this work we for the first time realize shaped saturation in human in-vivo experiments on the basis of spatially selective saturation pulses with pTX at 3T. For this purpose, we introduce a 2D variable-density spiral trajectory design incorporating the a-priori target pattern and available B1 magnitude information, which inherently enhances RF power efficiency and spatial response of the RF pulses. This design is further compared to a variable-density sampling scheme (VD) saturating shaped patterns in the brain and thoracic spine.

Methods: The proposed target-driven (TD) trajectory design is based on the recently introduced approach presented in (1) and further improved and specified for a 2D spiral pTX trajectory. Basically, the method directly computes an analytical k-space density metric, which is used to determine the geometric sampling density and sampling velocity of the spiral. In this sampling strategy, solely k-space regions are considered which contribute to the desired target pattern \mathbf{m} . Those k-space regions are further weighted with a spectral-spatial window to optimize the balance of spatial accuracy and the RF power expense. Particularly, the window width of the weighting window controls the focus of the k-space sampling towards k-space center versus the outer k-space regions encoding the spatial details of the target pattern. In this study, a Hanning window function was chosen to weight the k-space regions of interest. Its window width α was determined by an empirically found linear functional relationship taking the available mean B1 magnitude over all TX

channels $b1_{mean}$ and pattern size A_m into account: $\alpha = b1_{mean} \cdot (\frac{\beta}{A_m} + \gamma)$. The functional parameters β and γ were calibrated via linear regression to optimally chosen α values of multiple simulations with varying α based on datasets from different anatomical positions. Potential benefits of the TD design compared to a VD sampling scheme (2) are shown in two human in-vivo shaped saturation experiments. First, a checkerboard pattern was saturated in a sagittal brain slice (FOV 240x240 mm²) to highlight the spatial fidelity of the two trajectory designs. Second, a sagittal spine-shaped saturation was applied in the t-spine (FOV 300x300 mm²) to point out the RF power efficiency of the RF pulses. Images were acquired on a 3T MAGNETOM Skyra (Siemens, Erlangen, Germany) with a two-channel whole-body transmit array using a prototype gradient echo sequence with matrix = 256x256, TR/TE = 100/10 ms and GRAPPA acceleration factor 2. RF pulses were 1.4-fold accelerated and optimized following the small-tip-angle approach of (3) leaving the frequency response uncontrolled. No additional high-flip optimization strategy was applied. RF pulses were further regulated to stay within RF hardware and SAR constraints. Local/global SAR handling was done using the commercially implemented SAR supervision of the scanner.

Results/Discussion: Exemplary VD and TD 2D spiral trajectories for an elliptical target pattern are shown in Fig. 1. Clearly, the TD design aligns well with the Fourier representation of the target pattern. The corresponding sampling histogram over k-space shows a localized sampling of specific k-space regions. In contrast, the VD design shows a center-focused coverage and sampling of the k-space. The results of the human in-vivo experiments are depicted in Fig. 2. Bloch simulations and experiments match well for areas containing water. Residual signals were found in fat-containing areas due to the single-band RF optimization strategy. In both imaging scenarios, the TD-trajectory-based shaped saturation pulses showed superior results compared to the respective VD pulses. The TD offered either enhanced spatial accuracy (Fig. 2a) or a higher magnetization/saturation level (Fig. 2b, bottom) under given RF hardware and SAR constraints. Root-mean-square errors (RMSE) to the target pattern revealed a relative improvement by 20% (brain) and 31% (spine) compared to the VD approach.

Conclusion: The target-driven trajectory design (TD) enables increased RF power efficiency and spatial accuracy by incorporating the a-priori information of the target pattern and available B1 magnitude. Thus, RF pulses can be generally designed more efficiently and further accelerated. Based on the proposed approach, we could realize shaped-saturation human in-vivo experiments for the first time. The TD pulses showed improved spatial fidelity and saturation performance compared to the default variable-density trajectory design.

References: [1] Schneider et al. (2013). Proc. ISMRM 21:4261. [2] Liu et al. (2008). MRI 26:1122-1132. [3] Setsompop et al. (2008). MRM 60:1422-1432.

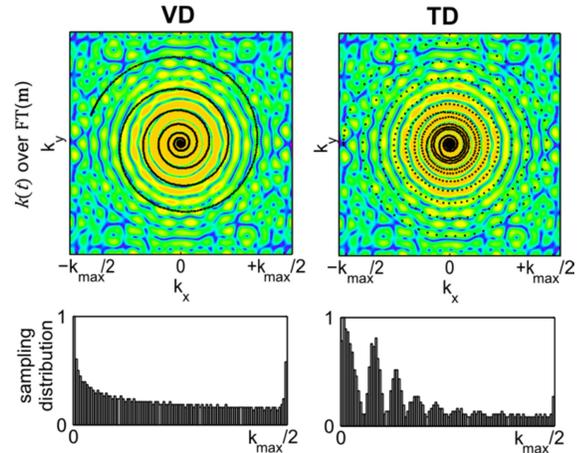


Figure 1: 2D spiral designs for an elliptically shaped target pattern. Top row shows the Fourier transform of the target pattern overlaid with VD and TD spiral trajectory. Bottom row: sampling distribution histogram over k-space.

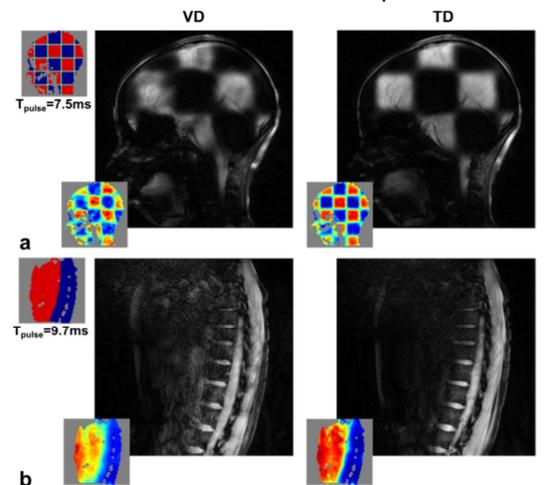


Figure 2: a Sagittal head with checkerboard pattern. b Sagittal t-spine with spine-shaped pattern. Target pattern and pulse durations are stated in the upper left corner. Bloch simulations are attached at left corner of each image.