Combination of Basic and Tailored RF Shimming using Curved Spoke Trajectories

U. Katscher[1], and P. Börnert[1]
[1]Philips Research Europe, Hamburg, Germany

Introduction In principle, two different approaches are reported to diminish wave propagation effects, and thus, improve B1 homogeneity with parallel transmission. The first approach is given by "basic" RF shimming, adjusting amplitude and phase of the different transmit channels to obtain a homogeneous B1 distribution [1]. The second approach is given by "tailored" RF shimming, i.e., multidimensional RF pulses aiming for a constant overall B1 energy, with a k-space trajectory potentially shortened by a suitable interplay of the sensitivities of the different channels [2-5]. Basic RF shimming is a stable and fast method, however, with limitations in flexibility and shimming potential. Tailored RF shimming is a more complex approach requiring significant modifications of the applied sequence, however, with superior flexibility and shimming potential. The method investigated in this study tries to form a compromise, which combines the advantages of both approaches. It applies a slight curvature of the "straight" k-space trajectory given by standard slice selective excitation, maintaining short RF pulse durations, and sharp slice profiles. Simultaneously, this method allows a higher freedom for (low-resolution) in-plane variation of B1, leading to an enhanced shimming potential.

Theory Standard slice selective excitation corresponds to a straight line (or "spoke") in the excitation k-space, reflecting a sharp through-plane profile (z-direction) and no in-plane variations (x/y-direction). In this study, this straight spoke along z will be slightly curved in the transverse x/y-direction, enabling a smooth in-plane excitation profile. In principle, the curvature can be arbitrary, however, calculations can be facilitated by suitable parameterization of the curvature like

$$k_T(k_z) = A \sin(2\pi f k_z / k_z^{\max} + \varphi) \ . \qquad (1)$$

Here, A is the curvature amplitude, f the curvature frequency, and φ the curvature offset. Furthermore, the 2-dimensional curvature as described by Eq. (1) can be extended to the third dimension by a “twist” angle τ and a rotation ζ around k_z

$$k_x(k_z) = k_T(k_z) \cos(\tau k_z / k_z^{\max} + \zeta) \ , \qquad (2)$$

$$k_y(k_z) = k_T(k_z) \sin(\tau k_z / k_z^{\max} + \zeta) \ . \qquad (3)$$

Given the target excitation pattern (typically a constant slice with the desired orientation and off-center position) and the (3D) sensitivity distributions of the N available transmit channels, the RF pulses for the different transmit channels can be calculated via a Transmit SENSE method [2-4]. The curvature's parameters can be optimized with respect to achieve maximum correlation between expected and desired excitation pattern.

Methods A 5 liter bottle with doped water was investigated using a Philips Achieva 3T system (Philips Health Care, Best, The Netherlands) equipped with multiple, independent transmit channels [6]. Four B1 maps were measured using "Actual Flip angle Imaging" [7] with TR1/TR2 = 20/100 ms, α = 60°, and 48×48×18 voxels with size = 4×4×10 mm³. A slightly offcenter transverse slice was chosen as the target excitation pattern. The curvature of the k-space trajectory was optimized using the trajectory parameterization Eqs. (1-3) and RF pulses calculated via [2]. The resulting excitation patterns were compared with basic RF shimming, i.e., a curvature amplitude of A = 0.

Results For the investigated example scenario, the optimal parameters for the trajectory’s curvature are A = 0.7 Δk_T, f = 0.38, φ = 9°, τ = 30°, and ζ = 60°. Thus, the trajectory goes roughly through the center of the k-space as expected, and the in-plane curvature of roughly one pixel is relatively small (Fig. 1). Excitation patterns for "basic" and "curved spoke" RF shimming are compared in Figs. 2,3. The in-plane variation reduces from a normalized root-mean square error (NRMSE) = 14.2% to 5.7% (Fig. 2). The through plane profile is found to be deteriorated only slightly (Fig. 3).

Discussion / Conclusion RF shimming using "curved spoke trajectories" introduces degrees of freedom, which seems to be able to improve RF shimming results. The resulting RF pulses have approximately the same length as standard slice selective pulses, thus eliminating the need of modifying sequence timing as is the case for tailored RF shimming.

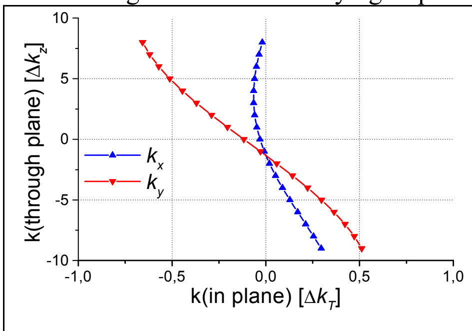

Fig. 1: Spoke trajectory with curvature optimized for the scenario of Fig. 2,3.

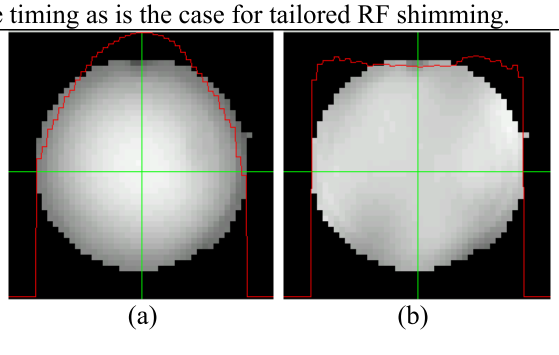

Fig. 2: In-plane excitation pattern for (a) no curvature (NRMSE = 14.2%), (b) optimized curvature (NRMSE = 5.7%)

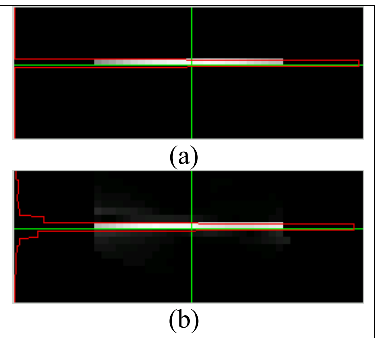

Fig. 3: Obtained slice profile for (a) no curvature, (b) optimized curvature

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