Spatial selective excitation performance of parallel transmission using a 3x8 Z-stacked RF coil array at 3T

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Target audience: RF engineers and MR physicists. **Purpose:** Recently it has been shown that B1 shimming and SAR performance can be significantly improved with increased number of RF transmit coils (1,2). These studies were limited to transversal imaging planes which are geometrically aligned with the parallel transmit (pTX) array arrangement and thus can fully exploit the available degrees of freedom (DoF). For sagittal and coronal RF shimming a Z-encoded parallel transmit array has been shown to be superior to the commonly used in-plane pTX coil geometry (3). However, the performance of the different coil configurations regarding spatially selective RF pulses (SSP) as a function of the TX acceleration factor has not been evaluated, which is important for many applications, e.g. to shorten echo time and for the management of off-resonance effects.

The goal of this study is firstly to analyze the performance of different pTX coil configurations for body imaging at 3T with respect to SSP. Secondly, to investigate different TX acceleration factors. Thirdly, to study the coil performance both for sagittal and transverse imaging applications. For this purpose, simulations were performed for single-row 8 and 24ch arrays and a Z-stacked 3x8 TX channel array. We compared the excitation error, RF peak voltage and overall RF power.

Methods: B1+ fields were simulated based on the three different pTX coil configurations, i.e. in-plane 8 TX channels (1x8ch), in-plane 24 TX channels (1x24ch) and three Z-stacked rings of 8 TX channels each (3x8ch, see **Fig. 1a**), similar to the approach of ref. (2): All arrays were based on a cylindrical body coil geometry and were loaded with a realistic body model (1 mm isotropic resolution, 33 tissue types, the coil isocenter placed on the liver). Simulations were performed with using the co-simulation strategy described in (2). Based on the respective B1+ maps of all TX channels, 2D SSP were calculated using the spatial domain design approach in (4). In order to study the performance of the TX arrays for a variety of slice positions and orientations, SSP pulses were designed for imaging *a) the central sagittal slice* (parallel to the B0 field axis of the scanner), *b) the central transversal slice* (contained in the central row of the 1x8ch, 1x24ch and 3x8ch pTX coils). For both *a)* and *b)* target magnetization patterns were anatomically-shaped saturation patterns within the low flip angle regime (**Fig. 1b,c**). SSP were designed using a dual-density spiral trajectory with the k-space center area 5 times oversampled to balance RF power deposition. In both cases the field of excitation was set to match the actual FOV of 305x400 mm^2 (sagittal) and 400x600 mm^2 (transversal). Excitation resolution was 5 mm. The maximum RF peak voltage and total RF power were calculated as required for protection of the RF hardware components and as an indirect indicator of global SAR. Two different RF pulse optimization schemes were used to analyze the performance of the different coil configurations: First, optimization was done without any further constraints or damping (free optimization) in order to highlight the inherent optimization effects and benefits. Second, the optimization process was modified via dynamic RF power regularization to match a fixed magnetization error resembled by a predefined root mean square error (RMSE) to the target magnetization pattern (fixed RMSE). This scheme corresponds to one specific point on an L-curve describing RF power vs. fidelity. It allows a direct comparison of the RF hardware efficiency and potential SAR level for an equal RMSE = 1. All scenarios were repeated for different pulse acceleration levels by systematically reducing the number of spiral turns up to a TX acceleration factor R~8. RF pulse durations decreased from approx. 10 ms / 14 ms (R=1) to 1.4 ms / 1.8 ms (R=8) for the sagittal / transversal direction. Excitation quality was assessed via numerical Bloch simulations based on an isotropic 5 mm grid, i.e. 61x80 sagittal and 80x120 transversal.

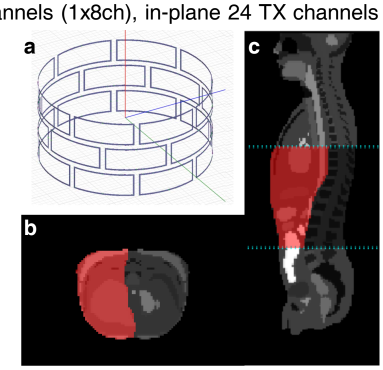

***Figure 1: a)** Z-stacked 3x8ch pTX coil configuration. **b-c)** Slices of model with corresponding target patterns (overlaid in red). **b)** central transversal slice. **c)** central sagittal slice.*

Results: **Fig. 2** shows the performance results for the sagittal scenario. The 3x8ch coil configuration always yields significant lower RF power/peak voltage metrics independent of the optimization scheme. The effect becomes increasingly prominent with larger acc. factors R (see fixed RMSE, **Fig. 2** right). Inherently it also provides the lowest excitation error (RMSE, free optimization, **Fig. 2** left). The 1x24ch and 1x8ch setup have similar trends except for the noteworthy increased RF power demand of 1x24ch within free optimization (up to +750% compared to 1x8ch). For transversal slice orientation we obtained quite similar RSME and RF peak voltages for all coil configurations independent of the optimization scheme. Only slight differences regarding RF power efficiency were observed. The 3x8ch coils, however, showed again the lowest RF power deposition in all scenarios.

Discussion/Conclusions: Increased number of TX channels in-plane (1x24ch) showed generally no significant gain in excitation quality for spatial selective pulses compared to the 1x8ch configuration, but substantially increased forward RF power. These results are in agreement with the RF shimming performance in (1,2). The Z-stacked coil setup 3x8ch showed a considerable gain in hardware efficiency (up to 93% less RF power and 65% less RF peak voltage than best 1x24ch/1x8ch values for equal RMSE) and excitation performance (up to 45% less RMSE in free optimization) along the sagittal direction getting most exhibited for high acceleration. Thus, compared to the other coil designs, SSRF pulses can be calculated more efficiently and can be further accelerated, which is important in practice to stay within RF hardware limits and to reduce off-resonance effects. Interestingly, also a gain in RF power efficiency could be observed for 3x8ch in transversal direction (19% less RF power for fixed RMSE). Statements about concrete SAR behavior purely based on RF power deposition are not possible and need further investigation, since high TX channel configurations potentially could exhibit an inverse relation between the two metrics (1,2). In our study we found that Z-stacked coil arrangements enhance excitation performance and efficiency for arbitrary anatomical directions.

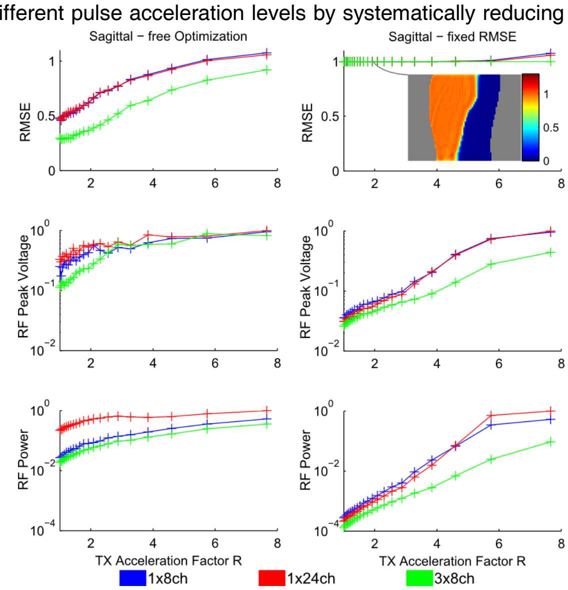

***Figure 2:** Simulation results of both optimization schemes (left free optimization, right fixed RMSE) for sagittal direction. 2D spatial selective RF pulse performance metrics for different coil configurations are noted as a function of TX acceleration factor R. Mind: RF power and RF voltage metrics have a logarithmic scale and were normalized to the overall maximum value. Exemplary a normalized flip angle map of the 3x8ch excitation for RMSE=1 is shown.*

References: [1] Harvey PR (2010). Proc. ISMRM 18:1486. [2] Guerin B (2012). Proc. ISMRM 20:2612. [3] Wu X (2012). Proc. ISMRM 20:0638. [4] Setsompop K (2008). MRM 60(6):1422-1432.