RF Elements with Switching Transmit Sensitivities Allow For Improved Flip Angle Homogeneity in 400 MHz UHF MRI

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Purpose

To investigate the effect of fast switching transmit sensitivities on flip angle homogeneity in ultrahigh field MRI

Introduction

The concept of rapidly reconfigurable radio frequency (RF) receiver elements for ultrahigh field MRI has been shown to offer improved parallel imaging performance [1]. In this simulation study, a first attempt is made to use fast switching coaxial dipoles for transmission. In contrast to the receive application, the use of fast switching transmit coils is aimed at improving the flip angle homogeneity, which is one of the major challenges in ultrahigh field MRI.

Methods

An array of eight 19 cm long coaxial dipoles was designed, closely folowing [2]. Similar to [1], each end was equipped with a circuit that could be switched between inductance and capacitance. This biased the current distribution in the dipoles toward the inductive end, resulting in a spatial shift of the B_1^+ sensitivity in the same direction. Experimental validation of the concept was done with a single element at 9.4 T (400 MHz). For reference, a similar array was simulated using conventional coaxial dipoles without the switchable elements. Simulations were performed for 400 MHz in CST Studio using the Duke voxel model and resulted in 3 sets of sensitivity profiles: "up" and "down", where all sensitivity profiles were shifted in the cranial/caudal direction (**Figure 1**), and "reference" for a symmetrical dipole.

A homogeneous flip angle distribution of 10° throughout the brain was chosen as the optimization target. The normalized root mean square error (nRMSE) of the obtained flip angle distribution was used as a quality metric. The optimization was performed similarly to the spatial domain method [3] using the variable exchange method [4] to solve the magnitude-least-squares problem with 20 iterations on an unregularized minimization.

Both single-channel operation in circularly polarized (CP) mode and 8-channel pTx operation were tested. For the switchable array, fast switching during the pulse was implemented by changing the coil profiles from "up" to "down" configuration after half the excitation time. In this case, magnitude and phase were optimized for each subpulse.

For CP mode operation, one (reference) or two (fast switching) global magnitudes and phases were calculated. For pTx operation, one or two RF shims were calculated instead. A 2-kT point excitation was also evaluated for both modes. The k-space location of the first kT point was chosen by randomly generating 10,000 k-space positions in the range $-14\,m^{-1} \leq k_{x,y,z} \leq 14\,m^{-1}$ and selecting the one that gave the best performance for the given scenario. The second kT point was positioned in the center of the k-space.

Results

For CP mode operation, switching between the two coil sensitivities only improved the nRMSE from 32.47% to 30.08%. When using kT points, switching improved the nRMSE from 28.15% to 16.75% (**Figure 2**). **Figure 3** shows the flip angle distribution for the pTx case. Here, the single excitation pulse also benefited from fast sensitivity switching, as the nRMSE decreased from 29.47% to 19.08%.

Discussion

The introduction of transmit elements with rapidly switchable B_1^+ sensitivities appears to allow for a significant reduction in flip angle inhomogeneity in ultrahigh field MRI. The switchable array achieved FA homogeneity in CP mode that approached the performance of a conventional array using parallel transmission. Similar to the observations made with reconfigurable Rx elements, switching between different Tx sensitivity patterns within a single element can be seen as a way to effectively emulate a larger number of independent virtual Tx elements. When comparing the cost and technical complexity of both systems, it becomes clear that the use of rapidly switchable B_1^+ sensitivities in transmit elements should be further investigated.

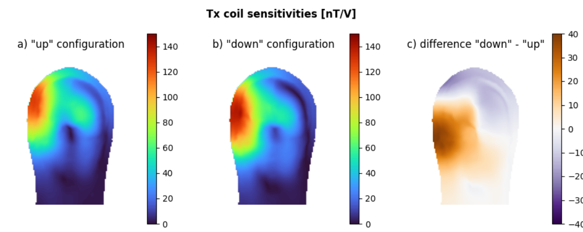

Figure 1: Coil sensitivity of the "up" and "down" configuration of a single switchable transmit element (**a** and **b**) and their difference (**c**) in nT/V.

Conclusion

This study did not investigate differences in energy deposition between the two arrays. It is still unclear how the SAR distribution changes between the two switched configurations. In addition, in order to use such an array efficiently, a method of SAR monitoring that takes into account the current switching state needs to be developed. Integrating this into existing MR scanners may be a non-trivial task.

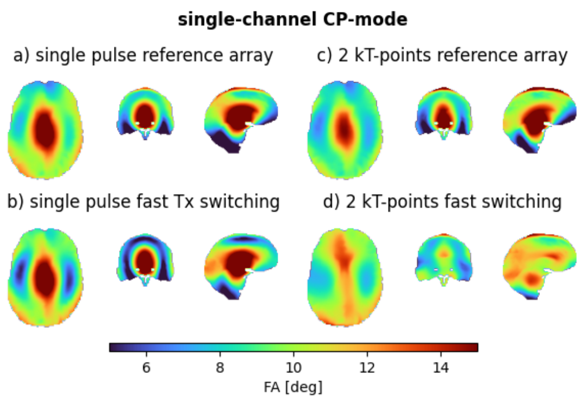

Figure 2: In CP mode, fast Tx switching for a single pulse reduced the nRMSE from 32.47% to 29.90%. Using 2-kT points, fast switching reduced the nRMSE from 28.11% to 16.35%.

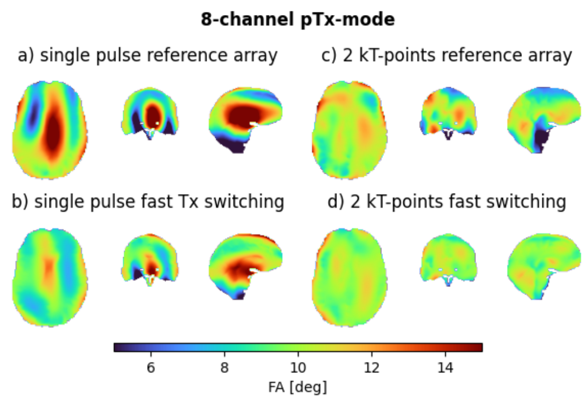

Figure 3: In pTx mode, fast Tx switching for a single pulse reduced the nRMSE from 29.47% to 19.08%. Using 2kT-points, fast switching reduced the nRMSE from 15.80% to 7.27%.

References

[1] G.A. Solomakha et al 2023; ISMRM #5070; [2] G.A. Solomakha et al 2023; ISMRM #1061; [3] W. Grissom et al 2006; Magn. Reson. Med., 56: 620-629.; [4] K. Setsompop et al 2008; Magn. Reson. Med., 59: 908-915.