Comparison of multi-element RF coil designs for 3D spatially selective excitation

T. Nielsen[1], P. Börnert[1], U. Katscher[1], and I. Graesslin[1]
[1]Philips Research Europe, Hamburg, Germany

Introduction

Multi-element RF excitation is of high interest to accelerate RF pulses for spatially selective excitation and B_1 shimming [1]. Coil design has a significant impact on the extent of pulse acceleration, i.e., the encoding capability of a transmit array. Therefore, we investigated the performance of different multi-element coil designs with a special focus on 3D excitation [2-4].

Methods / Theory

The investigated RF coils consisted of 1 to 4 cylindrical segments with linear antennas oriented parallel to the main field direction and equally distributed around the circumference of each segment. Different number of elements per segment (5, 6, or 8) and different angular orientations of the segments were investigated. For instance, Fig. 1 shows three different coils having 3 segments and 8 elements per segment. Here, the segments are rotated against each other by 0°, 22.5°, and 15°, respectively. The sensitivities of the coils were modeled by a static calculation using the Biot-Savart law.

The excitation trajectory used, was a stack of 8 spirals having 8 revolutions each with an isotropic resolution of 1 cm along the *x,y,z*-direction. Using a single transmission element, this would allow for encoding a field of excitation with 16×16×8 voxels with a size of 1 cm³. Different rotations of the trajectory in k-space with respect to the physical coordinate system were investigated to study the influence of the reduced sampling in the stacking direction. A rotation angle $\alpha = 0°$ corresponds to spirals in the transversal plane, $\alpha = 90°$ correspond to spirals in the sagittal plane.

The target excitation pattern was a 3D checkerboard pattern with a block size of 2 cm in each direction. The size of the field of excitation was varied from 16×16×16 cm³ to 40×40×40 cm³ keeping the voxel size fixed at 1×1×1 cm³. This corresponds to reduction factors R varying from R=2 to R=31.

RF excitation pulses were calculated using the small tip angle approximation for constant maximum pulse power [5]. The excitation quality was evaluated using the correlation between the target pattern and a Bloch forward calculation.

Results and Discussion

The orientation of the stack of spirals in k-space has a strong influence on the achievable excitation quality. Fig. 2 shows that the correlation is low for an orientation of $\alpha = 0°$. Here, the low number of phase encoding steps of the trajectory coincides with the segmentation direction of the coil, i.e., the direction with the lowest encoding capability of the coil. For $\alpha = 90°$ the correlation is much higher. Remarkably, there are pronounced maxima at intermediate angles. These oscillations are pattern-specific and are not present for a spherical target pattern. Thus, the trajectory orientation is a parameter that should be optimized individually for the desired target pattern.

Fig. 3 shows how different coils perform with increasing reduction factor. As expected, more elements lead to better performance. It is surprising that the relative orientation of the segments does not have a significant influence on the results. Particularly, all coils shown in Fig. 1 produce almost identical results. For better comparison, Fig. 4 shows the achievable correlation with the different coils for a reduction factor of 16. This demonstrates that spatially selective excitation is robust and does not depend critically on the coil geometry. It should be noted, that the coil with 3×5 elements performs significantly worse than the coils with 2×8 and 3×6 elements, although the total number of elements is comparable. This indicates that a number of 5 elements per segment is too low.

Conclusion

3D excitation is very robust with respect to different coil designs. Mainly the total number of transmit elements influence the excitation quality. These results provide input for the design of future Tx coils.

References

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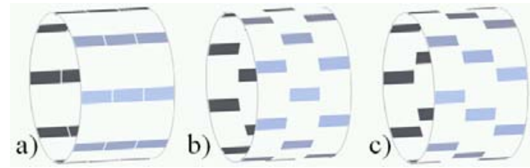

Fig. 1: Arrangement of the antennas for a coil with 3 segments and 8 elements per segment. a) all antennas are in line, b) adjacent segments are maximally rotated (angular difference 22.5°), and c) equal angular distribution of all elements (angular difference 15°).

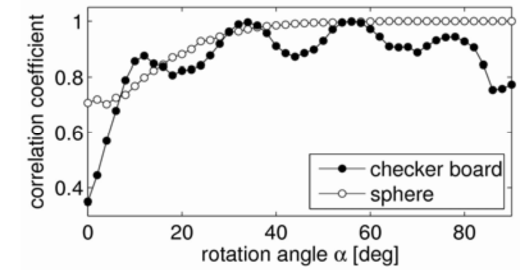

Fig. 2: Correlation vs. rotation angle α for different target patterns. Note that a correlation below 0.8 corresponds to a significant degradation of excitation quality. The oscillations in case of the checker board are due to the high symmetry of the pattern, which leads to preferred directions in k-space.

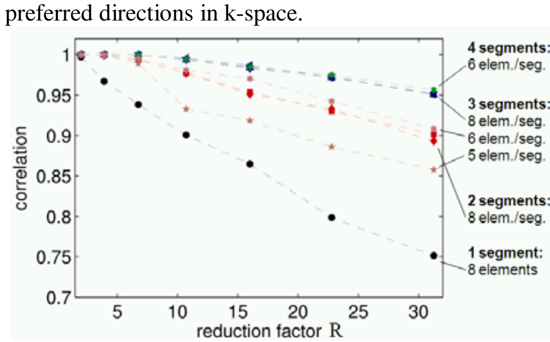

Fig. 3: Correlation vs. reduction factor for different coil configurations. More elements result in higher performance. The relative rotation of the segments has no influence on the results.

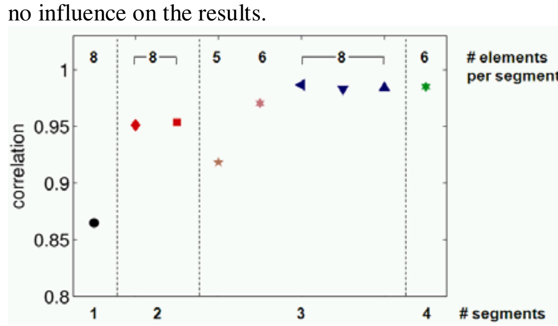

Fig. 4: Excitation quality for different coil configurations for a reduction factor of 16. Configurations with equal number of segments and equal number of elements per segment differ by the angular difference between the segments (see Fig. 1).