Numerical optimization of a 3-channel array coil for ^{31}P functional spectroscopy at 7T

Andre Kuehne[1,2], Ewald Moser[1,2], and Elmar Laistler[1,2]
[1]Center for Medical Physics and Biomedical Engineering, Medical University of Vienna, Vienna, Austria, [2]MR Centre of Excellence, Medical University of Vienna, Vienna, Austria

Introduction: The goal of this work was to design and optimize a transceiver coil for ^{31}P NMR spectroscopy in the visual cortex at 7 T using 3D electromagnetic simulation. SNR is a critical factor in spectroscopy, especially when temporal and/or spatial resolution of the experiment should be improved, therefore usually surface coils are used. To achieve homogeneous excitation and increase penetration depth despite the inherently inhomogeneous B_1 field of surface coils, adiabatic pulses are employed. These come at the cost of high transmit powers and associated high SAR. We therefore investigate a three channel array to improve both transmit efficiency and receive sensitivity, keeping power deposition low while increasing the obtained signal.

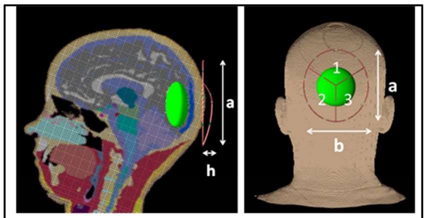

Fig. 1: Coil layout and ROI (green) placement in the central sagittal plane (left) and shown from the back (right). a and b are the coil major and minor axes, h is the coil height and 1-3 correspond to the coil channel numbers.

Methods: A schematic drawing of the investigated coil array is shown in Fig. 1. The coil outline is elliptical, with a minor-to-major axis ratio (b/a) of 0.9 to conform to the contours of the human head. It is split into three segments with shared conductors, allowing capacitive decoupling between all elements. To find the optimal coil dimensions w.r.t. B_1 efficiency, the major axis was varied between 9 and 15 cm in four steps. The height of the coil (h) was adjusted for each size to yield an approximately equal distance of all conducting elements to the head. Simulations were performed for a coil-head-distance of 1.5 and 2 cm, resulting in 8 variations in total. The B_1 field was evaluated in an ellipsoidal ROI (Fig. 1) in the target region, corresponding to the usual placement area of the spectroscopy voxel. Simulations were done in XFdtd 7.3 (Remcom, State College, PA, USA) using the head of the "Ella" model as a load [1]. After iterative tuning and decoupling of each configuration, the single channel fields were exported into MATLAB (Mathworks, Natick, USA) for post-processing.

For each coil size, B_1^+, B_1^-, and local SAR_{10g} were computed for all phase combinations with equal channel amplitudes in 5° steps (5184 total). To quickly evaluate local SAR, the algorithm presented in [2] was adapted to yield the local power correlation matrices (Q-matrices) [3, 4], which allowed sampling the entire 2D phase parameter space in less than one minute. Feeding all channels with identical phases and compensating for coupling losses results in an excitation like a simple loop coil due to current cancellation in the shared conductors, serving as a reference to determine the gain of the optimized 3 channel array.

Exc. mode	Loop	max B_1^+	opt. SAR
$B_1^+/\sqrt{(P)}$ [$\mu T/\sqrt{W}$]	2.4	**3.9**	3.3
$B_1^+/\sqrt{(SAR_{10g})}$ [$\mu T/\sqrt{(W/kg)}$]	1.8	1.5	**2.4**
B_1^+ rel. std.dev [%]	**18.9**	28.4	24.1
Exc. phases [°]	[0, 0, 0]	[0, -60, 60]	[0, -30, 20]

Tab. 1: Figures of merit and respective phase settings for the three excitation modes

Results: Decoupling between all elements ranged from -13 dB for the smallest to -17 dB for the largest coil. Transmit efficiency comparisons for differently sized coils at a distance of 2 cm, which take coupling losses into account, are shown in Fig. 2. Optimum $B_1^+/\sqrt{(SAR_{10g})}$ is reached at a major axis size of 11 cm. Compared to the single loop of same size, the performance of the optimized three channel array is improved by 37%, 27%, and 51% for $B_1^+/\sqrt{(SAR_{10g})}$, transmit efficiency $B_1^+/\sqrt{(P)}$, and receive sensitivity $B_1^-/\sqrt{(P)}$, respectively. Out of all phase variations, three modes stand out in particular. The "Loop mode" delivers the best homogeneity, whereas two distinct excitations yield maximum $B_1^+/\sqrt{(P)}$ and maximum $B_1^+/\sqrt{(SAR_{10g})}$, respectively. Tab.1 compares these modes for the optimum coil size. The corresponding sagittal B_1^+ and local SAR distributions are shown in Fig. 3. The distance variation only had a minor effect, with $B_1^+\sqrt{(SAR_{10g})}$ slightly increasing (1-4%) with a simultaneous decrease in $B_1^+\sqrt{(P)}$ by 1-5%.

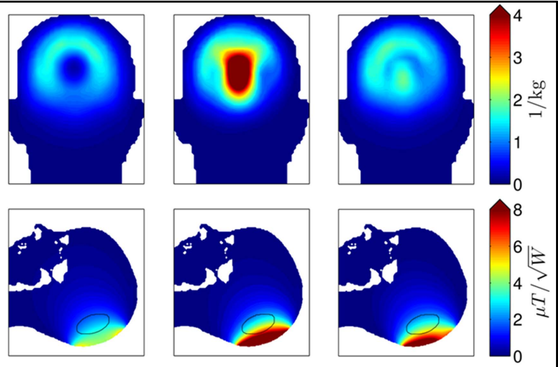

Fig. 3: Local SAR_{10g}/P (top, coronal MIP) and B_1^+ (bottom, central sagittal plane) distributions for the three excitation modes: loop; max. $B_1/\sqrt{P}$; max $B_1/\sqrt{SAR_{10g}}$ (from left to right). The ROI is outlined.

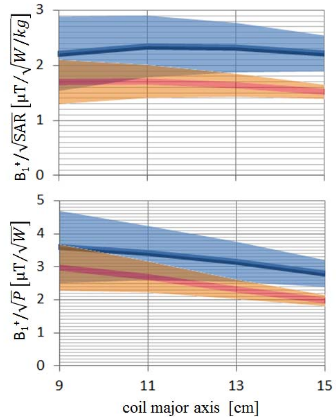

Fig 2: Transmit efficiency vs. coil size w.r.t. input power (bottom) and peak local SAR_{10g} (top). Single loop performance is in red, array performance in blue. Shading indicates the B_1+ standard deviation in the ROI.

Conclusion: The proposed three-channel array performs significantly better than a single loop coil in terms of B_1 efficiency at the cost of a slight reduction in homogeneity. It is noteworthy, that the superposition yielding the maximum B_1^+ per input power does not coincide with the local SAR optimized excitation, which highlights the importance of taking both parameters into account during optimization, even if the coil is to be used with static phase shifts (single channel transmit). For this setup, the optimized SAR mode would be the best choice. The coil will be built in the proposed optimal configuration and complemented by a 2-channel proton coil that is being optimized in the same manner.

References:

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