

## Effects of tuning condition, head size and position on the SAR of a 9.4T dual row array

Mikhail Kozlov<sup>1</sup>, G Shajan<sup>2</sup>, and Robert Turner<sup>1</sup>

<sup>1</sup>Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Saxony, Germany, <sup>2</sup>Max Planck Institute for Biological Cybernetics, Tuebingen, Germany

**Introduction:** Specific absorption ratio (SAR) measurement is not available for in-vivo human subjects. MRI scanner manufacturers and most national committees (e.g. FDA) support evaluation of SAR using numerical simulation. The transmit performance of UHF MRI coils benefits from a dual-row array configuration [1]. However, it is hard to assess the safety of such coils because of the difficulty in matching simulated and actual coils. If the decoupling of array elements is assumed to be ideal, the SAR can be readily calculated for several excitation modes, and/or complex parallel transmit pulses [2]. In the easiest case, a single array tuning condition, the actual and simulated element matching and adjacent element coupling are compared in decibels. The influence of coupling phase on SAR has generally been neglected despite the well-known existence of under-coupled and over-coupled cases. In previous work we developed a simulation work-flow closely corresponding to the fabrication steps of an array, but the results reported were obtained for circuit level optimization reaching a global minimum [3]. Our numerical simulation goals in this study were: a) to investigate the effect of different tuning conditions on SAR of an already constructed 9.4T dual-row array [1]; and b) to explore the sensitivity of SAR to both head size and position within an array. Low sensitivity to these variables would simplify safety supervision.

**Method:** The realistic 3-D EM model of the arrays included all coil construction details for the resonance elements, simulated with precise dimensions and material electrical properties. However, neither RF cable traps nor coax cable interconnection wiring were included in the model. The loads utilized were the multi-tissue Ansoft human body models, cut in the middle of the torso, with different scaling factors: head #1 with scaling  $X=0.9$ ,  $Y=0.9$ ,  $Z=0.9$  (simulating an average head), head #2 with scaling factors  $X=0.85$ ,  $Y=0.85$ ,  $Z=0.9$  (simulating a small head), and head #3 with scaling factors  $X=0.95$ ,  $Y=0.975$ ,  $Z=0.9$  (simulating a large head). We analyzed geometries where the head is placed symmetrically in the transverse plane, and where the head is positioned 22 mm lower, to allow space for the mirror of a visual stimulus system. In both geometries each head was located at four axial positions so that the distance between crown of the head and array top was 16, 21, 26, and 31 mm. We use the following head position abbreviations: "16 mm", "21 mm", "26 mm", and "31 mm". In the first geometry the first head was also shifted to both sides by 5 and 10 mm.

Only six components (feed-point, variable capacitor, and 4 sub-circuit of distributed capacitors and decoupling inductor connected in series) in each resonance element were substituted as ports to reduce the time required for post-processing as well as to limit the amount of simulation data. The Q factor of all capacitors was equal to 200. The array decoupling pin diode resistance was 0.2 Ohm.

To obtain values of the variable array components - decoupling inductors, tune and match capacitors - we used two circuit-level array optimization strategies: 1) optimization based on S parameters, mimicking the commonly used optimization during fabrication, where the reflection coefficient ( $S_{xx}$ ) for each individual array element and the coupling coefficient ( $S_{xy}$ ) for each decoupled pair of array elements were minimized at the array operating frequency ( $F_{MRI}$ ); 2) mode optimization, minimizing an error or cost function ( $EF$ ), which consisted of individually weighted sums derived from the S parameter matrix and power reflected by array rows, for a given set of excitation modes [2]. For each geometry and four positions of head #1, optimization was independently performed in two steps: 30,000 random tries, followed by "Quasi-Newton" method until no further improvement was possible. This resulted in two sets (one per each geometry) of eight values for the variable components (tuning conditions) and a corresponding set of E and H fields (on an equidistant 1 mm mesh) for each independently excited radiative element. The fields were exported from the 3-D EM domain to files in MATLAB format. The peak SAR averaged over 10 gram ( $SAR_{10g}$ ) was calculated for CP and some other excitation modes using an in-house MATLAB procedure, developed consistently with the IEEE 1528.1 standard and validated by means of an IEEE TC 34 interlab comparison study [4]. For each 3D EM domain simulation, the total number of calculated  $SAR_{10g}$  values was 96 (the number of tuning conditions '8' multiplied by the number of excitation modes '12').

**Results and discussion:** For circuit level optimization strategy #1 and the first symmetrical geometry, the magnitudes of the  $S_{xx}$  ( $< -40$  dB) and  $S_{xy}$  ( $< -18$  dB) were similar for each axial position of head #1, but the mutual inductor coupling coefficients  $K_{di}$  for the decoupling inductors and the  $S_{xy}$  phases were significantly different between position "26 mm" and other positions. When variable component values were used from another position of head #1, the  $S_{xx}$  magnitude slightly increased (remaining below -20 dB) and the  $S_{xy}$  was slightly decreased. Therefore in all configurations array appeared to be adequately tuned. Variation of the  $S_{xx}$  and  $S_{xy}$  for head #2 and head #3 simulations was more pronounced, but the array tuning remained reasonable in all configurations (only a couple of  $S_{xx}$  were about -16 dB, others  $S_{xx} < -20$  dB and all  $S_{xy} < -18$  dB).

For the second offset geometry, all circuit level optimizations of both circuit level optimization strategies resulted in values of similar magnitude for  $S_{xx}$  and  $S_{xy}$ . The  $S_{xx}$  and  $S_{xy}$  behaviour for different head positions and head sizes was similar to the symmetric geometry. However  $K_{di}$  was different for each strategy. For the offset geometry and a given excitation mode,  $SAR_{10g}$  variations were less than  $\pm 5\%$  for each optimization strategy, and about  $\pm 30\%$  including results for both optimization strategies.

If tuning results for the symmetric geometry with head position "26 mm" were excluded from the  $SAR_{10g}$  database, variations for optimization strategy #1 and both geometry cases would be very similar. But for this latter head position, there was up to 30% increase of variation in  $SAR_{10g}$  for some excitation modes. When head position #3 tuning was applied, i) significant variation of current through the radiative elements was observed; ii) the constructive E-field interference had a different pattern; iii) finally, the value and spatial location of the peak  $SAR_{10g}$  were significantly different.

To perform a sensitivity analysis, the circuit level optimization strategy #1 was applied 100 times for the symmetric geometry. We obtained solutions where the values of  $K_{di}$  were grouped into two values with small dispersion, the first being close to that of the original optimization for the head in head positions "16 mm", "21 mm", and "31 mm", and the second close to that of the original optimization with head positions "26 mm". The probability of obtaining the first value was 83%.

**Conclusion:** A precise match of dual row array conditions between the simulated and actual domains is vital for reliable SAR assessment. The tuning condition may significantly affect the  $SAR_{10g}$  of a dual row array. When the array diameter is relative large, for a given tuning condition the variation of both head size and position results in small variations of array circuit level measures. Here  $SAR_{10g}$  differences are relatively small (less than 20%), and can be easily accommodated by the array safety margin. However it is impossible to conclude in general that the variation of an array property has a negligible influence on  $SAR_{10g}$  for any dual row array. A given dual row array should be comprehensively and reliably investigated (including sensitivity analysis) in order to define the scanner SAR assessment parameters. If neither a precise match of conditions nor a sensitivity analysis can be obtained, the safety margin should be considerably increased.

[1] G. Shajan, J. Hoffmann, K. Scheffler, and R. Pohmann, *Proceedings of the 20<sup>th</sup> ISMRM*, p. 308, 2012. [2] B. Guerin, M. Gebhardt, E. Adalsteinsson, and L. Wald, *Proceedings of the 20<sup>th</sup> ISMRM*, p. 2215, 2012. [3] M. Kozlov, R. Turner, *Proceedings of 34th IEEE EMBS*, p. 1089-1092, 2012., [4] V. Monebhurrun, Y. Braux, H. Devos, M. Kozlov, W. Simon, T. Wittig, *Proceedings of the BEMS2012*, p.315-317, 2012