Electromagnetic Fields and SAR Computations in a Human Head with a Multi-port Driven RF Coil at 11.7 Tesla

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Abstract : Using a commercially available 3D electromagnetic code based on the FIT method [1], we computationally investigate the transverse B_1-field homogeneity and SAR values in an 11.7 T / 500 MHz 4-port driven RF head coil loaded with a high-resolution human model. As first results, the simulations reveal the expected enhancement of the B_1 field in the center of the head compared with the unloaded case and no significant changes in the maximum 1g SAR values between 2-port linear and circular polarizations.

Introduction : In ultra-high field (> 8 T) MRI systems, the RF coil is an essential element to provide a higher imaging quality at higher proton resonance frequencies with a reasonable B_1-field homogeneity in the imaging area, low SAR in the biological tissues and a good signal to noise ratio (SNR). As frequency increase, the electrical dimensions of the head/body and the RF coil become comparable ($\lambda_0/2$=30 cm at 500 MHz). RF fields interact more strongly with human tissues [2] and wave behaviour of the B_1-field should be prejudicial inside the high dielectric permittivity head. During the last decade, numerical methods have been generalized for supporting the design of RF coils as frequencies were increased. With the complexity in accessing noninvasively to measurements on human subjects, these methods offer, when coupled to anatomically detailed human models, a very practical tool to investigate the distributions of the magnetic field and the maximum of local SAR values for various kind of coils [3][4][5].

Methods : The 3D transient solver MicroWave Studio [6] coupled to a high resolution 3D anatomical data set HUGO [7] was used to simulate the time varying fields inside a designed RF head volume coil [8] loaded with a human head/shoulder representing a mass of 7.81 kg. The total number of mesh cells over the entire volume of calculation is 1,982,178 with about 1,100,000 cells for the tissues corresponding to a $3 \times 3 \times 5$ mm average resolution (roughly 18 voxels per 1 cm^3 of tissue). All the external surfaces of the volume of calculation are open boundaries with PML layers. The materials constitutive of the coil are loss free. In order to facilitate the comparison with the unloaded coil, we defined a capacitor set in parallel with the virtual ports for better matching to the dielectric losses (Q_D=42.2). The four ports are positioned at $\pi/2$ angle in the axial plane. During one simulation, calculations of the fields and the loss power density for a selected frequency are performed on each port. For the results presented, only the two ports in quadrature are defined, the others were deleted in order to relaxing the calculation time (70 h per simulated port). With the post processing tool, the results obtained for each port are combined with specific amplitudes compensating for reflections, and phase (0 and $\pi/2$) in order to create the circularly polarized excitation with a total effective input power of 1 Wrms CW. The SAR calculation is done as a post processing step with this new excitation. SAR is strictly defined as the time derivative of the incremental energy dW dissipated in an incremental mass dm contained in a volume element dV of a given mass density dρ so that SAR = d/dt (d W/ dm) = d/dt (d W/ ρdV). Local SAR gives a numerical value per element volume and becomes a space distribution function for an average tissue mass of 1 g.

Results and Discussion : Extracting the magnitude of the fields along the three axial directions x, y and z (lines in blue Fig. 1 & 2), we observe the enhancement of the H_1-field in the center of the brain up to 1.2 A/m for the loaded coil (Fig. 3) compared to the 0.95 A/m uniform profile of the unloaded coil, and the decrease of the uniformity with a resonant behaviour compared to the unloaded case shown Fig. 4 where we could observe the equalization of the x and y B_1 profile when perform a circular polarization (curves green and red) compared to the linear polarization (orange and purple). The difference between the two curves Fig. 3 indicates that we did not strictly perform a circular polarization for the loaded coil. In Fig. 5 and 6, we give the magnitude of the E-field for the loaded and unloaded case. The values of 1g local SAR and H_1-field are shown for 2 cut planes Fig.7 to 10. The average SAR is found equal to 0.127 W/kg with a total dissipated power of 0.964 W giving an estimation of the radiated power less than 5 % of the input power. For the local SAR in 1g of tissue, the maximum is found to 1.14 W/kg localized in the center of the brain. These SAR evaluations normalized to 1 Wrms CW allow the calculations of the expected SAR for MRI sequences.

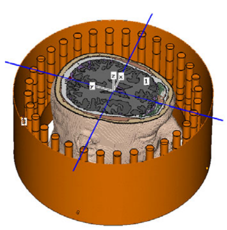

Fig. 1 : Lines x and y

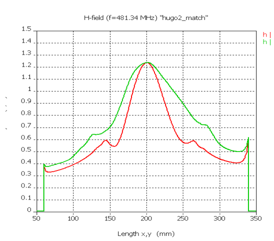

Fig. 3 : $|H_1|$- loaded coil

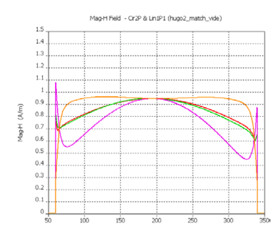

Fig. 4 : $|H_1|$ - unloaded coil

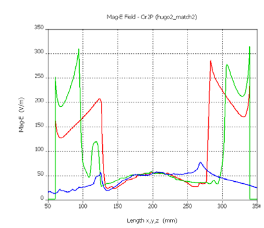

Fig. 5 : |E| - loaded coil

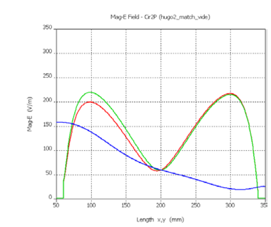

Fig. 6: |E| - unloaded coil

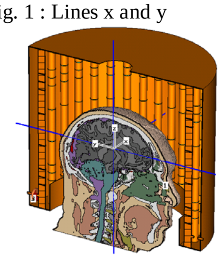

Fig. 2 : Lines y & z

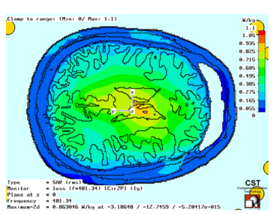

Fig. 7 : 1g SAR plane xy

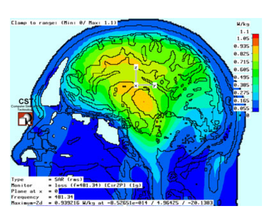

Fig. 8 : 1g SAR plane yz

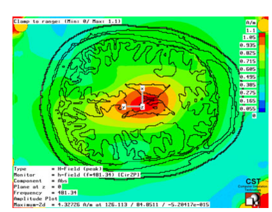

Fig. 9 : $|H_1|$ plane xy

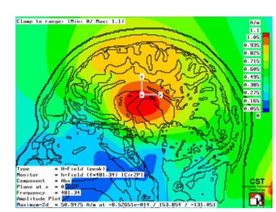

Fig. 10 : $|H_1|$ plane yz

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