Faster B1 Field and SAR Estimation in Parallel Transmit Arrays without Tuning using Voltage Sources

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Purpose: Finite-difference time-domain (FDTD) analysis is a popular method for calculating electromagnetic (EM) fields by solving Maxwell's equations in the time domain [1]. In ultra-high-field magnetic resonance imaging (MRI), there are two specific needs for EM simulation: one is the estimation of transmit and receive magnetic (B_1^+ and B_1^-) field distributions and the other is the estimation of specific absorption rate (SAR) via electric (E) field simulation. In this study, we compare and evaluate two methods of simulating an eight channel parallel transmit transceiver coil. Method 1 is the conventional tuning method whereby one voltage source is placed on each element and 'manually' tuned using explicit capacitor values. Method 2 is known as the ideal current driving method, which only uses voltage sources rather than explicit capacitors [2]. For Method 2, broadband tuning is not required, simplifying the simulation setup and reducing the simulation time. We compare the generated B_1^+ fields and SAR distribution in a 7T cylindrical phantom and human head model (Duke, Virtual Family).

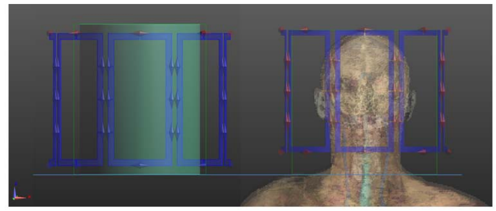

Fig 1. SAR average line of phantom and human head model

Methods: The 8-channel transceiver coil was simulated using SEMCAD X (Speag, Switzerland) with a GPU accelerated computer. The coil consists of eight rectangular elements, each formed from copper strip (lateral and longitudinal length of each element: 110 mm and 220mm; 10mm strip width). The eight elements are arranged around a 300mm diameter cylindrical former without shield. The simulated cylindrical phantom had diameter of 200mm and length of 250mm. Electrical conductivity and relative permittivity were calculated using the average of human grey matter and white matter at 297.2 MHz (ε_r: 52, σ: 0.55 S/m, density: 1042 kg/m^3). Additionally, the human model was placed along the center of the coil and aligned such that the top of the head was aligned with the top of the coil. Both methods were evaluated at 297.2 MHz (7T). In Method 1, seven capacitors were equally distributed around eight positions for each element, with the eighth position used as the voltage source. The capacitor value was chosen such that S_{11}<-5.0dB at 297.2 MHz without matching and decoupling. In total 8 voltage sources are used as ports to generate the fields and delay periods were incorporated for the 8 voltage sources to yield a phase difference of $\pi/4$ between coil elements and thus a circularly-polarized (CP) mode. For Method 2, eight voltage sources were equally placed around each of the eight elements, giving 64 voltage sources in total. The delay period was set identically for all voltage sources within a given element and, in the same manner as for Method 1, a phase difference of $\pi/4$ between coil elements was introduced. The B and E field information within the region of interest (Fig. 1) was then simulated using SEMCAD X. MATLAB (The Mathworks, USA) was used to normalize the fields. The B_1^+ field, SAR, and 10g averaged SAR were normalized to fields that produced 2μT at the center of the coil [3]. The B_1^+ field was normalized by multiplying with a normalization factor V, and SAR data are normalized by multiplying by V^2 (Fig. 2). Global SAR was calculated as the average normalized local SAR data within the region of interest and the maximum 10g averaged SAR is found in MATLAB (Fig. 3).

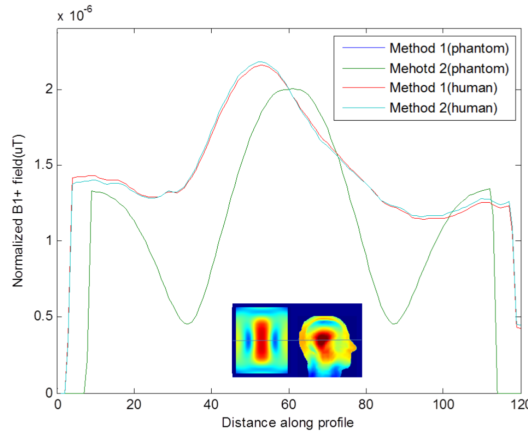

Fig 2. B1+ field profile at coil center

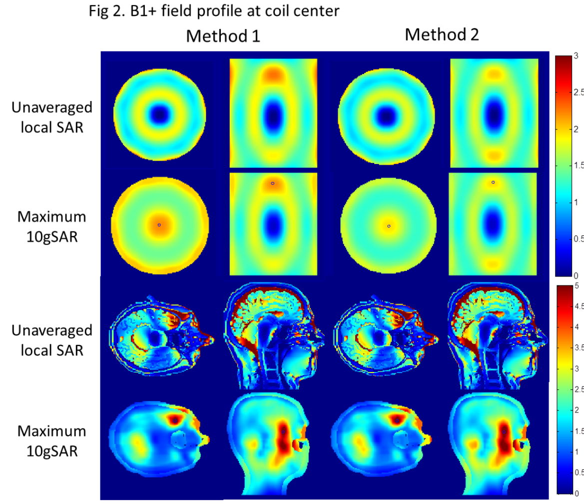

Fig 3. Result of unaveraged local SAR and location of $10gSAR_{max}$

Results: Both methods showed less than 2% difference in B_1^+ field profile at the coil center. The difference in the averaged SAR was 6.5% and 3.7% in the phantom and human model, respectively (Table 1). In the phantom simulation, an 11.5% difference was found in the maximum 10g averaged SAR, but only a 3.1% difference was observed in the human model simulation. The calculation time was on average 66% faster for Method 2 versus Method 1.Figure 2 shows the B_1^+ profile both the phantom and human model demonstrating near identical profiles for the phantom.

		Method 1	Method 2	Differences
Phantom (Cylinder)	SAR_{avg} (W/kg)	1.53	1.43	-6.5%
	$10gSAR_{max}$ (W/kg)	2.20	1.95	-11.5%
	Calculation time	11 min	4min	-7 min
Human model (Duke, Virtual Family)	SAR_{avg} (W/kg)	1.66	1.73	+3.7%
	$10gSAR_{max}$ (W/kg)	5.41	5.58	+3.1%
	Calculation time	22 min	7min	-15min

Table 1. Result of unaveraged local SAR and location of $10gSAR_{max}$

Discussion and Conclusion: The ideal current-driven simulation has been compared with the conventional capacitor tuned simulation in SEMCAD X. The largest difference in 10g averaged SAR was found for the phantom model. In terms of B_1^+ field generation, the two methods agreed well. In Method 1, additional time is required for a broadband simulation to tune the coil for each target phantom and frequency, whereas Method 2 is simpler to set up and faster to run and provides an accurate depiction of the B_1 field distribution and a good estimation of the SAR characteristics. Further studies are needed to evaluate differences between the two methods when using other coil geometries, human models and at different frequencies and effects of more realistic distributions of capacitors in tuned coils. In conclusion the ideal current method is a feasible option for rapid evaluation of B_1^+ and SAR distributions in parallel transmit coils.

References: [1] Kunz KS et al, CRC Press, 1993, [2] Collins C et al. MRM 40, 1998 [3] Collins C et al. MRM 45, 2001

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