A fast algorithm to optimize transmit efficiency for local excitation with a transmit array

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Introduction: With short wavelengths in the human body in high field MRI, use of a transmit array to achieve homogeneous RF magnetic (B_1) fields for excitation across the entire torso or abdomen for planar imaging is much more difficult than in the brain (1). This has led to increased interest in advanced pulse design (2), and also in array-based optimization of the transmit efficiency on only a small region of interest rather than considering homogeneity across an entire cross-section or a large volume (3, 4). In cases where a small ROI can be used to acquire the necessary data, local B_1 shimming can provide dramatic improvements in transmit efficiency, which can translate into lower SAR, more optimum flip angles and SNR, and even increased imaging speed for SAR-limited sequences. For local B_1 shimming with phase adjustment only, optimization of transmit efficiency at a single location is very direct and fast (3). Although they should offer greater improvements, optimization techniques considering both phase and magnitude currently require searches of multi-dimensional space and numerous calculations of dissipated power. Here we describe a very simple, fast, and effective method for optimizing efficiency in localized RF shimming using both magnitude and phase of the driven elements, and compare with more conventional optimization methods. In essence, after ensuring all elements produce B_1^+ with the same phase at the location of interest, the method will decrease current in less efficient elements and increase that in more efficient elements according to a simple algorithm. Compared to more conventional searching algorithms, the method performs very well.

Methods: The B_1^+ and E field distributions for each individual coil of a transmit array operating at a frequency of 300 MHz (Fig. 1) were calculated using commercial software XFDTD (Remcom, Inc.) and the results have been processed in Matlab (The Mathworks). If $B_{1,i}^+$ is the circularly polarized component of the magnetic field generated by the i^{th} wire at the location of interest when driven with unit current, the optimized relative current for the i^{th} element is assumed equal to $I_i = C \left| \frac{B_{1,i}}{\sum_{i=1}^{N} |B_{1,i}^+|} \right|^{\alpha} e^{-j\angle B_{1,i}^+}$. With this arrangement, the current amplitudes of less efficient elements are reduced relative to more efficient elements and all elements are driven to interfere constructively at the location of interest. The optimization process is very fast because only one parameter needs to be optimized (α). Using the cost function $f_1 = \frac{\sqrt{P_g}}{B_1^+} = \frac{\sqrt{\frac{1}{2}\sum_{j=1}^{N}\sum_{i=1}^{N} Re\{Z_{ij}\}\left(I_i I_j^*\right)}}{B_1^+}$ where P_g is the generated power, $Re\{Z_{ij}\}$ is the real component of the mutual impedance between the i^{th} and j^{th} coil. In addition, it can be shown that we have a single optimum value of α that optimizes the field for every location in case all the elements of the array are of similar geometry and well decoupled.

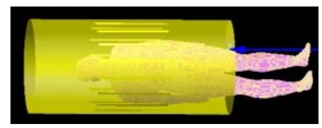

Figure 1. Model used for Numerical simulations.

Results and Discussion: the performance of the proposed algorithm was tested by comparing it with three other methods to compute the coil currents: 1) the current distribution for a classic birdcage coil, 2) the algorithm explicitly given in (3), where only the phases of the coil currents are optimized, and 3) a more conventional conjugate-gradient based optimization routine considering magnitude and phase. The comparison consists of examining the resulting magnitude of B_2^+ in the location of interest with the same input power. All RF fields were calculated using the Finite Difference Time Domain Method with commercially available software (Remcom, Inc.) for a human body model in the transmit array.

Compared to the field generated by a classic birdcage coil, the proposed algorithm produces a B_1^+ field having amplitude 2.15 times larger at the center of the structure (heart), and 5.07 times larger at a location far from the center of the structure (arm) for a given dissipated power. Compared to the field generated by the transmit array with only the optimization of the phases, the proposed algorithm produces an increase of the B_1^+ field amplitude larger than 1.07 times at the center of the structure, and an increase larger than 1.84 times at a location far from the center of symmetry. Comparing to the results obtained by other optimization routines such as the conjugate gradient method, where the bond of the same exponent alpha for all the currents has been removed, and allowing the currents to assume all possible values, when all the elements of the array are of similar geometry and well decoupled the conjugate gradient method could not find a current scheme that minimizes the cost function f_1 more than the proposed algorithm. In all the other evaluated cases the conjugate gradient method could find the best current scheme only when using the result of the proposed algorithm as starting point of convergence. Also, the proposed algorithm was notably faster than the conjugate gradient based method.

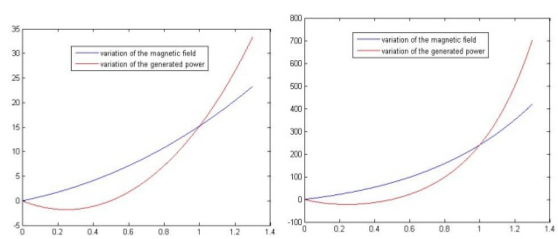

Figure 2. Percentage variation of both the magnetic field H_1^+ (blue line) and the input power (red line) as function of α for a location close to the heart (left) and far from the heart (right).

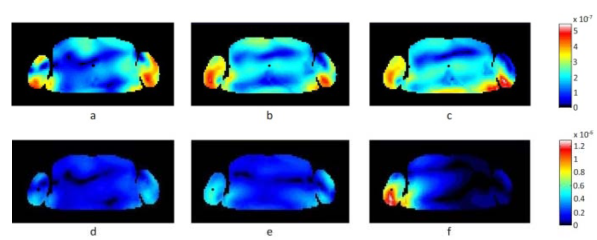

Figure 3: Magnetic field B_1^+ distribution for the currents scheme of a transmit array: of a birdcage coil (a, d), of the phase-only optimization for a location (black dot) close to the heart (b) and far from the heart (e), and of the phase and amplitude optimization for a location close the heart (c) and far from the heart (f). In all cases, the total dissipated power in the subject is the same.

References

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