# An analytical method 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]. 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. Previously, a local $B_1$ shimming method with phase adjustment only at a single location has been presented [3]. Recently a simple iterative method has been presented [4] to optimize both phases and amplitudes requiring optimization of a single parameter rather than a search of multi-dimensional space. Here we present an exact analytical solution for the magnitudes and phases required to optimize the transmit efficiency, with the knowledge of both the fields $B_1^+$ generated by each element of the transmit array and the matrix impedance of the array.

**Method**: The $B_1^+$ and E field distributions for each individual coil of a transmit array operating at a frequency of 300 MHz (Figure 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 $I_i = CA_i e^{-j\angle B_{1,i}^+}$ (1) where $C$ is a scaling factor equal for all the elements of the array and $A_i$ are the amplitudes that provide maximum transmit efficiency. Using the cost function $f = \frac{\sqrt{P_g}}{B_1^+} = \frac{\sqrt{\frac{1}{2}Re\{\boldsymbol{I}^{*T}\boldsymbol{Z}\boldsymbol{I}\}}}{|\boldsymbol{B}_1^{+T}\boldsymbol{I}|}$ (2) where $P_g$ is the generated power, $\boldsymbol{Z}$ is the matrix impedance, $\boldsymbol{I}$ is the currents vector and $\boldsymbol{B}_1^+$ is the vector containing the values of the circularly polarized field $B_1$, the optimum set of currents can be computed. In case of negligible coupling among the elements of the array, or equivalently in case the matrix impedance is diagonal, substituting in (2) the definition of the currents given in (1) the optimum amplitudes $A_i$ are obtained by setting to 0 the derivative of the cost function $f$ with respect to the amplitudes $A_i$. The solution is $A_i = \frac{|B_{1,i}^+|}{Re\{Z_{ii}\}}$ (3). In case of non negligible coupling among the elements of the array, it is possible to use the properties of symmetry of the matrix impedance to diagonalize $\boldsymbol{Z}$. This is obtained by rewriting the cost function as $f = \frac{\sqrt{\frac{1}{2}\boldsymbol{E}^{*T}\boldsymbol{D}_R\boldsymbol{E}}}{|\boldsymbol{F}^T\boldsymbol{E}|}$ (4) where $\boldsymbol{D}_R$ is the diagonalization of the real part of the impedance matrix given by the equation $\boldsymbol{Re}\{\boldsymbol{Z}\} = \boldsymbol{Q}_R^{-1}\boldsymbol{D}_R\boldsymbol{Q}_R$ (5), $\boldsymbol{E} = \boldsymbol{Q}_R\boldsymbol{I}$ (6) and $\boldsymbol{F} = \boldsymbol{B}_1^{+T}\boldsymbol{Q}_R^{-1}$ (7). It is then possible to find the optimum values of $\boldsymbol{E}$ by using the formula (3), and then to find the optimum currents $\boldsymbol{I} = \boldsymbol{Q}_R^{-1}\boldsymbol{E}$ (8).

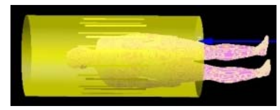
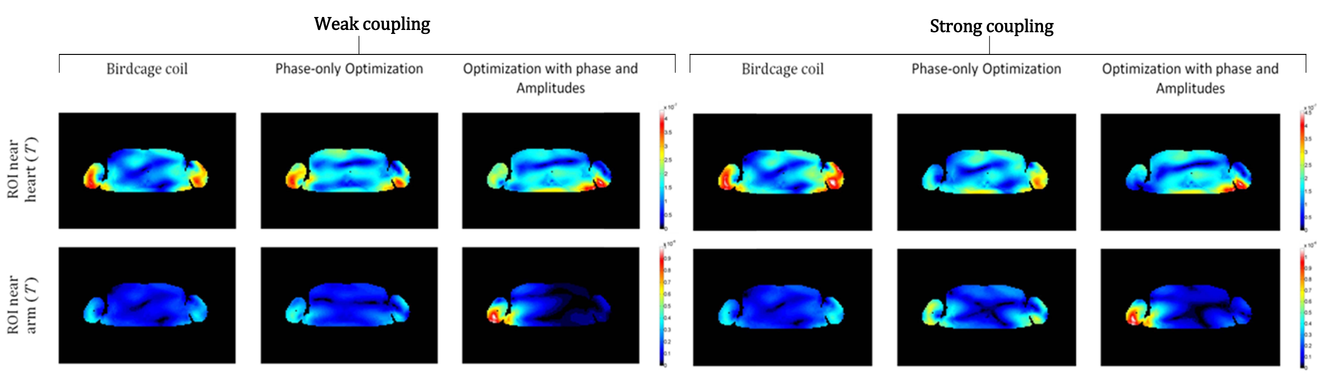


**Figure 1**. Model used for Numerical simulations.

**Results**: The performance of the proposed algorithm was tested by comparing it with two 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. The comparison consists of examining the resulting magnitude of $B_1^+$ in the location of interest with the same input power for a human body model in the transmit array. The results are reported for a negligible coupling case in Figure 2 (a), and for a non negligible coupling case in Figure 2(b).




| | Weak coupling | | Strong coupling | |
|---|---|---|---|---|
| | $\lvert B_1\rvert$ for a ROI in heart ($\mu T$) | $\lvert B_1\rvert$ for a ROI in shoulder ($\mu T$) | $\lvert B_1\rvert$ for a ROI in heart ($\mu T$) | $\lvert B_1\rvert$ for a ROI in shoulder ($\mu T$) |
| Birdcage coil | 0.082 | 0.280 | 0.100 | 0.331 |
| Phase-only optimization | 0.169 | 0.391 | 0.163 | 0.456 |
| Optimization with phase and amplitude | 0.180 | 0.699 | 0.192 | 0.780 |

**Figure 2**: Comparisons of the magnetic field $B_1^+$ distribution (figures) and the $|B_1^+|$ values in two specific locations (table) for three different currents schemes of a transmit array having its elements weakly and strongly coupled. All the $|B_1^+|$ fields have been normalized so that the total generated power by the transmit array is about 1 kW.

## References

1. Vaughan *et al.*, MRM 2006;56:1274
2. Saekho *et al.*, MRM 2006;55:719
3. Metzger *et al.*, 2008;59:396
4. Carluccio et al., 2011; ISMRM, Montreal; p. 3856

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