On the E-field construction/deconstruction and B1+ Efficiency/Homogeneity with Transmit Array Eigen Modes

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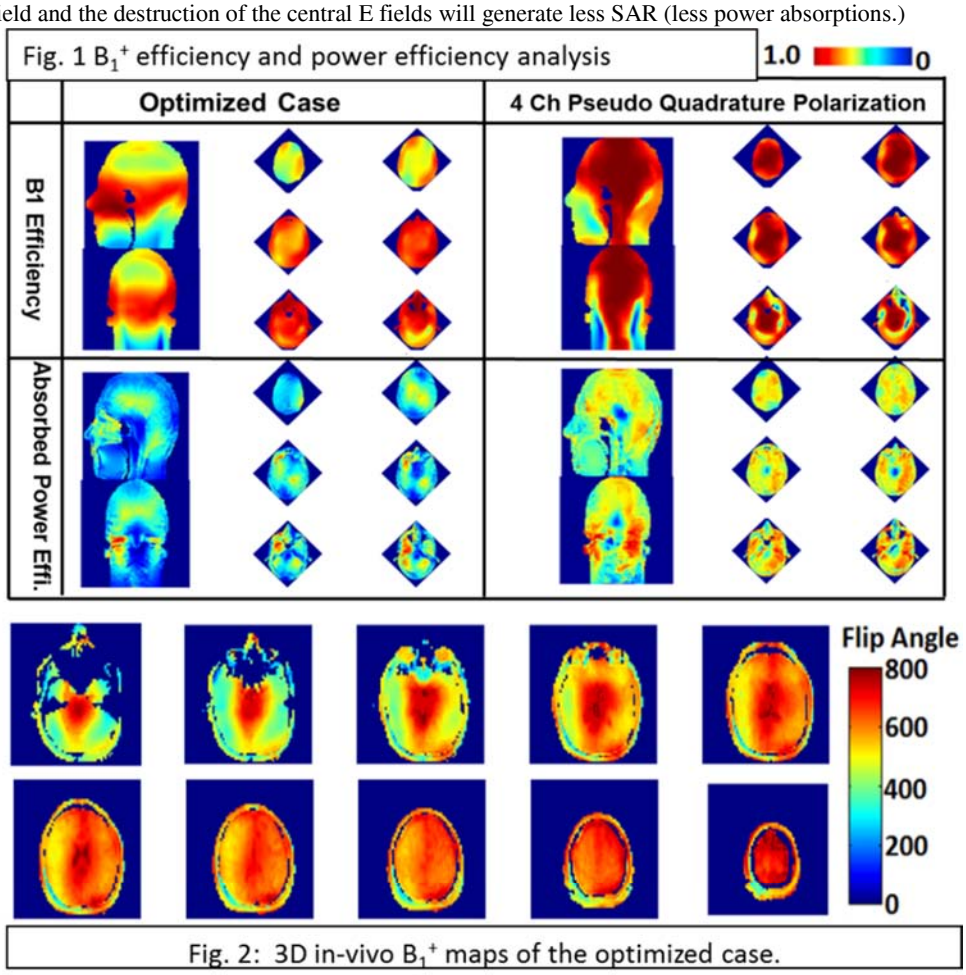
Target Audience: MRI researchers working on the ultrahigh field human MRI, RF safety (specific absorption rate or SAR) and B_1^+ homogeneity

Purpose: The inhomogeneous distribution of the excitation field (B_1^+) and the potential rise in local RF absorption (SAR) are two of the major obstacles hampering potential clinical applications of the ultrahigh field human MRI (7T and higher.) Ideally, the "quadrature" excitation construction will give the most efficient B_1^+ [1] field and the destruction of the central E fields will generate less SAR (less power absorptions.)

In this study, the multi transmit array and B_1 shimming methods are used to optimize the modes generated by sets of different coil elements on the same array in order to produce uniform 3D excitation. While there could be many different optimization solutions (we include many of which into several of our in-vivo studies) for the RF excitation that achieve a very similar fidelity to the targeted excitation pattern (homogenous B_1^+ field), minimizing the local SAR [3, 4] and maximizing the B_1^+ efficiency are two of the most important constraints of the optimization procedure.



Methods:

Theory: The transmit coil produce $B_1^+ = (B_{1x} + jB_{1y})/\sqrt{2}$, which is the circularly polarized component of the magnetic flux density that is responsible for exciting the spins. When two linear transmit fields combine, the generated B_1^+ field intensity will be $\sqrt{2}$ times of the transmit field generates with the same input power. The relative magnetic fields efficiency [2] is $B_{ef} = \frac{\sum B_1^+}{\sum |B_1^+|}$ and the relative absorbed power efficiency is $E_{ef} = \frac{\sum E^2}{\sum |E|^2}$. We aim at high relative magnetic fields efficiency to gain spin excitation and low relative absorbed power efficiency to reduce SAR effects. The homogeneity is evaluated by $COV = \frac{covariance}{mean}$.

Simulations: In-house FDTD simulation package and GUI optimization tool box have been used to simulate the human head model and optimization the field distribution. The calculation results from the GUI tool box are processed by the SAR calculation packages to get SAR, relative B_1^+ efficiency and absorbed power efficiency.

Coil and Experiments: 20-ch Tic Tack Toe transmit array could excite 20 different pseudo orthogonal modes with capability of producing 5 different modes at the same time from 5 different sets of 4 elements. Some mode could excite the center area and periphery area could be excited by other modes. Each mode has the amplitude and phases that are adjusted to achieve a more uniform (in terms of B_1^+ distribution) excitation. In-vivo B_1^+ mapping method is used for verification purposes. All experiments were done using 7T Magnetom MRI scanner (Erlangen, Germany) equipped with 8 channel parallel transition (PTX 2.0).

Results and Discussion: Examples of the simulation and the relative field/power efficiency comparisons are shown in Fig1. For the 4 channel pseudo quadrature polarization case, inside the whole brain $B_{ef} \approx 78\%$, which means B_1^+ is constructed in most of the volume, especially in the middle of the brain and $E_{ef} \approx 56\%$. For the optimized case, $B_{ef} \approx 65\%$ and $E_{ef} \approx 32\%$. Therefore, the optimized case could generate about 30% higher B_1^+ when absorbing the same amount of power. The B_1^+ is uniquely constructed most from the ventricle to the cerebellum (more than 90%). For both cases, there is one small area the absorbed power ratio is almost 0 (very low SAR).

The low 10g local average SAR, low absorbed power, high B_{ef} and high signal homogeneity cases are considered potential cases for in-vivo testing. One of the most efficient modes (in terms of lowest local SAR/transmit field efficiency) we have tested in-vivo called "zero phase". The B_1^+ maps of the "zero phase" are shown in Fig.2. For the 3D region occupying brain, COV≈ 21%. These simulated parameters are in excellent agreement with the measured B_1^+ maps even though the simulation head model is different than the in-vivo subjects. These results were consistently achieved with 8 different in-vivo subjects.

Acknowledgements: This work was supported by NIH. **References:** [1] Ibrahim, T.S., MRM, 2005. [2].Hetherington, H.P., et al., MRM, 2010. [3] Eichfelder, G. et al, MRM, 2011, 66: p1468-1476 [4] Lee, J. et al, MRM, 2011, 67: p1566-1578