Lower RF Power Absorption Combined with Uniform Excitation Using Multi-Port B_1 Shimming: Numerical Simulations and Experiments at 7T

L. Tang[1], T. S. Ibrahim[2,3], and Y-K. Hue[4]

[1]Electrical and Computer Engineering, University of Oklahoma, Norman, OK, United States, [2]Radiology and Bioengineering, University of Pittsburgh, Pittsburgh, PA, United States, [3]Electrical and Computer Engineering and Bioengineering Center, University of Oklahoma, Norman, OK, United States, [4]Radiology, University of Pittsburgh, Pittsburgh, PA, United States

Introduction: In 7T imaging, the interactions between the electromagnetic waves and the human head can degrade the homogeneity of the MRI excite (B_1^+) field and increase the RF power absorption. Thus, it is imperative to not only improve the homogeneity of B_1^+ field but also maintain an acceptable RF power requirement to achieve it. For the purpose of improving the B_1^+ field homogeneity, it has been widely accepted that the use of B_1 shimming (variable phase and variable amplitude excitation) or transmit SENSE [1-5] with transmit arrays may result in a significant increase of the RF power deposition. In this work, the finite difference time domain (FDTD) method combined with a coupled-element coil was used to improve the B_1^+ field homogeneity over three dimensional (3-D) regions with volumes as large as the whole head while simultaneously reducing the total RF absorption by human head to values lower than that associated with quadrature excitation. The concept of B_1 shimming with reduced RF power absorption was validated using a 7T whole-body system and the same coupled coil design.

Methods: A 16-element TEM resonator [6] operating as a transmit array and loaded with an anatomically detailed human head mesh was modeled by using the FDTD technique. With the superposition of the 16-channel transmit array, the B_1^+ field (clockwise circularly-polarized component of the transverse magnetic field) in selective regions of interest was optimized to achieve homogeneity as well as lower RF power absorption (compared to quadrature excitation).

In the simulations, the B_1^+ field calculations and optimizations were all performed on nine 3cm-thick slabs and three 6cm-thick slabs oriented in axial, sagittal, and coronal directions, as well as large 3D brain, and whole head regions. The total RF power absorbed in the head mesh was controlled such that it does not exceed the power absorption during quadrature excitation. Specific absorption rate (SAR) was calculated for every 10 gm of tissue (following the IEC regulations).

To demonstrate the validity of B_1 shimming optimized for both RF power and B_1^+ field homogeneity, a similar TEM coil design was modeled, built, and tested with a saline phantom on a 7T human MRI system using 4-port excitation/reception (performed with a Tx array). The B_1^+ field was optimized to achieve lowest COV (coefficient of variation) while maintaining or lowering the total power absorption by the load. Figure 1 shows an excellent agreement between the FDTD calculations and the experimental images. Comparing to quadrature excitation, the presented results show that a B_1 shimming scheme can lower COV by approximately 59% while consuming 94% of the total power absorption consumed during quadrature excitation.

Results and Discussion: Using B_1 shimming, Figure 2 shows that while maintaining lowering total RF power, the homogeneity of B_1^+ field was significantly improved (compared to quadrature excitation) over whole-head, the brain, and the twelve slab regions. Among these 14 regions, the greatest improvement of the homogeneity of B_1^+ field distribution was for posterior 3-cm coronal slab where the COV was reduced to 23.5% of its original value. The SAR peak values and the COV of SAR distributions obtained using optimized excitation were compared to the ones obtained under quadrature excitation as shown in Figure 3. The results show increases in the peak SAR values and in the COV of the SAR distribution. Local SAR minimization was not considered in these optimizations as it currently could not be experimentally confirmed with our 7T system.

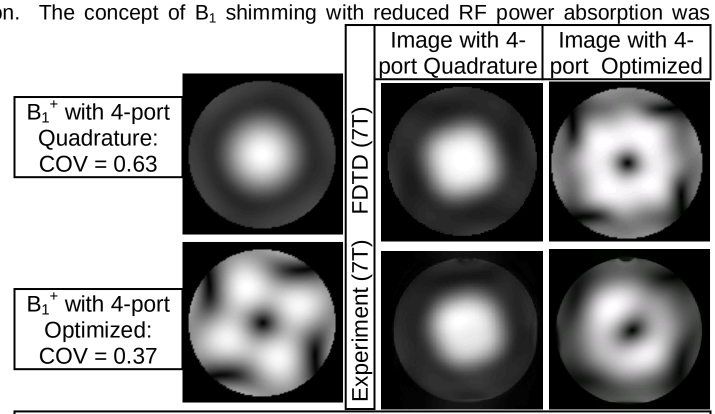


Figure 1: B_1^+ field calculated under quadrature and optimized excitation and the resulting images obtained using FDTD simulations and experiment. In the experimental and calculated images, a sum of squares algorithm was applied on the receive field.

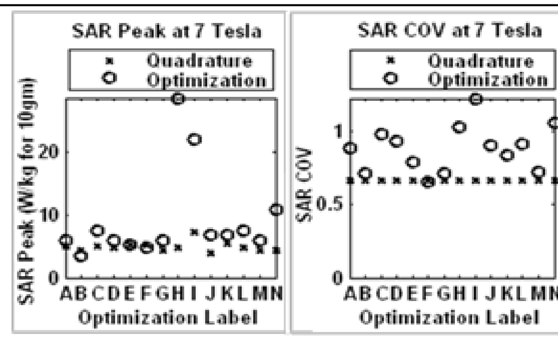
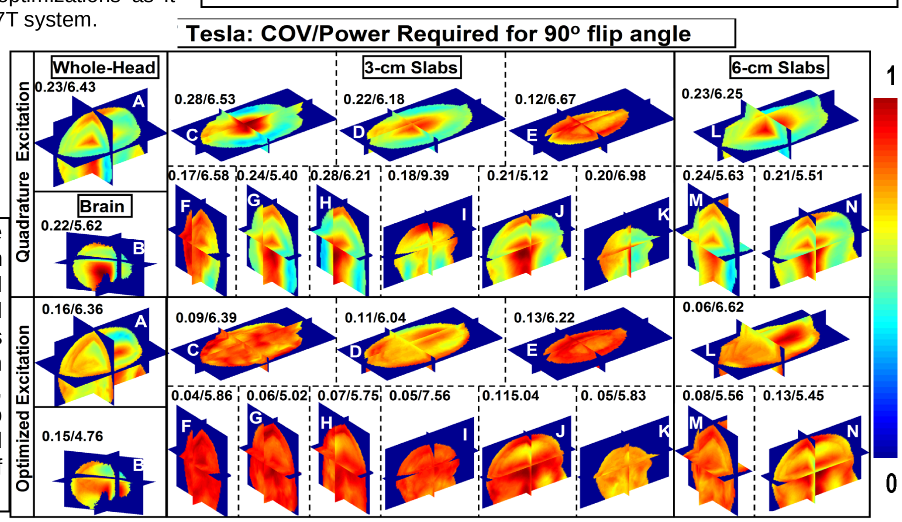


Figure 3: SAR peak values and COV plots. The optimization labels on the x axis are defined as in Figure 2. The SAR peak values were averaged for every 10gm-tissue and the SAR distributions' COV are presented using quadrature ("x") and optimized ("o") excitations.



References:

1. Hoult, D.I., JMRI, 2000. p.46-67.
2. Van de Moortele, P., et al., MRM, 2005. p.1503-18.
3. Wald, L., et al. *14th ISMRM,* 2006. Seattle.
4. Ibrahim, T.S., IEEE TME, 2006. p. 1341-7.
5. Katscher, U., et al., MR Mat. in PBM, 2005. p. 81-88.
6. Vaughan, J., et al., MRM, 1994. p. 206-218

Figure 2: Normalized B_1^+ field distributions at 7T. The 14 subfigures represent whole head, brain, 3-cm slabs and 6-cm slabs under the quadrature and optimized excitations. Every subfigure is normalized to its maximum value, and the normalized color bar is for all the subfigures. The numbers above each subfigure represent the "COV/the absorbed power", where the absorbed power in each case is scaled to the RF power required to achieve a mean B_1^+ field intensity, 1.957 micro Tesla, through each region of interest.