7 Tesla Whole-Slice and Localized Excitation Everywhere in the Human head

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Introduction: Before ultra high field (UHF) human MRI (≥ 7T), many techniques for achieving field homogeneity or any specific type of field distribution within the load (head/abdomen) have been studied [1-3]. Since all of these algorithms were proposed for low field imaging, incorporating the specific characteristics of the load into the design parameters of these methods was not needed, and therefore was not implemented. In early numerical work for UHF MRI, it was shown that the RF Coil/head interactions could be altered by changing the excitation mechanism [4] of the coil. This concept has been clearly verified in recent experimental head studies at 7T and 9.4T with Stripline TEM coils by varying the phases of the voltages driving the array of decoupled coils [5]. Based on these findings, multi-port excitation by varying the phase and/or the phase and amplitudes of the coil's drive ports was seen as a possible solution for achieving uniform excitation in axial slices. In this work, multi-port excitation with variable phase/amplitude approach is further investigated in order to achieve homogenous whole-slices excitation as well as precise localized excitation within the same slices that are targeted for global homogeneity. Through the use of electromagnetic theory, phased array excitation concepts, and numerical modeling, it is demonstrated that 1) highly homogenous 7T excitation over whole- axial, sagittal, and coronal slices of the human head and 2) spatially positioned highly focal excitation (localized to a particular region of interest within the same aforementioned slices) can both be achieved in any region of the head with the same RF volume coil.

Methods: To achieve localization and global homogeneity in whole-slices, a 16-port TEM head coil was numerically designed, such that the mode of operation tuned near 298 MHz (7T). The mathematical model of the coil was tuned while it was loaded with an anatomically detailed human head mesh. The coil struts (in this case 16) were all excited to achieve global and localized excitation in whole-slices. Both of these excitations were obtained using optimization routines that utilize superposition theory of the calculated magnetic field data. The global coverage criterion is to obtain the best homogeneity possible for the excite (B_1^+) field, namely lowest standard deviation in a slice of interest. The main approach taken in the localized coverage is to relocate the high intensity spot(s), due to the non-uniformity of the B_1^+ field, to a particular region of interest in any of the slices that were chosen for global homogeneity, or simply in electromagnetics terms, produce a strong and uniform B_1^+ field in the chosen region. To study the proposed localized coverage mechanism, regions of interest were first arbitrarily chosen in the same slices that were utilized for global excitation such that when they are superimposed, the entire slice area is covered. Two optimization criteria were implemented: a) maximizing the spin excitation in the region of interest and 2) minimizing the spin excitation everywhere else in the same slice, both of which were done simultaneously. Superficial regions ranging from 16 to about 60 cm^2 were chosen to demonstrate the effectiveness of this method.

Results: The top row of Figure 1 displays axial, sagittal, and coronal slices of the B_1^+ field, normalized such that the highest flip angle is 90°. The figures show both non-optimized (standard progressive phase shifts, i.e. multiple fractions of π/8, and uniform amplitudes), and globally-optimized (over a whole slice) 16-port excitation cases. In terms of B_1^+ field homogeneity, the results demonstrate that 3.5-fold improvement (evaluated by the standard deviation values shown on the top left corner of each subfigure) for the axial and sagittal slices and 4-fold improvement for the coronal slice, over that obtained with the non-optimized technique. The bottom and middle rows of Figure 1 show the arbitrarily chosen superficial regions of interests and the B_1^+ field distribution for the localized coverage mechanism at 7T. The described arrangement demonstrates that the average B_1^+ field in superficial regions ranging from 16 cm^2 to about 60 cm^2 can be on the order of 5 to 46 (localization factor) times higher than anywhere else in the same slice containing this region, with the only exception being the case where the superficial regions of interest are in the central section of the axial slice. The localization factor for these regions varied from 2.7 to 7.2. The B_1^+ field distributions and the spatial locations of the selected superficial regions demonstrate that a focal excitation can be achieved everywhere in each slice.

Discussion: The benefits of the whole-slice homogenous MRI excitation are obvious; combined with slice-selective gradients, it is potentially possible to image the entire head if whole-slice homogenous excitation can be achieved across the whole-head volume. Figure 1 reveals that highly homogeneous axial, sagittal, and coronal UHF MRI images can be attained anywhere in the head volume with this method.

In terms of excitation of the spins, the localization approach proposed in this work is different than tailored RF pulse techniques by itself and/or combined with multiple RF coils for transmit SENSE. Unlike the proposed method, transmit SENSE waveforms are totally independent from each other. Also, the proposed approach redistributes the RF fields within the load, rather than using gradients for selectivity as the case with tailored RF pulses which require adequate homogenous excitation (over the region of interest) or prior accurate knowledge of the exact B_1^+ field inhomogeneity (the latter being a condition for transmit SENSE as well). Furthermore, contrary to the proposed method, tailored RF pulses alone or combined with transmit SENSE will not adequately work for regions that possess very low B_1^+ field intensity. A disadvantage of this method, however, is that unlike tailored RF pulses and transmit SENSE, it cannot localize to exact arbitrary shapes. This can be seen from Figure 1, in which the RF field distributions do not exhibit sharp edges as the denoted boxes. Combinations of either tailored RF pulses or transmit SENSE, along with the proposed variable phase/amplitude excitation, targeted for the same selected region(s) will provide a highly accurate localization technique that is capable of imaging any region in the head at UHF MRI.

References:

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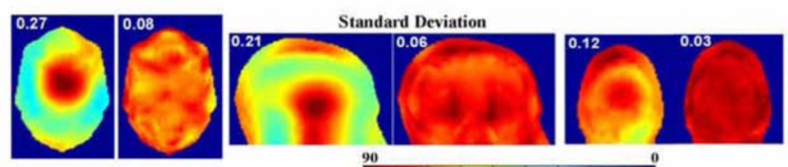

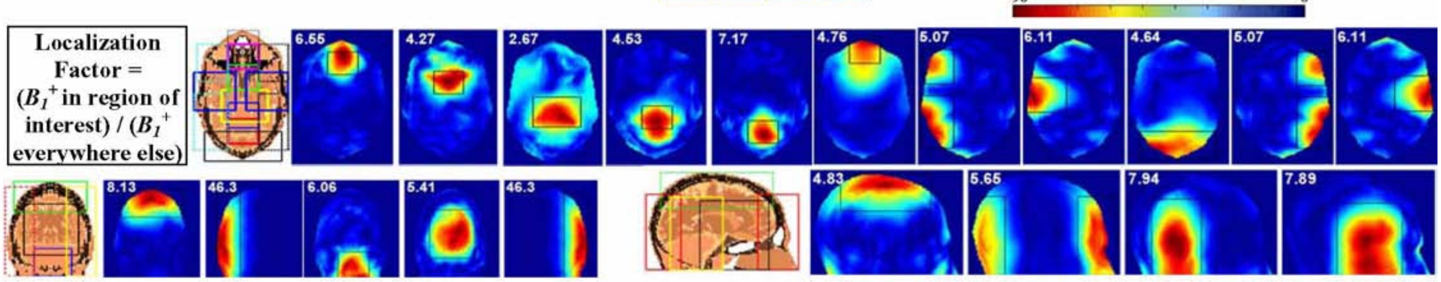

Figure 1: *Whole-Slice Homogeneous Coverage (top row)* and *Localized Coverage within Whole-Slices (middle and bottom rows) at 7T.*