Improving High-Field Transmit B1 Field Homogeneity Using Coupled Inner Elements

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Introduction: The inhomogeneous B1 field profiles of RF transmit coils are well known problems for MRI at high field strengths (1). Due to the much shorter wavelength inside the human head, the dielectric mode causes bright spots at the center and dark regions in the periphery of the head. B1-inhomogeneity is problematic for many applications and numerous efforts have been devoted to improve the homogeneity (2), (3). In this study, we present a new approach by using a multilayer resonance structure. The outer-layer is a regular volume transmit coil, for instance, a multi-rung birdcage coil in our study, and the inner layer is a structure that helps improve homogeneity over the structure. Here simulations are presented that show by appropriately coupling the two layers, B_1 field homogeneity can be improved.

Methods: The proposed method is to control different regions of the B_1 profile in the radial direction by using multi-layer radially positioned coil structures. In the current design, the outer-layer is a 32-rung birdcage coil, which generates very well known high B_1 regions at the phantom center. Instead of altering the out-layer coil directly to improve B_1 homogeneity as has been suggested, we leave the outer element as a standard birdcage and add a second layer of coils to act with the outer layer in transmit mode. This layer is dedicated to generate a periphery-dominated B_1 profile. As an initial step, we apply an array of surface coils in the inner-layer due to their well-known B_1 profiles that are higher on the surface. The transmit coil structure is illustrated in Fig. 1. To achieve an improved B_1 homogeneity, the coupling of the inner-layer coils to the outer birdcage needs to be properly determined. If a surface coil is tuned to the same resonant frequency as the outer-layer volume coil, the overall B_1 profile may be too bright in the periphery. On the other hand, if a surface coil is completely detuned, then its effect will not be seen. Since we want a balanced effect between these two extremes, the excitation is controlled by tuning surface coils to an appropriate resonant frequency and then passively coupling them to the outer-layer coil. Other procedures to control the amount of coupling can also be used, for instance, by using resistors to dampen the amplitude of the induced currents. Both procedures were considered in this study and the values were determined by a computer simulation program.

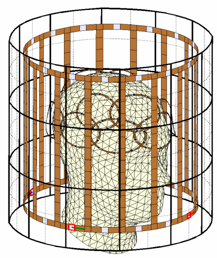

Figure 1: The transmit RF coil system and the human head.

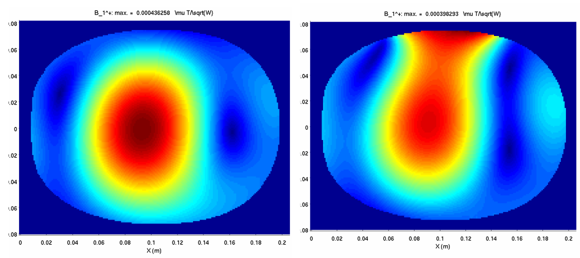

Figure 2: Left: Simulated B1 profile of a 7T 32-rung shielded birdcage coil. Right: simulated B1 profile shimming by using one inner-layer coil element.

Results and Discussion: We started with coupling a single element to the birdcage coil. Figure 2 shows the simulated birdcage B_1 profile in the human head and the overall B_1 profile of the coupled system. The appropriate amount of coupling is found by computer optimization. A cost function is defined with respect to the B_1 homogeneity and reduced by multi-directional optimization methods. The best combination of detuning frequency and resistance values minimizes the cost, which is shown on the right of Figure 4. To further verify the feasibility of the coupled system, we compared the MR images of a single volume coil and that of a volume coil coupled with one surface element. In both cases, volume coil is the only receiver. The volume coil is a 30-cm inner diameter TEM transmit coil, model NM008-7T-GE (Nova Medical, Wilmington, MA) and the experiments are performed in a 7.0 Tesla GE scanner. Gradient Echo images with 5 degree flip angle, TR = 150 ms, TE = 6.9 ms were taken. A surface coil with 8-cm inner diameter was positioned under the phantom. It was tuned to 300 MHz without additional resistors. Fig. 3 shows the resulting MR image together with the reference. It is clear that the intensity shifts upward toward the coupled surface coil. Due to the receive sensitivity profile of the volume coil, the periphery adjacent to the surface coil is (much) darker than the true transmit B_1 profile. This result shows that the B_1 transmit profile can be manipulated by the proposed coupled transmit coil. After verification, we continued to the design of a two-level 12-element system and the predicted B_1 profile on one axial slice is shown in Fig. 4. The improvement is obvious if we compare it to the reference profile on the left of Fig. 2. The standard deviations of the B_1 profiles on eight axial slices are shown in Fig. 4 and the average homogeneity improvement (or the reduction of standard deviation) is 43%. In all simulations a small frequency shift in the birdcage coil spectrum due to the coupling is predicted. However, this should not be problematic due to the low Q of loaded birdcage coils.

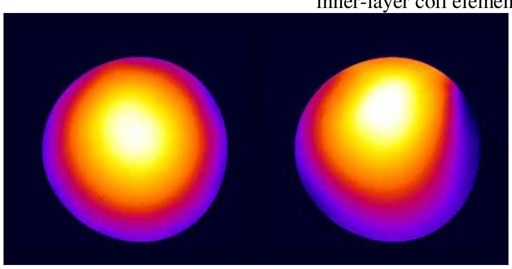

Figure 3: Left: the reference image of a 7T volume coil. Right: the MR image when coupling one surface coil element (on the bottom) to the volume coil during transmit. The volume coil is the only receive coil in both cases. Note that due to the receive sensitivity profile of the volume coil, the peripheral region adjacent to the surface coil is (much) darker than the true transmit B1 profile.

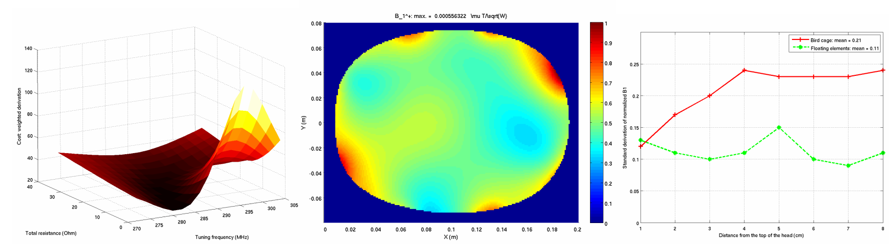

Figure 4: Left: Cost functions of a single inner-layer element. Middle: the simulated overall transmit B1 profile of the eight-element transmit system. Right: the standard deviation on eight axial slices from a 2-level 12-element design compared to that of a birdcage coil.

Conclusion: We propose a new method for improving the B_1 field homogeneity by using multiply layers of coils in the radial direction. The current design employs an outer-layer volume coil and an inner-layer coupled surface coil array. This design should be readily implemented and other variations are also possible, e.g., the inner elements can be tuned by varactors or actively driven rather than passively coupled to the outer element.

References: 1) Vaughan J.T. et al, MRM, 46:24-30, 2001 2) Alsop D. et al, MRM, 40: 49-54, 1998 3) Collins C.M. et al, ISMRM, Seattle, 2006, 702.