An Inverse Methodology for High Frequency RF Coil Design with De-emphasized B1 field

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INTRODUCTION: High magnetic field (frequency) MRI technology has brought considerable engineering challenges in the form of ancillary hardware, including RF resonators. Studies in high frequency MRI have shown significant interactions between the RF (B_1) field and biological loads [1]. Theoretical analyses and experimental results have also shown that, although the RF coils operated very well without loading, large distortions can be observed in MR images of larger biological samples [1, 2]. This necessitates the design of new types of high frequency RF coils considering the loading effect. The inverse method combined with Method of Moment has been introduced and described by Fujita et al. [4] and Lawrence, et al. [5] and the design concept presented here is an inverse method with de-emphasized B_1 target fields. The de-emphasis method has been proved to be an effective strategy for high frequency RF coil design [3]. As inverse methods for RF coil design can prescribe and pre-set the target B_1 fields in the DSV, we can therefore potentially include an estimate of the loading influences and de-emphasize the B_1 field to counteract the resultant higher B_1 strength in the centre of loads. In this work, the combination of both methods has been implemented, and FDTD simulations at 4T demonstrate that the method improve the B_1 homogeneity compared with traditional transmitter coils.

METHODOLOGY: The inverse method begins with an unknown current density on region of a cylinder and a DSV inside this cylinder. The time harmonic Green's functions are used to calculate the current density on this cylinder that is necessary to generate a desired field within the DSV. A stream function technique in conjunction with MoM method can then be employed to discretize the continuous current distributions and find the corresponding resonant conductor patterns and capacitor values [5]. The concept presented here is that by predefining the B_1 field to be depressed centrally, more uniform loaded images result .In this work, lineally polarized B_1 is de-emphasized as 40% lowered in the middle to take into account the perceived difference of the loading in 4T. The current density is calculated by the inverse method with this de-emphasized B_1 field. To accurately investigate the field/tissue interaction, the designed "head coil" is loaded with a voxel based human head model and an homogenous phantom ($\varepsilon r=78$, $\sigma=0.4$), where an in-house finite difference time domain (FDTD) routine is employed to calculate the fields and the resultant signal intensity within the head model. In FDTD calculations, the ideal current density distributions from the inverse method are used to initially test the feasibility of the method. A 16-rung, conventional birdcage coil is also simulated with FDTD to make the comparison. The B_1 fields and the resultant *SI* for a variety of loads are calculated.

RESULTS: In the simulation, the current density of a standard head coil with diameter of 25cm, length of 30cm and DSV sphere of 20cm diameter is calculated at 174MHz. The de-emphasized field and the corresponding current density on the coil cylinder are shown in Fig. 1. Here the B_1 field is de-emphasized to be 40% lower in the middle of the DSV than the periphery. This indicates that with the same geometry, different target B_1 fields generate different current densities on the coil cylinder. The B_1 fields induced by this current distribution in an unloaded condition, in the homogenous phantom and in a human head model are calculated and compared in Fig.2. In this figure, all the B_1 fields are normalized along the polarization direction. It can be seen that for the dielectric loads, the inverse method designed coil offers an advantage in the normalized B_1 homogeneity compared with the same size conventional coil. Fig. 3 is the resultant signal intensity for the human head images produced by a conventional birdcage coil and the inverse method designed coil with different B_1 emphasis directions. The results show that the inverse method designed coil results in almost uniform signal intensity values along the polarization direction. This again suggests that B_1 de-emphasis is useful in reducing the bright region typically introduced at 4T and above for head images.

CONCLUSIONS: In this theoretical work, a de-emphasized inverse method is proposed and one method of de-emphasizing the target field demonstrated. By de-emphasizing the target field in RF coil design, the generated B_1 field can be manipulated in an attempt to negate the alterations in image intensity caused by EM tissue/field interactions at high field. The results demonstrated here indicate that the method has promise and reduces anomalous intensity variations when compared to coils that are essentially designed to produce flat target fields in unloaded states.

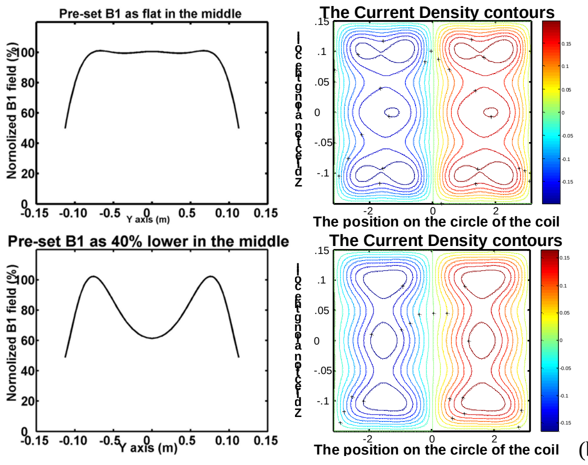
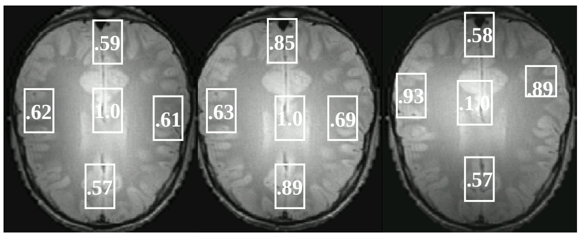


Fig.1 Differently Pre-set fields and the corresponding current densities for 4T RF head coil
(a) Flat B_1 field (b) De-emphasizing $B_1$to 40% lower in the middle



(a) (b) (c)

Fig. 3 signal intensity of human head in (a) birdcage coil
(b) Inverse method designed coil with x-axis B_1 de-emphasis
(c) Inverse method designed coil with y-axis B_1 de-emphasis

ACKNOWLEDGE

Financial support from the Australian Research Council and the NIH (P41 RR16105) are gratefully acknowledged

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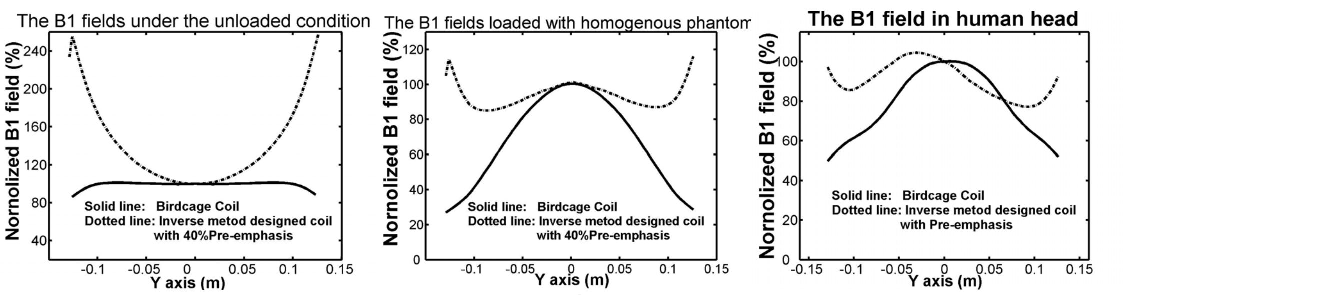

(a) (b) (c)

Fig.2 B_1 field in the birdcage coil and the coils designed by inverse method loaded with: (a) air (b) the homogenous phantom (c) human head