Improving B1+ Uniformity at 3T using Optimized Spiral Birdcage Phase Gradient RF Coils

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Introduction

Due to RF wave behavior and sample interaction at high B0 fields, $B1^+$ shimming aiming at uniform excitation is important for improved SNR and image uniformity, while avoiding complicated 2D spatially selective RF methods. Most methods have focused on optimizing the current distribution in a typical birdcage structure, but this alone is not sufficient as variation in the current distribution along the z-axis is required [1]. Improved B1 homogeneity can be achieved by varying the phase of the B1 field in the z-direction using a spiral birdcage design [2]. Such "phase gradient" RF coils are also required for a new RF-only MRI method [3-7] that benefits from a uniform $B1^+$-magnitude distribution. A multi-transmit array method offers some promise, however it is inadequate due to limited number of transmit channels. We propose RF coil designs that can be used to achieve uniform $B1^+$ fields using optimized single Tx-channel phase gradient coils at 3T.

Methods

Full wave RF simulations were performed using xFDTD v7 (REMCOM) and experiments were performed on a Siemens 3T Trio-Tim MRI system, using the Siemens 2L phantom (12cm diameter and 20cm long). All coils were 16cm in diameter and 13 cm long, driven in quadrature. Experimental $B1^+$ mapping was performed using the double angle method [8] with a spin-echo acquisition (TR=1.5sec).

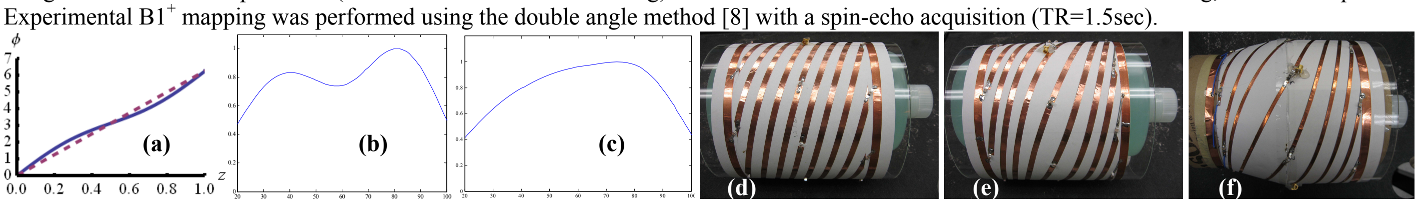

Fig. 1: (a) Leg twist phase angle and **(b,c)** 1D $B1^+$ field of the **(d)**standard 2π spiral birdcage and **(e)**variable pitch spiral respectively;**(f)**domed variable pitch spiral

Results and Discussion

Using a spiral birdcage coil, we investigated influence of the pitch angle (*Fig.1a*) of the spiraling leg currents and the radius of the cylinder (*Fig. 1f*) as a function of Z. These parameters determine a 3D spatial current distribution and thus the RF field produced by the coil. We focused on the 2π spiral birdcage phase gradient (*Fig.1d*) as our goal was to improve phase-gradient RF-only MRI, keeping in mind that a smaller phase gradient such as a 1π may be better suited for creating a general RF coil with perfect $B1^+$ homogeneity at 3T. *Fig.1b* shows the simulated 1D z-axis $B1^+$ magnitude distribution for a standard spiral birdcage (*Fig.1d*) that matches the experimental results (*Fig.2a*). Notice that the $B1^+$ field is not symmetric along the z-axis, and transverse inhomogeneity also exists (brighter in the periphery), a characteristic of strong spiral birdcage z-phase gradients. A variable pitch spiral birdcage (*Fig.1e*) was built with the pitch angle of the legs given by $\varphi=2\pi[z/L + 0.06\sin(2\pi z/L)]$ (*Fig.1a*). The simulated $B1^+$ is shown in *Fig.1c*. *Fig2b* shows that this variable pitch design removed the $B1^+$ inhomogeneity along z, but the $B1^+$ remained asymmetric with lower amplitude on the left (superior). To deal with this imperfection we domed the superior(left) end linearly from 16cm to 13 cm diameter (*Fig.1f*). *Fig. 2c* shows that the doming was a little too strong, but successfully increased $B1^+$ on the superior end. All these modifications for improving $B1^+$ uniformity over a standard spiral birdcage were accomplished without significantly changing the phase gradient linearity. Using a spiral pitch angle that is asymmetric along z, was not as effective as varying the diameter of the coil asymmetrically. Although optimization of the design is not finished yet, it can be seen that indeed we have the tools to alter the $B1^+$ field distribution to improve its homogeneity.

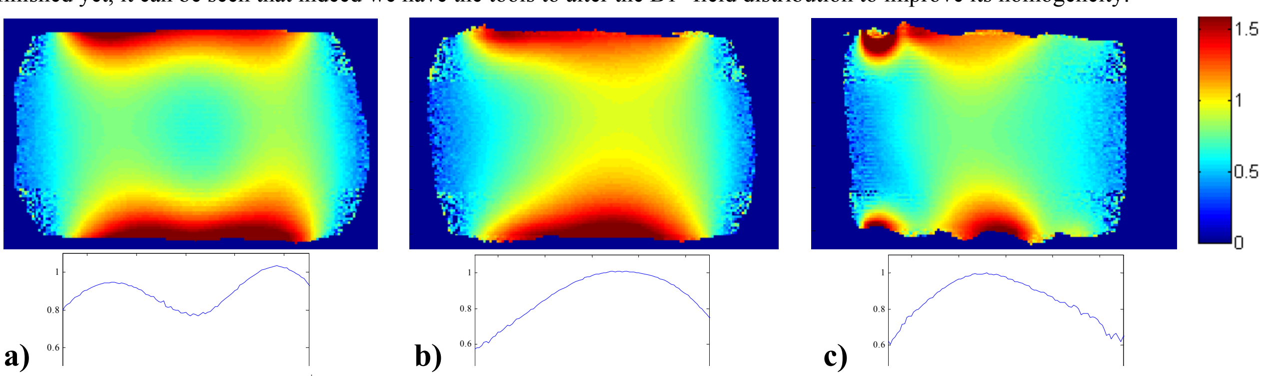

Fig. 2: Experimental 2D and 1D $B1^+$ field distributions for the **(a)** constant pitch spiral, **(b)** variable pitch spiral, **(c)** domed, variable pitch spiral.

Conclusions

With complex current distributions, which include both 3D spatial positioning of currents as well as varying the phase (twist) of the current sections, the $B1^+$ field distribution can be shimmed to enable more homogenous excitation in MRI. The 2π phase gradient is likely too strong for perfect $B1^+$ optimization. Although our results are not fully optimized, we have demonstrated that an asymmetrically variable pitch spiral birdcage with one end domed can be an effective method of $B1^+$ shimming, for obtaining a more uniform $B1^+$ field distribution, in addition to also generating a phase gradient for RF-only MRI. Such optimized current distributions may provide some insight into building blocks for Tx-array element designs.

References
[1] King et al, ISMRM 2009 p.390; [2] Alsop et al, MRM 40:49-54 (1998); [3] Sharp and King, MRM *(in press)*; [4]Sharp et al, ISMRM p2675 (2009); [5] Sharp et al. ISMRM p.829,p.1083 (2008); [6] King et al. ISMRM p.680 (2007); [7] King et al. ISMRM p.2628 (2006); [8] Insko et al, JMR Series A 103:82-85 (1993).