Less Wiggle Room at High-Field: A Segmented Birdcage-Like Example with Excellent Planar Uniformity

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Introduction

Although high-field MRI has various advantages, it also introduces problems due to shortened RF wavelengths, as well as increased RF heating. To address the larger B1 field inhomogeneity [1], the so-called "TEM resonator" [2] has been optimized by varying the driving magnitudes and phases of individual elements. Numerical simulations have also been made for volume coil or transmit arrays [3-5]. In this work, we present an analytical model as an alternative for optimization and insights. With this tool, we can achieve practically perfect RF planar homogeneity for a relatively short segmented birdcage-like model, which channels the spatial oscillations into the third dimension, a' la the familiar TEM mode.

Methods

To model the shorter wavelength effects over relevant dimensions, consider a dielectric constant ε = 60 (wavelength λ~9.68cm for 400MHz) over all space. A birdcage-like coil without an active end-ring structure is constructed with elements of length of 2.5λ (~24.2cm). The diameter of the cage is 25cm. Each element is composed with five electrically isolated, individually center-fed half-wavelength dipole antennas (Fig.1). The magnetic field produced by a dipole antenna with finite length carrying a sinusoidal standing wave current can be calculated analytically anywhere outside the antenna from a simple closed-form expression [6]. The field produced by the coil can be written as a linear combination of the unknown currents on the segments (after symmetry is imposed). A quadratic functional $W = \sum \left(B_{1,y} \left(I_{x,1}, I_{x,2}, \ldots, I_{y,1}, I_{y,2}, \ldots; \boldsymbol{x}_i \right) - B_0 \right)^2$ is therefore constructed to impose uniformity, and minimized with matrix inversion techniques. For the example discussed below, the minimization is performed in the central axial plane. Current magnitudes and phases solved in this way are then used to plot the magnetic field.

Results and Discussion

For 16-rung and 32-rung segmented cages, the optimized B1 field transverse profiles are shown in Fig.2, together with the B1 field profile of a conventional birdcage model (with in-phase currents that are azimuthally sinusoidal and axially uniform) with the same geometry. The B1 field produced by a birdcage (designed for low frequency) wiggles dramatically in the central transverse plane. However, the segmented 16-rung and 32-rung cages produce an excellent B1 field homogeneity in the central transverse plane. Along the transverse direction in the central axial plane, the B1 field variation over 8cm distance is 175% for a conventional birdcage, 0.009% for 16-rung segmented birdcage and 0.002% for 32-rung segmented birdcage. B1 field in central axial plane of segmented cages is aligned with vertical direction, while in conventional birdcage, the field turns around. Along the longitudinal direction, the field in the segmented cages wiggles as cos(*kz*). (Fig.3) Up to 6.5cm from the center, perfect transverse homogeneity of B1 field is maintained over different axial planes. These facts suggest that the optimized B1 field within segmented birdcages is a TEM mode. Furthermore, although currents on different sections of the 32-rung segmented birdcage have different magnitudes and phase angles, on each section at any time, the azimuthal current distributions among the elements are still sinusoidal. This implies that by increasing the degrees of freedom, we can restrict the special variation of the rf field entirely to the longitudinal direction (the wiggling that Maxwell demands is restricted completely to the z direction) and thus keep practically perfect transverse homogeneity. Although there is a large rf field "splash" outside the birdcage, we have also carried out modeling that includes shielding. The results are 1) the excellent transverse uniformity is maintained, 2) the universal azimuthally sinusoidal current is maintained, and 3) the splash-out can be reduced significantly. Finally, an LC network can be designed such that the segmented current distributions found in this work can be driven. Analogous modeling can also be carried out for concentric cylinders with different dielectric constants (e.g., air).

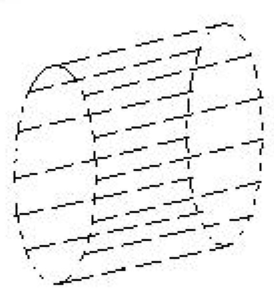

Fig.1 The segmented birdcage with five sections

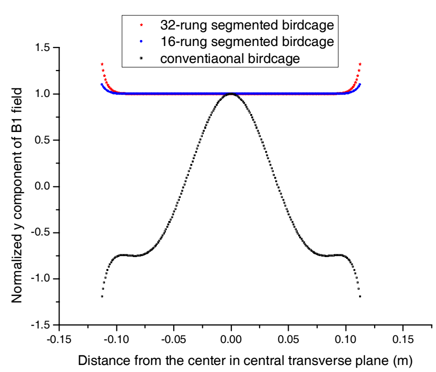

Fig.2 Normalized $B_{1,y}$ transverse distribution

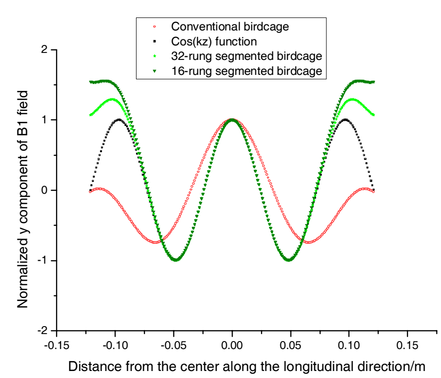

Fig. 3 Normalized $B_{1,y}$ along longitudinal direction

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