Evaluation of a Degenerated Birdcage Coil for Parallel Imaging

C. Wang[1], P. Qu[1], J. Yuan[1], and G. X. Shen[1]

[1]Electrical and Electronic Engineering, The University of Hong Kong, Hong Kong, Hong Kong

Introduction:

Generally, there are N/2 resonant frequencies (or N/2 order modes) for an N-rung low-pass birdcage coil [1]. Each order mode has different sensitivity. If all the modes can be resonant at the same frequency (totally degenerated), these modes have potential for parallel imaging. Standard homogeneous mode (mode 1) and first gradient mode (mode 2) of an eight-rung low-pass birdcage coil have been applied for parallel imaging at 1.5T successfully [2]. In this study the potential of using higher-order modes of a 12-rung low-pass birdcage coil for parallel imaging is investigated at 3T.

Methods:

A 12-rung low-pass birdcage coil (20-cm i.d. and 21-cm length) is modeled with 2mm isotropic resolution. Copper was modeled as a conductor with conductivity of $5.95\text{x}10^7$ S/m. The phantom was modeled as a sphere with 18cm diameter (relative permittivity = 63.025, conductivity = 0.464 s/m) which represents average brain tissue at 3T (128MHz). Capacitors were modeled as voltage sources. All the voltage sources have the same unit amplitude, and the initial phases of each voltage source for each order mode are given by Eq (1), where N is the number of rungs in the birdcage, $\theta_{m,n}$ is the initial phase of the voltage source in the n*th* rung ($1 \le n \le N$) for the m*th* order mode ($1 \le m \le N/2$). Finite difference time domain

$$\theta_{m,n} = \frac{360}{N} m(n-1) \qquad (1)$$

(FDTD) method [3] was used to calculate the transient $\mathbf{B_1}$ fields with the aid of commercially available software XFDTD (Remcom, Inc., State College, PA). Circularly-polarized components of the $\mathbf{B_1}$ field ($\mathbf{B_1}^+$ and $\mathbf{B_1}^-$) were calculated from two sets of transient $\mathbf{B_1}$ fields which are a quarter period apart in time and $(\mathbf{B_1}^-)^*$ can be taken as sensitivity of the coils by the principle of reciprocity [4]. Geometry factor (g-factor) describes the ability with a given coil configuration to separate pixels superimposed by aliasing, and it is regarded as an important criterion for design of RF coils for parallel MRI. Generally, the less the g-factor, the better the parallel performance of the coil becomes. G-factor can be calculated through Eq.(2) [5]:

$$g_\rho = \sqrt{\left(\left(S^H \psi^{-1} S\right)^{-1}\right)_{\rho,\rho} \left(S^H \psi^{-1} S\right)_{\rho,\rho}} \qquad (2)$$

where S is reformatted coil sensitivity matrix, Ψ is the noise correlation matrix and ρ is the index of the voxel within the set of voxels to be separated.

Results and Discussion:

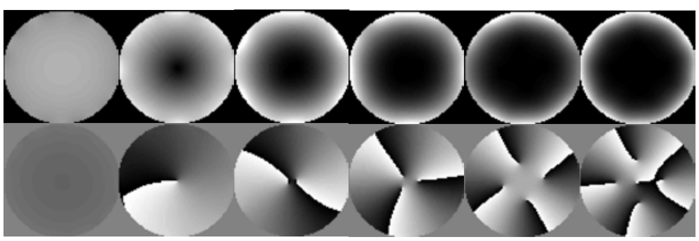


Fig.1 Magnitude (A) and phase (B) of $(\mathbf{B_1}^-)^*$ fields for 6 order modes of the 12-rung low-pass birdcage coil on the mid-axial plane at 3T

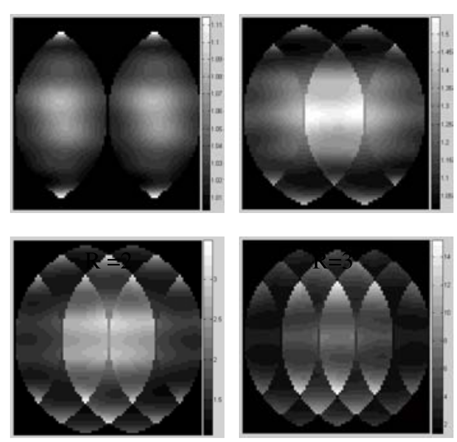
The magnitude and phase of $(\mathbf{B_1}^-)^*$ field for 6 order modes of the 12-rung birdcage coil is illustrated in Fig. 1. The higher-order modes produce increasingly less homogeneous $(\mathbf{B_1}^-)^*$ magnitude as the number of order increase. The phase distribution of each mode is also different, which may provide benefits for parallel imaging. The geometry maps (g-factor map) at different acceleration rates are shown in Fig.2, and the detail information about g-factor maps are listed in Table.1.

According to Fig.2, the distinct bright areas (with high g-factor) lie in the center of the folded FOV, reflecting unfavorable sensitivity relations. Note that in these maps the object borders are reflected by characteristic contours due to the exclusion of pixels outside of the sample. For imaging on the mid-axial plane, the average g-factor is still less than 1.8 and maximum g-factor is about 3.55 even the acceleration factor up to 4. If R>4, the g-factor increases dramatically.

In practice, the number of receive channels of MRI system is limited. In order to find out optimal mode combinations for a specific number of receive channels, we select different combinations of 4 modes out of 6 order modes to calculate g-factors for different acceleration factors. The results show the optimum choice of mode combinations may be different for different acceleration factors (R). For example, the combination of modes (1,2,3 and 4) has the lowest average g-factor (1.0372) for R=2, and the combination of modes (1,2,3 and 5) has the lowest average g-factor (1.3334) for R=3. The optimal mode combination for other number of receive channels can be calculated in the same way.

acceleration factor (R)	2	3	4	5	6
average g	1.0285	1.1880	1.7978	4.1331	9.1728
maximum g	1.1173	1.5625	3.5531	15.574	64.473

Table 1. Average and maximum g-factor for different acceleration rates



R =4 R=5

Fig.2 Geometry factor maps of different acceleration factors (R=2,3,4,5) with all 6 order modes employed for imaging on the mid-axial plane.

Conclusion:

The average g-factor is still less than 1.8 and the maximum g-factor is 3.55 even if acceleration factor is as high as 4 when all 6 order modes of 12-rung low-pass birdcage coil are incorporated for imaging on a mid-axial plane at 3T. Considering the limitation of the number of receive channel in MRI system, the optimum combination of resonant modes can be obtained based on different acceleration factors.

References:

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