Optimization of a multi-channel transmit, Quadrature Receive Birdcage Coil

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Introduction:

Although ultra high field (7T to 9.4T) MRI has signal-to-noise ratio (SNR) advantages, the associated RF inhomogeneity is a challenge for some applications. This is mainly caused by RF wavelength effects [1]. Some methods for reducing transmit $\mathbf{B_1}^+$ field inhomogeneity [2-3] of multi-channel coils are proposed by varying amplitude and phase of individual driving ports. Normally, it is difficult to use the same method for receive of birdcage-like volume coils. In this work, we optimize by varying amplitude and phase of multiple driving voltages during transmission, and quadrature reception is used for a multi-port birdcage-like volume coil. For comparison, a conventional transceiver quadrature birdcage coil is also investigated. The optimization procedure is based on a set of $\mathbf{B_1}^+$ field of all modes of 12-rung birdcage loaded with a sphere phantom. They are used to estimate the modes distribution of the desired $\mathbf{B_1}^+$ (homogeneous) field, and then the port voltage distribution of each port, with singular value decomposition (SVD) method.

Methods:

Normally, there are n resonant modes and (1+n/2) resonant frequencies for an n-rung birdcage coil. But we can generate all resonance modes at the same resonance frequency by controlling the amplitude and phases of driving voltage of each port for a multi-channel birdcage-like coil, regardless of the degree of degeneracy. The finite-difference time-domain (FDTD) method is used to calculate the transient $\mathbf{B_1}$ fields of each resonant mode through time-dependent Maxwell's equations at resonant frequency of 300MHz. A region of interest (ROI), 26×26×28 cm^3 is divided into a mesh of 2,366,000 Yee cells, where the basic element of 3D meshes in FDTD method is 2 mm/cell in each dimension. A 12-rung birdcage coil (20-cm i.d. and 21-cm length) is modeled in the ROI. The conductivity of copper (5.95×10^7 S/m) is assigned to the coil cells. Voltage sources are placed at each rung to model capacitors and driving ports. The phantom is a sphere with 16cm diameter ($\varepsilon r = 51.898$, $\sigma = 0.553$ s/m) which represents average brain tissue at 300MHz. Transmit $\mathbf{B_1}^+$ fields and receive $\mathbf{B_1}^-$ fields of each mode are calculated from two sets of transient $\mathbf{B_1}$ fields which are a quarter period apart in time [4]. The target $\mathbf{B_1}^+$ is assumed as a homogeneous 1.17μT (for 5ms duration 90^0 pulse). By using SVD method, the coefficients of the mode distributions and the port voltage distribution for generating desired $\mathbf{B_1}^+$ field can be obtained [3]. For comparison, SNR of conventional transceiver birdcage and optimized multi-port birdcage are calculated by Eq.(1) [5], where τ is pulse duration, γ is gyromagnetic ratio, ρ is material density. The $\mathbf{B_1}^-$ fields for both cases (calculated based on mode1) are the same.

$$SNR \propto \frac{\sum_N \left|\sin(\gamma\tau\left|\bar{B}_{1n}^{+}\right|)\left|\bar{B}_{1n}^{-}\right|\right|}{\sqrt{\sum_N SAR_n \times \rho_n \times \Delta V}} \qquad (1)$$

Results:

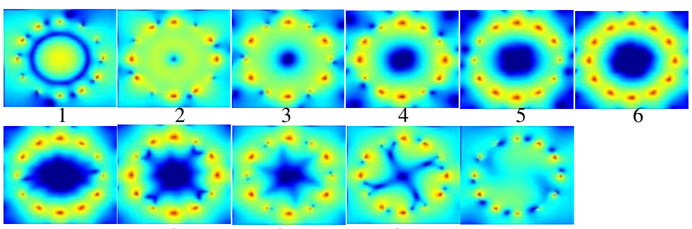

Fig.1, Amplitude patterns of 11 modes $\mathbf{B_1}^+$ field (phase patterns are not shown here)

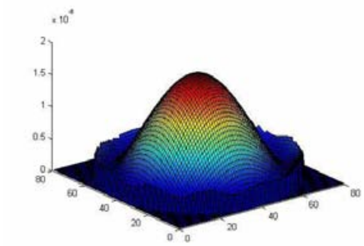

Fig.2 Non-optimized $\mathbf{B_1}^+$ field profile of conventional Birdcage (mode 1)

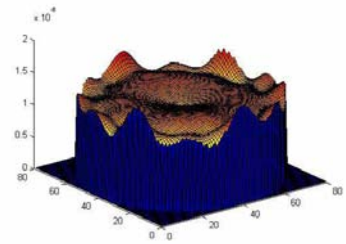

Fig.3 Optimized $\mathbf{B_1}^+$ field profile of multi-port driving Birdcage

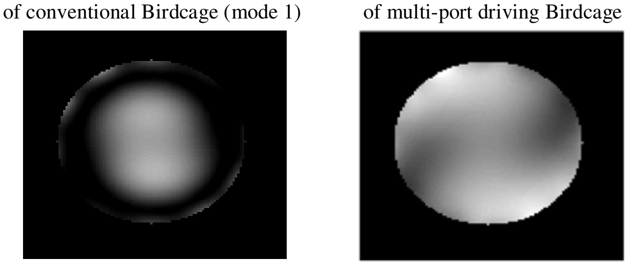

Fig.4, Axial signal intensity distributions for sphere phantom in conventional quadrature birdcage (left) and multi-port birdcage-like coils with optimized driving voltage distribution (right) at 300MHz

The $\mathbf{B_1}^+$ field of the 11 modes for the 12-rung birdcage coil are shown in Fig.1 (the rung current is 0 for mode 0 of birdcage). The $\mathbf{B_1}^+$ field of mode 1, which is the operational mode for conventional birdcage, is extracted and shown in details in Fig.2. The 'peak' at center indicates wavelength effects. The $\mathbf{B_1}^+$ field of the multi-channel birdcage optimized by SVD method is illustrated in Fig. 3. The percentages of the samples on axial plane having a $\mathbf{B_1}^+$ field magnitude within ±10% of the average $\mathbf{B_1}^+$ field magnitude on that plane are 23.47% and 80.06% for conventional quadrature birdcage and optimized multi-channel birdcage-like coil, respectively. The homogeneity of $\mathbf{B_1}^+$ field improves dramatically by optimization. Compared with the SAR of conventional birdcage (2.72W/kg), the SAR of the optimized multi-channel birdcage increased slightly to 3.04 W/kg. After normalization, the relative *SNR* on central axial plane for conventional birdcage and optimized multi-channel birdcage are 1 and 1.73 respectively. The simulated image intensity of phantom is shown in Fig.4. Although the phantom in this work is homogeneous, this method also can fully handle heterogeneous samples.

	$\mathbf{B_1}^+$ homogeneity within 10% variety*	Average SAR (W/kg)	Normalized SNR
Quadrature Birdcage	23.47%	2.72	1
Optimized multi-port coil	80.06%	3.04	1.73

Table11. $\mathbf{B_1}^+$, SAR and SNR comparison for conventional birdcage and optimized multi-channel birdcage. *The percentages of samples on axial plane having $\mathbf{B_1}^+$ field magnitude within ±10% of the average $\mathbf{B_1}^+$ field magnitude on that plane

Conclusions:

Compared with conventional transceiver quadrature birdcage, optimized multi-channel-transmit, quadrature-receive birdcage coil has dramatically improved $\mathbf{B_1}^+$ filed homogeneity and relative SNR, with slight penalty of increased average SAR.

References:

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