A Detailed Quantitative Analysis of B1 Components at 1.5T and 3T

X. Chen[1], and M. Steckner[1]
[1]Toshiba Medical Research Institute USA, Inc., Mayfield Village, OH, United States

INTRODUCTION: While SAR is crucial for the RF safety control of an MR scan, B_{1rms} (defined as $\sqrt{\int_0^{t_s} |B_1(t)|^2 dt \,/\, t_s}$ where B_1 is the total RF magnetic field) [1] serves as a supplemental safety metric. For example, B_{1rms} is useful for defining the MR conditional labeling of implants [1]. An unloaded quadrature driven (QD) birdcage coil generates nearly perfect B_1 with circular polarization: B_1^+ (the tipping component) is homogeneous and B_1^- (the component rotating counter to the spin precession) is zero and thus $|B_1^-| << |B_1^+|$ is usually assumed [2]. Loading the coil distorts the B_1 field, causing B_1^+ and B_1^- components. While only B_1^+ is useful for MRI purposes, both components contribute to RF power deposition ($|B_1| = \sqrt{|B_1^+|^2 + |B_1^-|^2}$). In this work we use FDTD (Finite Difference Time Domain) numerical simulations to demonstrate that B_1^- should not be ignored in loaded coils at either 1.5T or 3T.

METHODS: All simulations were performed with xFDTD and 39 tissue Visible Man model (both from Remcom, Inc., State College, PA) using a 24 rung high pass birdcage coil [3], with 63cm diameter, 68cm shield diameter and 70cm length (both coil and shield). The coil model was tuned to 64MHz (1.5T) and128MHz (3T) respectively with appropriate end-ring capacitors. QD was generated with two voltage sources of equal amplitude but 90 degree phase difference in one end-ring. The heart was aligned with the coil center, and the back was 13cm below the coil center (Fig.1). Frequency appropriate tissue parameters (dielectric permittivity and conductivity) were used. B_1^+ and B_1^- components for both unloaded and loaded situations were recorded after all simulations converged to steady state.

RESULTS: Fig. 2 shows B_1^+ and B_1^- maps for unloaded coil model at 1.5T and 3T. At both field strengths, $|B_1^+|$ is highly uniform and $|B_1^-|$ is negligible, confirming the $|B_1^-| << |B_1^+|$ assumption. Fig. 3 shows the distortions to B_1 fields due to loading. Numerical evaluations of $|B_1^-|/|B_1^+|$ at coil center and averaged in central axial slice (Table 1) show that the $|B_1^-| << |B_1^+|$ assumption is violated at 1.5T and more significantly at 3T. As a result, using $|B_1^+|$ alone will underestimate total B_1 field strength (see $|B_1^+|/|B_1|$ in Table 1) by up to 16%, on average over a 25 cm radius within the central axial slice and up to 74% within a 1 cm radius at 3T.

CONCLUSIONS: Numerical simulations show that loaded coils have distorted circularly polarized B_1 fields at both 1.5T and 3T. Ignoring B_1^- contributions results in underestimating total B_1 field strength. Total B_1 is essential for estimating implant risk and for the development of in-vivo SAR measurement [2, 4-6]. Additionally, B_1^- contribution can be more significant in parallel transmit systems than birdcage coils. Modeling and experiments are needed to accurately understand all contributions to total B_1 field for various imaging conditions.

REFERENCES: [1] IEC 60601-2-33. 3rd edition. [2] T. Voigt et al., ISMRM 2010, p. 3876. [3] W. Liu et al., Appl. Magn. Reson. 29 (2005): pp 5-18. [4] T. Voigt et al., ISMRM 2009, p. 4513. [5] M. A. Cloos et al., ISMRM 2009, p. 3037. [6] U. Katscher et al., ISMRM 2009, p. 4512.

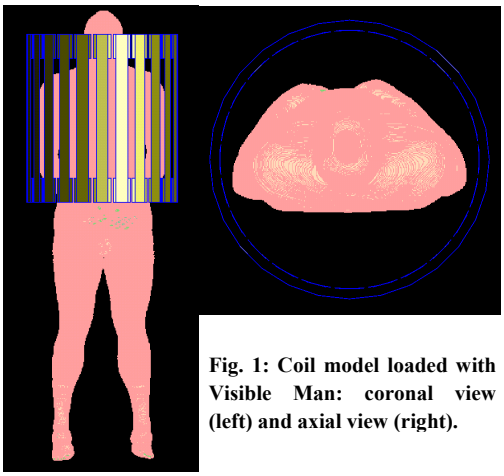

Fig. 1: Coil model loaded with Visible Man: coronal view (left) and axial view (right).

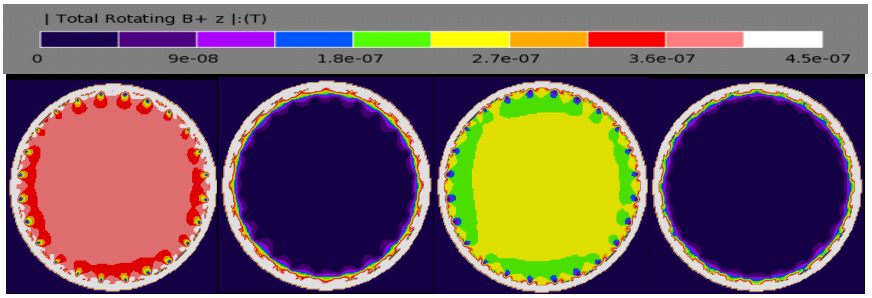

Fig. 2: B_1 maps for unloaded birdcage coil: (from left to right) B_1^+ at 1.5T, B_1^- at 1.5T, B_1^+ at 3T, and B_1^- at 3T.

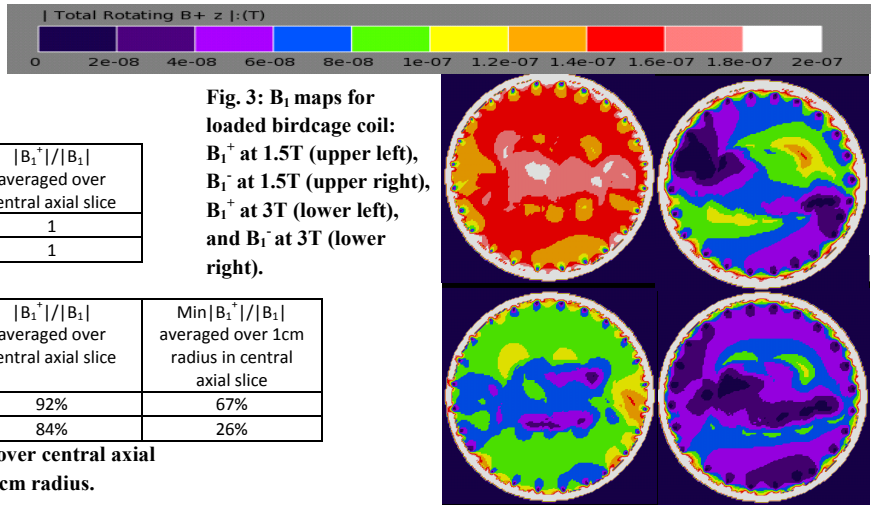

Fig. 3: B_1 maps for loaded birdcage coil: B_1^+ at 1.5T (upper left), B_1^- at 1.5T (upper right), B_1^+ at 3T (lower left), and B_1^- at 3T (lower right).

	Main Magnetic Field Strength	$\|B_1^-\|/\|B_1^+\|$ at coil center	$\|B_1^-\|/\|B_1^+\|$ averaged over central axial slice	$\|B_1^+\|/\|B_1\|$ averaged over central axial slice
Unloaded	1.5T	2%	3%	1
	3T	1%	3%	1

	Main Magnetic Field Strength	$\|B_1^-\|/\|B_1^+\|$ at coil center	$\|B_1^-\|/\|B_1^+\|$ averaged over central axial slice	$\|B_1^+\|/\|B_1\|$ averaged over central axial slice	Min $\|B_1^+\|/\|B_1\|$ averaged over 1cm radius in central axial slice
Loaded	1.5T	39%	44%	92%	67%
	3T	54%	65%	84%	26%

Table 1: Numerical comparison of $|B_1^+|$ and $|B_1^-|$. The average over central axial slice was calculated within a circular region of interest with 25cm radius.