Analytical examination on asymmetric distributions of transmission and reception RF fields by a quadrature coil at high magnetic field

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Introduction

Image non-uniformity occurs at high field MRI due to inhomogeneous distributions of RF fields inside a dielectric sample such as human body. It has been known that transmission and reception fields differ and can be represented as B_1^+ and B_1^{-*}, respectively, where these are complex vectors and * denotes complex conjugate (1). These fields show asymmetric and mirror symmetric distributions in human brain at high field. We examined the source of the difference between these fields by a single-channel ("linear") coil and found that the difference is caused by the phase term in the laboratory frame (2). In this work, we analytically examine the asymmetric distributions of these fields by a quadrature coil.

Method

A quadrature coil has two orthogonal coils or feeding ports for generating orthogonal magnetic field components. Figure 1 shows a schematic of a quadrature volume coil. In transmission mode, excitation is done via two feeding ports, P and Q, with a 90° phase difference and an RF field component B_{1t}^+ with the same direction of nuclear spin precession can be generated. The RF fields in the laboratory frame generated via port j are denoted by B_{1x}^j and B_{1y}^j (j = P, Q). B_{1t}^{j+} and B_{1t}^{j-} represent components with the direction of spin precession and an opposite one in transmission mode, respectively. Considering the phase, these components are described as follows.

$$B_{1t}^{P+} = (B_{1x}^P + iB_{1y}^P)/2 \quad [1a], \qquad B_{1t}^{Q+} = (-iB_{1x}^Q + B_{1y}^Q)/2 \quad [1c]$$

$$B_{1t}^{P-} = (B_{1x}^P - iB_{1y}^P)^*/2 \quad [1b], \qquad B_{1t}^{Q-} = (-iB_{1x}^Q - B_{1y}^Q)^*/2 \quad [1d]$$

Two orthogonal modes are electromagnetically isolated and the total RF fields, B_{1t}^+ and B_{1t}^- are calculated by superposing the fields at P and Q.

$$B_{1t}^+ = [(B_{1x}^P - iB_{1x}^Q) + i(B_{1y}^P - iB_{1y}^Q)]/2 \quad [2a], \qquad B_{1t}^- = [(B_{1x}^P - iB_{1x}^Q) - i(B_{1y}^P - iB_{1y}^Q)]/2 \quad [2b]$$

The magnitude of the complex vector B_1 can be calculated by $(B_1 B_1^*)^{1/2}$ and the following expression is derived.

$$B_{1t}^{\pm} = [|B_{1x}^P - iB_{1x}^Q|^2 + |B_{1y}^P - iB_{1y}^Q|^2 \pm 2Im[(B_{1x}^P - iB_{1x}^Q)(B_{1y}^P - iB_{1y}^Q)^*]^{1/2} / 2 \quad [3]$$

where B_{1t}^+ and B_{1t}^- denote magnitudes of B_{1t}^+ and B_{1t}^-, respectively. In a quadrature coil, adjustment should be done for maximizing B_{1t}^+ and minimizing B_{1t}^- for generating an RF field with a direction the same as spin precession. In this condition, $B_{1t}^- \approx 0$. Rearranging Eq. [3] by $B_{1t}^- \approx 0$ and the expressions of $B_{1x}^j = B_{1x}^j \exp(i\theta_x^j)$ and $B_{1y}^j = B_{1y}^j \exp(i\theta_y^j)$,

$$B_{1t}^+ = [|B_{1xyMag}^{QD}|^2 - B_{1xyPhase}^{QD}]^{1/2} \quad [4]$$

In reception mode, we derive the relationship as follows using the quadrature condition of $B_{1r}^+ \approx 0$.

$$B_{1r}^- = [|B_{1xyMag}^{QD}|^2 + B_{1xyPhase}^{QD}]^{1/2} \quad [5]$$

In these expressions, B_{1xyMag}^{QD} and $B_{1xyPhase}^{QD}$ are

$$B_{1xyMag}^{QD} = (|B_{1xyMag}^P|^2 + |B_{1xyMag}^Q|^2)^{1/2} \quad [6a], \quad B_{1xyPhase}^{QD} = B_{1x}^P B_{1x}^Q sin(\theta_x^P - \theta_x^Q)) + B_{1y}^P B_{1y}^Q sin(\theta_y^P - \theta_y^Q)) \quad [6b]$$

where

$$B_{1xyMag}^j = [(|B_{1x}^j|^2 + |B_{1y}^j|^2)/2]^{1/2} \quad (j = P, Q) \quad [7]$$

Eqs. [4] and [5] shows that the transmission field B_{1t}^+ and the reception field B_{1r}^- are expressed by B_{1xyMag}^{QD} and $B_{1xyPhase}^{QD}$. The difference between B_{1t}^+ and B_{1r}^- in a quadrature coil is a positive or a negative sign of $B_{1xyPhase}^{QD}$ in the laboratory frame. This relationship is similar to that in a linear coil (2). By rearranging Eqs. [4] and [5], B_{1xyMag}^{QD} and $B_{1xyPhase}^{QD}$ can be derived from the components in the rotating frame.

$$B_{1xyMag}^{QD} = [(|B_{1r}^-|^2 + |B_{1t}^+|^2)/2]^{1/2} \quad [8a], \qquad B_{1xyPhase}^{QD} = (|B_{1r}^-|^2 - |B_{1t}^+|^2)/2 \quad [8b]$$

Volunteer studies were performed using a 4.7 T whole-body NMR spectrometer (*INOVA*, Agilent). A quadrature volume TEM coil with 300 mm diameter was used both for transmission and reception. B_{1t}^+ maps of human brains were measured by the phase method (3) and B_{1r}^- maps were calculated from B_{1t}^+ by the reported method (4). Maps of B_{1xyMag}^{QD} and $B_{1xyPhase}^{QD}$ were calculated by Eqs. [8a,b].

Results & Discussion

Figure 2 shows maps of B_{1t}^+, B_{1r}^-, B_{1xyMag}^{QD} and $B_{1xyPhase}^{QD}$ of a subject. Maps of B_{1t}^+ and B_{1r}^- showed asymmetric and mirror symmetric distributions along the lateral direction. The B_{1xyMag}^{QD} map had an almost symmetric profile with higher amplitude in the center. These symmetric profiles were consistent with the fact that an RF coil is designed to achieve homogeneous fields and human brain has almost symmetric structures along the lateral direction. In contrast, the $B_{1xyPhase}^{QD}$ map showed an almost antisymmetric distribution. From these results, we concluded that asymmetry in B_{1t}^+ and B_{1r}^- maps in a quadrature coil is caused by the phase term in the laboratory frame.

References

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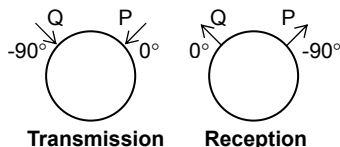
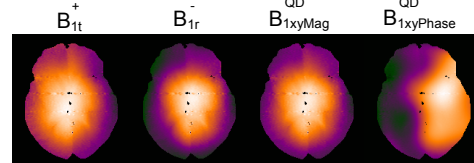Fig. 1. A schematic of a quadrature volume coil.

Fig. 2. Maps of RF fields of a subject in the rotating and the laboratory frames.