Study of concomitant fields in multipolar PatLoc imaging

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Introduction:

For spatial encoding in magnetic resonance imaging only the B_z component of the magnetic vector is of interest. In conventional imaging B_z is varied linearly along the three directions x, y and z to allow for orthogonal and rectangular voxels. One source of voxel distortion or signal dephasing for particular sequences are the concomitant fields B_x and B_y which are unavoidable to fulfil Laplace's equation. For linear gradients, e.g. for the x-gradient, the component B_z along x is transferred into B_x along z, Figure 1a/b. With the introduction of non-linear magnetic fields for imaging [1], concomitant fields of higher order harmonics become less trivial. This work studies the concomitant fields of higher order harmonics and of a simplified model of a PatLoc gradient coil [2].

Materials and Methods:

Magnetic fields inside a source-free region can be calculated from Laplace's equation for the magnetic scalar potential $\nabla^2\Psi = 0$ [3].
Its solution is given by an infinite series of spherical harmonics [4]

$$\Psi = \sum_{m=0}^{\infty}\sum_{n=m}^{\infty}(A_n^m\cos(m\varphi) + B_n^m\sin(m\varphi))r^n P_n^m(cos\theta) \quad (1)$$

where P_n^m are the associate Legendre polynomials and r, θ, φ are polar coordinates. From this potential the gradients B_x, B_y and B_z of the magnetic field can easily be derived. The maximum of the calculated B_z component inside a unit sphere is used to normalise the magnetic fields to ±1. The total volume in which the magnetic fields are calculated is in arbitrary units of ± 2, corresponding to a typical bore diameter to be twice the target spherical region. With the given B_x and B_y components the resulting concomitant field is calculated $B_r = \sqrt{(B_x^2 + B_y^2)}$.

In order to study the impact of the finite coil length, longitudinal and return current paths a step away from harmonic expansions towards wire patterns is required. Second order harmonics are of primary interest here, corresponding to the available PatLoc coil [3]. It is, however, difficult to draw general conclusions from a particular coil implementation. Therefore a vastly simplified model with a low number of parameters has been developed. This model includes a cylindrical magnet bore with a radius 2 with two flat single loop coil elements with a radius 2 placed atop the bore liner separated by a distance of 1/5 to represent one pole of the quadrupolar magnetic field. Total of 4x2 coil elements with alternating current directions are required to mimic a PatLoc gradient coil. B_x, B_y and B_z were calculated based on an analytic field formula of a circular current loop. The simulated magnetic field components were scaled to normalize B_z to ±1 inside the unit sphere.

Results & Discussion:

For the linear x-gradient (A11) there is no radial component, which corresponds to the common assumption about the concomitant fields of linear gradients [5]. Figure 1a/b shows the scaled B_z component and the corresponding concomitant field B_x. Figure 2a/b displays the concomitant field B_r of the second order harmonics A22 (corresponding to the PatLoc encoding field) at $z = 0$ and a 1D representation to visualize the distribution along $y = 0$. Figure 3a/b displays the same plots for the concomitant field B_r of the third order harmonics. The 1D distributions suggest that the radial dependency of the concomitant field B_r is n-1 with the order of the harmonics. Figure 4a displays the encoding component B_z of the model PatLoc coil and Figure 4b the concomitant component B_r.

For linear gradients the magnitude of the main and concomitant fields is of the same order. For higher order magnetic fields the concomitant fields have a n-1 distribution with respect to the order of the harmonics. For the calculated harmonics of A22, the maximum B_r inside the sphere at z=0.5 is 0.8 (Figure 4a) compared to the calculations from the simplified model with 1. This emphasises how important a realistic wire path is to estimate the concomitant fields. It is also important to know the concomitant fields to evaluate their effect on imaging and also for prediction of peripheral nerve stimulation which is induced by $\vec{B}$ and not only by B_z.

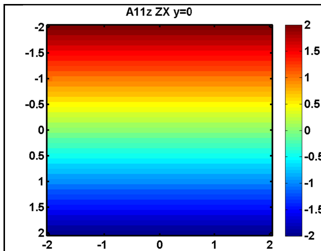

Fig.1a z component of A11 (x-gradient) in ZX plane

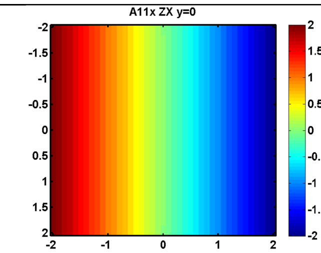

Fig.1b x component of A11 (x-gradient) in ZX plane

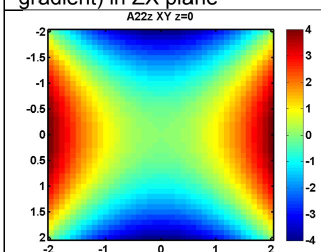

Fig 2a Bz component of A22

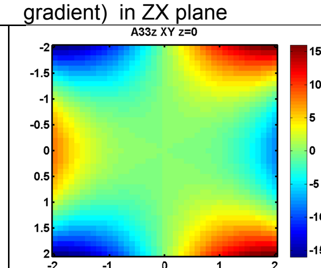

Fig 3a Bz component of A33

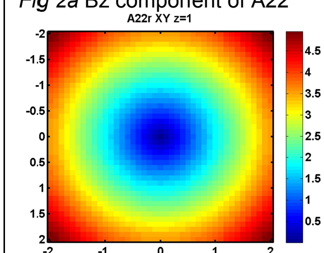

Fig 2b radial component of A22

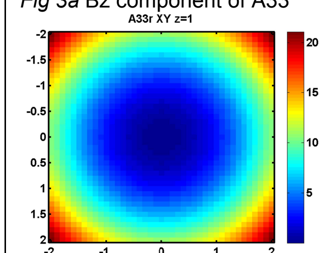

Fig 3b radial component of A33

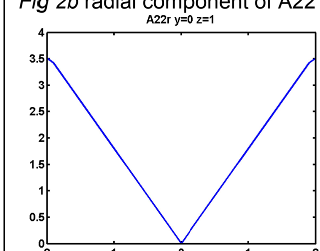

Fig 2c 1D plot through Fig2a

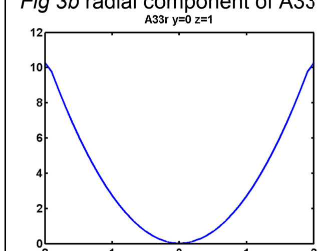

Fig 3c 1D plot through Fig2a

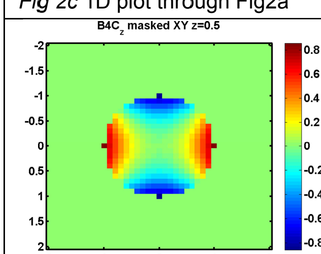

Fig 4a z component of model

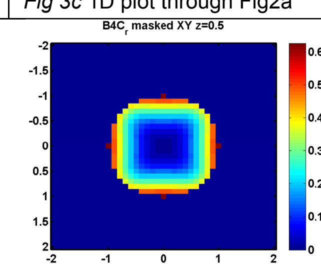

Fig 4b r component of model

References: [1] Hennig et al, MAGMA 21(1-2):5-14 (2008); [2] Welz et al, ISMRM 2009, p.3073; [3] Romeo Hoult MRM 1,44-65(1984); [4] Hillenbrand et al, Applied Magnetic Resonance 29, 39-64(2005); [5] Bernstein et al., MRM 1998 39(2): 300-308

Acknowledgment: This work is a part of the INUMAC project supported by the German Federal Ministry of Education and Research, grant #13N9208