Simulataneous B1 and B0 mapping at 7T

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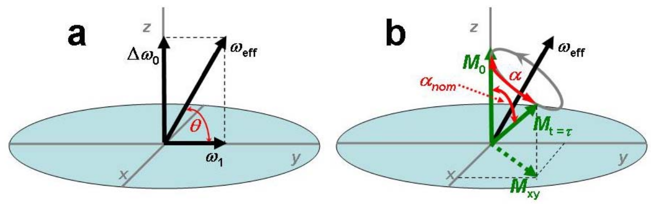
Introduction

Many applications in MRI require accurate measurement of the spatial distribution of the transmitted radiofrequency magnetic field (B_1). The recently proposed *actual flip angle imaging* (AFI) method[1] presents an elegant approach to B_1 mapping by direct calculation of the transmit RF field using a modified 3D spoiled gradient-echo sequence. Radiofrequency field mapping is particularly critical at high main magnetic field (B_0) strengths, where wavelength and penetration effects create extremely heterogeneous B_1 fields. The challenges at high field are further compounded by increased B_0 heterogeneity, which can result in inaccurate calculation of the actual transmit B_1 field by standard methods.

Like most radio-frequency field mapping approaches, the AFI method is sensitive only to the nominal flip angle, not the total nutation angle including off-resonance effects. Consequently, under significant off-resonance conditions the B_1 field is underestimated. One solution to this problem is to use large B_1 amplitudes in the RF pulses, reducing the relative degree of off-resonance. However, SAR limitations, large imaging FOVs, and multiple coil arrays with significantly heterogeneous B_1 fields, often make it impractical to maintain the condition that B_1 is large compared to ΔB_0. A more straightforward solution is to acquire accurate maps of both fields, and to calculate the true transmit B_1 field from a solution of the full system of equations. In this work, a modification of the AFI sequence is presented which simultaneously acquires both B_0 and B_1 maps, with no additional scan time requirements. A solution to the relationship between the nominal flip angle obtained by the AFI method and the true B_1 transmit field in the presence of off-resonance is derived. The results are validated with phantom imaging results.

Theory

Consider an RF pulse applied along the y-axis of the rotating frame of reference as depicted in Figure 1. If the spin magnetization is off-resonance when exposed to the RF pulse, then the magnetization nutates about an effective B_1 field tilted at an angle θ from the transverse plane by an angle given by $\theta = \tan^{-1}(\Delta\omega_0/\omega_1)$ where $\Delta\omega_0$ and ω_1 are the off-resonance frequency and the amplitude of the B_1 pulse. With the application of the B_1 pulse for duration τ, the magnetization rotates in a solid angle about the effective field by an amount given (in radians) by $\alpha = 2\pi\omega_{eff}\tau$. When $\Delta\omega_0 \neq 0$, the amount of magnetization flipped into the transverse plane is altered, and the nominal flip angle, α_{nom}, is less than α. The true and nominal flip angles can be related by equating the relationships $M_{z,t=\tau} = M_0(\sin^2\theta + \cos^2\theta\cos\alpha)$ and $M_{z,t=\tau} = M_0\cos\alpha_{nom}$, yielding the relationship:

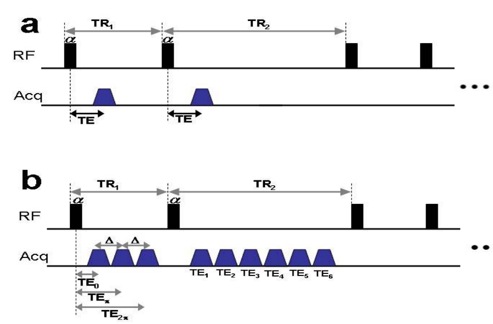


$$\cos(\alpha_{nom}) = \sin^2\left[\tan^{-1}\left(\frac{\Delta\omega_0}{\omega_1}\right)\right] + \cos^2\left[\tan^{-1}\left(\frac{\Delta\omega_0}{\omega_1}\right)\right]\cos\left(2\pi\sqrt{\omega_1^2 + \Delta\omega_0^2}\,\tau\right) \quad [1]$$

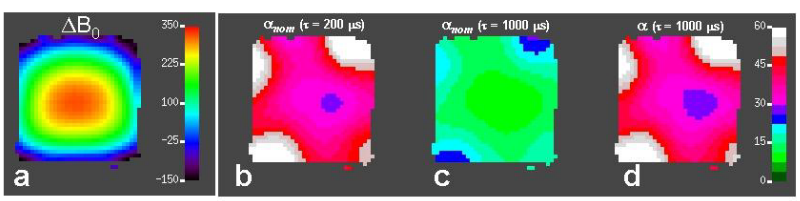
Inversion of Eq. [1] provides the actual B_1 amplitude, ω_1, given the empirically determined maps of α_{nom} and $\Delta\omega_0$ from the modified AFI sequence.

Methods and Results

In Figure 2, the original AFI sequence (a) and the modified sequence (b) for simultaneous B_0 and B_1 mapping are shown. The original sequence is a double TR, 3D spoiled gradient echo. The modified sequence incorporates multiple gradient-echoes, including the 3-point Dixon [2] method for separation of fat and water signals in the first TR period, and six gradient echoes in the second TR period for accurate B_0 mapping (image encoding and spoiling gradients are not shown). The first echoes from each TR period are used to calculate the nominal flip angle according to the conventional AFI method.



Images of a phantom were acquired on a 7 tesla whole-body Siemens MRI scanner using a single channel, transmit-receive quadrature headcoil. The phantom was a 1.7 liter plastic container filled DI water doped with 0.07 mM $MnCl_2$ and 0.2mM NaCl. The images were acquired with the following parameters: TR_1/TR_2 = 50/200ms; FOV = 192x192x192 mm; matrix = 48x48x48, $TE_0/TE_\pi/TE_{2\pi}$ = 1.42, 2.18, 2.90; TE_1-TE_6 = 1.42, 2.18, 2.90, 3.62, 4.34, 5.06 ms; flip angle (requested) = 45°; bandwidth = 2000 hz/pixel. A non-selective hard pulse was used for excitation. The imaging protocol was repeated four times, with RF pulse widths of 200, 600, 1000, and 1400 µs. The B_0 and flip angle maps from the phantom images are shown in Figure 3. The nominal flip angle maps determined by the AFI method (fig 2b and 2c) show considerable dependence on pulse width (i.e. increasing relative off-resonance). However, the corrected actual flip angle map (fig 2d) reveals the same pattern as the high B_1 data, indicating the true radiofrequency field of the transmit coil. (The color scale for (2a) is in hertz; for (2b), (2c) and (2d) the color scale is in degrees).



Conclusion

Simultaneous mapping of B1 and B0 fields allows for the accurate measurement of the transmit radiofrequency field in the presence of significant off-resonance effects. Using a modification of the AFI method for B1 mapping, both fields can be acquired with no additional scan time. A primary advantage of this approach is that the sequence can be run with low power RF pulses (i.e. longer pulse durations) without incurring errors in B_1 field estimation due to greater relative off-resonance effects. This has particular utility at high fields, where SAR limitations and static field heterogeneity are both problematic.

References

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Acknowledgements

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