Simultaneous $B_0$ and High Dynamic Range $B_1$ Mapping Using an Adiabatic Partial Passage Pulse

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Introduction

Many $B_1$ mapping sequences, such as the double angle method (DAM) [1] or actual flip-angle imaging (AFI) [2], only cover a limited dynamic range (approximately a factor of 2 between the largest and smallest $IB_1$ that can be resolved) and do not measure $B_0$. We adapt the AFI sequence to extend the $B_1$ dynamic range using an adiabatic partial passage (APP) pulse and measure $B_0$ by using different TEs for the alternating TRs.

Many situations where $B_1$ mapping is necessary have a large range of $IB_1$ and $B_0$ variation. Surface coils, such as those used for parallel transmit, and current-carrying wires, such as those used in RF ablation, can have an order of magnitude or more variation in field strength. Air/tissue interfaces, different chemical species and the presence of metal wires create off-resonance, which can lead to artifacts caused by large variations of $B_1$. The AFI pulse sequence acquires two interleaved images with different flip angles, so it tends to cancel some of the $T_2^*$ dependence, which limits the dynamic range to about a factor of 2 or 3.

An adiabatic pulse can be used to extend the dynamic range. If the adiabatic pulse is not brought all the way to on-resonance, the flip angle will be dependent on the magnitude of $B_1$, which is the vector sum of $B_0$ and the off-resonance frequency of the pulse. The sequence parameters are: $TR/TR_0=6$, $T_1=60$ ms, $TE_T=2.9$ ms, $TE_p=3$ ms, 1 mm resolution, 7.5 mm slice thickness, 3D stack-of-flyback-EPI readout with 4 echoes, gradient and RF spoiling.

A sequence was optimized to trade off pulse duration and SAR for SNR, as well as potentially extending the dynamic range even further.

Theory

$B_0$ Mapping

The AFI sequence acquires two interleaved images with different TEs, allowing a 16-fold range of $B_0$ mapping or simultaneous $B_1$ and $B_0$ mapping. It can cover a large (16-fold) $B_1$ dynamic range in a fraction of the time required by other $B_1$ mapping techniques and is less susceptible to Gibbs ringing artifacts caused by large variations of $B_1$. The adiabatic partial passage can be further optimized to trade off pulse duration and SAR for SNR, as well as potentially extending the dynamic range even further.

Methods

Pulse and Sequence Design

The adiabatic partial passage pulse was created by truncating a hyperbolic-secant adiabatic half passage pulse when the frequency offset reached 2.15 kHz. The pulse was optimized for a $B_1$ range of 0.1-1.6 G (426 Hz-6.8 kHz) using the technique of Ugurbil et al [4]. The sequence is a standard AFI sequence with a different TE for each TR. The sequence parameters are: $TR/TE=6$, $T_1=60$ ms, $TE_T=2.9$ ms, $TE_p=3$ ms, 1 mm resolution, 7.5 mm slice thickness, 3D stack-of-flyback-EPI readout with 4 echoes, gradient and RF spoiling.

The AFI sequence and a SDAM [5] sequence with a hard pulse excitation were used for comparison. The AFI sequence parameters were the same as above with a single TE=2.9 ms. The SDAM sequence used the same parameters except for a single TR=420 ms. Both the AFI and SDAM sequence used a 294 μs hard pulse, with the sequence repeated while halving the $IB_1$ each time. $B_0$ magnitudes were used for AFI, and 5 were used for SDAM. All k-space data was apodized using a Tukey window to reduce Gibbs ringing.

Results

Figure 3: Wire Transmit/Receive Phantom $B_1$ Maps

APP: scan time 1:29

Simulation

AFI: scan time 5:56

SDAM: scan time 7:25

Figure 4: Oil and Water Phantom $B_1$ and $B_0$ Maps

$B_0$ falls off rapidly away from the coil. The oil (top of image) has the expected frequency shift of approximately -220 Hz relative to the water. The oil is spatially shifted relative to the water in the image due to off-resonance during the long readout.

Discussion and Conclusions

The APP technique is useful for applications requiring high-dynamic range $B_0$ mapping or simultaneous $B_1$ and $B_0$ mapping. It can cover a large (16-fold) $B_1$ dynamic range in a fraction of the time required by other $B_1$ mapping techniques and is less susceptible to Gibbs ringing artifacts caused by large variations of $B_1$. The adiabatic partial passage can be further optimized to trade off pulse duration and SAR for SNR, as well as potentially extending the dynamic range even further.

References


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