Lowering the $B_1$ threshold for BEAR $B_1$ mapping in magnetic resonance imaging

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**INTRODUCTION**

In magnetic resonance imaging (MRI), the accurate measurement of the transmit radiofrequency ($B_1$) field is useful for a variety of applications, such as the transmit system calibration of the scanner and evaluating coil performance. Phase-based $B_1$ mapping methods offer a variety of benefits over magnitude-based methods, for example improved insensitivity to $T_1$, $T_2$ and TR. The recently proposed BEAR method (1) is a phase-based $B_1$ mapping method, which has linear phase sensitivity to variations in $B_1$ and is insensitive to off-resonance frequency variations, $T_1$, $T_2$, and TR. The method relies on two hyperbolic secant pulses operating in their adiabatic regime to produce a twice-refocused spin-echo, which in turn limits the $B_1$ range. We redesign the BEAR method to use HSn adiabatic pulses, resulting in a $B_1$ mapping method which can be used to reliably measure lower nominal peak $B_1$ values.

**METHOD**

The BEAR method, which has a flat phase response with respect to off-resonance frequency, relies on two hyperbolic secant (HS1) pulses operating in their adiabatic regime. This limits the range of $B_1$ that can be accurately measured due to the requirement that it stays near or above the adiabatic threshold of the pulses.

When substituting HSn adiabatic pulses (2) into the sequence, which have lower adiabatic thresholds than HS1 pulses, the sequence has a moderate quadratic variation in phase with respect to off-resonance frequency. This quadratic phase variation can be largely canceled by choosing appropriate values of $n_1/n_2$. Given an $n_1$, $n_2$ is chosen by minimizing the maximum percent off-resonance phase difference from the on-resonance phase, over the slice profile and range of expected $B_1$ variation.

The optimization method for $n_2$ used here kept the total power of the sequence constant, independent of $n_1/n_2$. Thus the optimizations used different nominal $B_1$ values for every $n_1/n_2$ pair.

**EXPERIMENTS:** Volunteer studies were performed on a GE Discovery MR750 3T scanner. The adiabatic pulse parameters were $T/\beta/\mu=12$ ms/5.3 rad/5.5 and $\delta=0.9$. A 40° tip angle, TE/TR=49/500 ms, was used for a single 2DFT acquisition. Phase-difference images had a second acquisition reversing the order of the two adiabatic pulses.


**SIMULATED SPIN-ECCHO PROFILE RESULTS**

![Simulated spin-echo profile results](image)

**FIG. 2.** Simulation results. a: The columns show slice profiles for magnitude, phase and phase difference from 0 Hz for $n_1/n_2 = 1/1$ (top row), and 4/4.153 (bottom row). The optimized HSn pulses minimize the phase difference due to off-resonance frequency over the given $B_1$ range and slice profile for 3T, indicated by the black boxes: $B_1 = 1\pm 0.4B_{1,\text{nom}}$, $B_{1,\text{nom}} = 0.1144$ G. b: The phase as a function of $B_1$ shows that increasing $n$ increases the phase sensitivity of the method. c: The maximum phase difference from 0 Hz over the boxed range as a function of $n_1$ and main-field strength shows less than 10% difference for all optimizations. The $B_1$ variations were 20/40/50% for 1.5/3/7T.

**IN VIVO RESULTS**

![In vivo results](image)

**FIG. 3.** In vivo results. The top row shows in vivo $B_1$ map results for varying $n_1/n_2$. From left to right, $n_1/n_2 = 1/1, 2/2.040, 4/4.153, 8/8.504$. The maps are normalized by $B_{1,\text{nom}}$. The bottom row shows percent differences with $n_1/n_2 = 1/1$ used as the reference, with average errors of [2.68, 1.93, 2.50] % respectively.

**CONCLUSION**

We redesign the BEAR method to use HSn pulses, reducing the peak RF amplitude required for accurate $B_1$ measurement, while maintaining insensitivity to off-resonance frequency, linear phase sensitivity to $B_1$, and approximately constant total RF power. Optimizations of a few $B_1$ ranges were made since different amounts of variation are expected depending on the transmit coil used (e.g., the 40% variation in $B_1$ is typical for a head transmit coil at 3T). Scan results show the methods accurate $B_1$ mapping ability for low $B_1$, while maintaining comparable $B_1$ sensitivity and similar SAR. Alternatively, by lowering the sequence $\delta$, we can choose to operate at higher $B_1$ ranges, with an increase in sensitivity and total RF power.