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

Kalina V. Jordanova[1], Dwight G. Nishimura[1], Adam B. Kerr[1]

[1]Electrical Engineering, Stanford University, Stanford, California, USA

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.

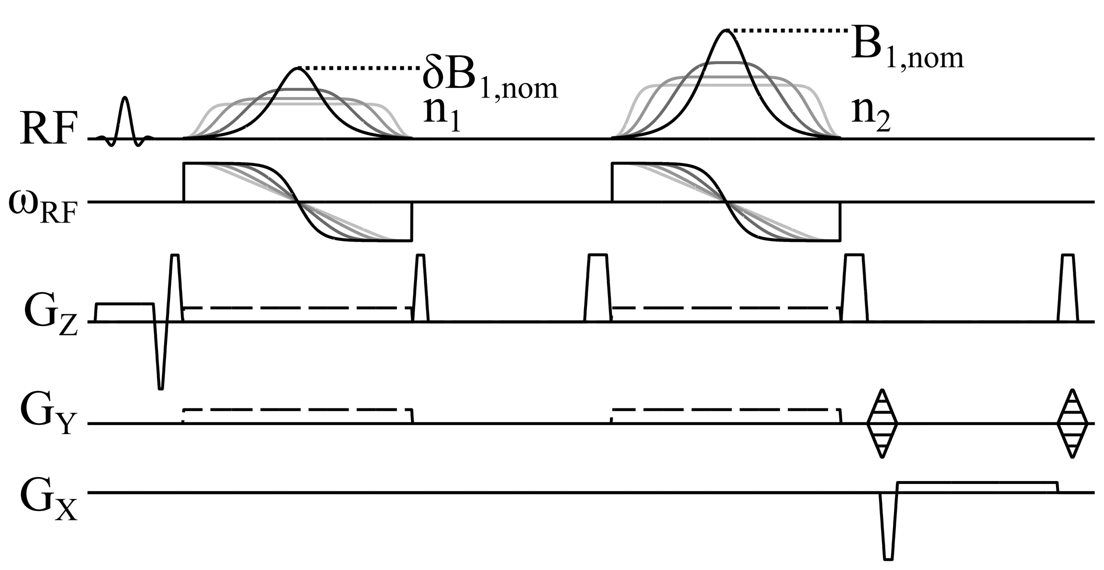

FIG. 1. *BEAR pulse sequence with HSn pulses:* Lighter gray lines represent n_1=n_2=[1,2,4,8]. n_1 and n_2 determine the shape of the magnitude sweep and can be non-integer. The original BEAR method is the case when n_1=n_2=1. $B_{1,nom}$ reflects the adiabatic threshold for each HSn pulse, [0.091, 0.064, 0.052, 0.045] G respectively. Increasing n reduces the adiabatic threshold, allowing for use of a lower $B_{1,nom}$.

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 δ=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.

References: [1] Jordanova et al., Proceedings of ISMRM, Salt Lake City, p. 370, 2013. [2] Tannus et al., NMR in Biomed, 10:423-434, 1997.

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Simulated spin-echo profile results

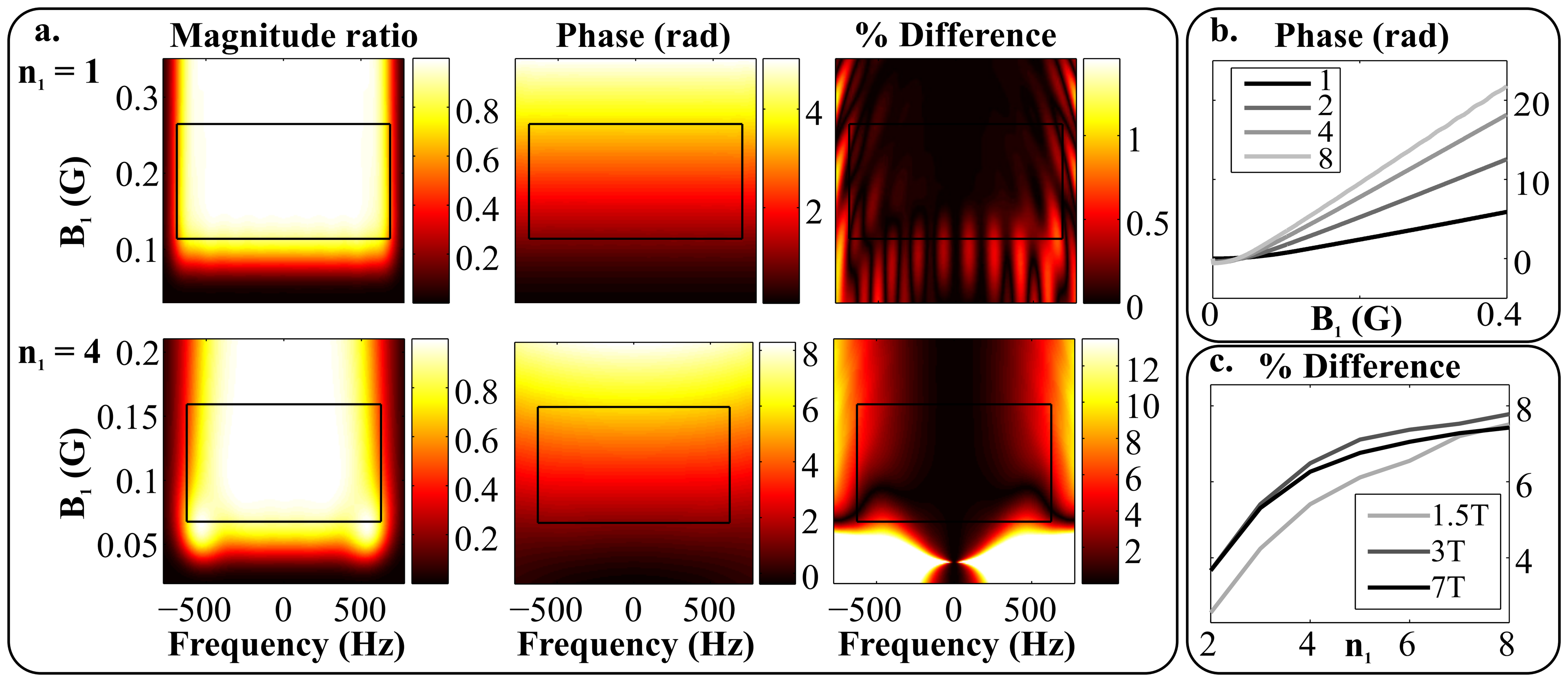

FIG. 2. *Simulation results.* **a:** The columns show slice profiles for magnitude, phase and phase difference from 0 Hz for n_1/n_2 = 1/1 (top row), and 4/4.153 (bottom row). The optimized HSn pulses minimize the phase difference due to off-resonance frequency over the given B_1 range and slice profile for 3T, indicated by the black boxes: $B_1 = 1\pm0.4B_{1,nom}$, $B_{1,nom}$ = 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

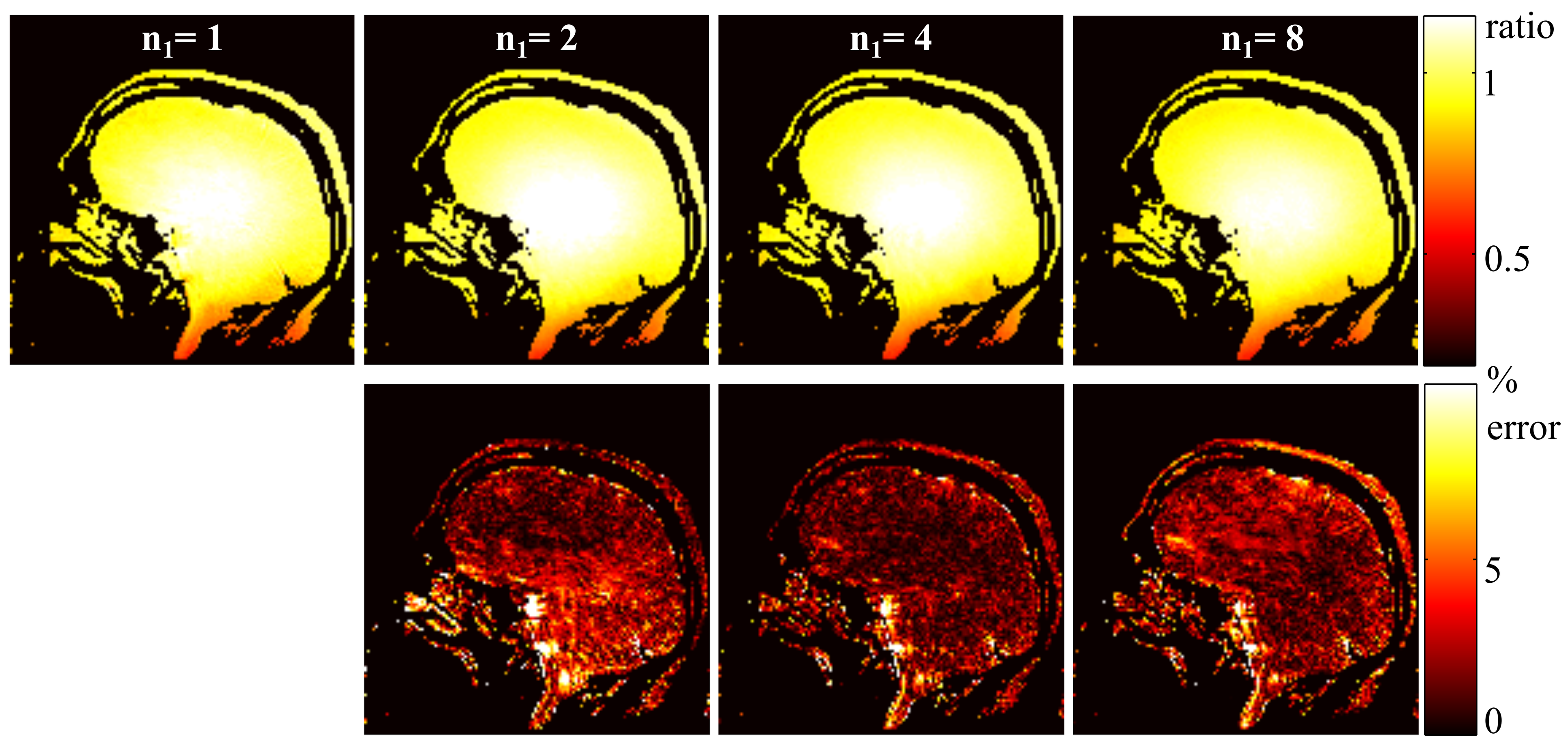

FIG. 3. *In vivo results.* The top row shows in vivo B_1 map results for varying n_1/n_2. From left to right, n_1/n_2 = 1/1, 2/2.040, 4/4.153, 8/8.504. The maps are normalized by $B_{1,nom}$ = [0.2106, 0.1416, 0.1144, 0.1023] G respectively for easier comparison, and it is evident that the maps are all closely matched. 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 δ, we can choose to operate at higher B_1 ranges, with an increase in sensitivity and total RF power.

Contact: kalinaj@stanford.edu