B_1 Estimation using Adiabatic Refocusing: BEAR

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Introduction: Accurate measurement of B_1 transmit fields is important for calibration of the transmit system and quantitative MRI. We describe a novel phase-based B_1 estimation method using adiabatic refocusing (BEAR). Some important characteristics of the BEAR method are that the B_1 measurement is insensitive to off-resonance, T_1 and T_2. BEAR also provides good image quality even in regions of B_0 inhomogeneity due to its robust spin-echo acquisition. We validate BEAR's performance in simulation and experimentally with comparison to Bloch-Siegert[1] (BS) B_1 measurements.

Methods: The second echo in a spin-echo sequence using two repeated adiabatic full passage (AFP) pulses will have no phase variation over the slice profile[2]. The BEAR method relies on the novel observation that by changing the relative magnitude of the two AFP pulses the phase of this echo will depend approximately linearly on B_1 and with very little variation over the slice profile. Fig. 1 shows the BEAR sequence with two sech[3] AFP pulses of magnitude δB_{1nom} and B_{1nom}, where δ is a scaling factor and B_{1nom} is the nominal peak B_1 of the second AFP pulse. Numerical Bloch simulations were used to determine the signal phase dependence on B_1 for this sequence.

The sech pulses were designed with parameters T/β/μ equal to 12ms/ 800rad·s^{-1}/5.5 giving a BW of 1.4kHz. The adiabatic threshold B_{1A}, which we define as the minimum B_1 that ensures refocusing of 90% M_{xy}, for this pulse is 0.095G. Assuming a B_{1nom} of 0.175G, then $\delta B_{1nom} > B_{1A}$ for $\delta > 0.54$. The BS method used an 8-ms Fermi pulse, with off-resonant frequency of ±4 kHz. A tip angle of 42°, TE of 44ms and TR of 500ms were used with a 2DFT acquisition on a GE Signa Excite 1.5-T scanner. To eliminate unwanted phase effects, phase-difference images were made from multiple acquisitions. For BEAR, the second acquisition reversed the order of the two adiabatic pulses; for BS, the second acquisition negated the off-resonant frequency of the Fermi pulse.

Imaging could be confined to a specified volume by making the refocusing pulses selective in Y (Fig. 1), and limiting the X readout receiver bandwidth. Fast, 1D projections could also be acquired using a single readout with $k_y = 0$. For comparison to these fast projection acquisitions, 2D B_1 maps were also acquired, and their B_1 magnitude averaged along Y.

Results: Fig. 2a shows Bloch simulation results of BEAR's signal dependence on B_1 and δ, with approximately linear phase dependence on B_1 for $B_1 > B_{1A}$. The simulated magnitude and phase of the refocused M_{xy}, as a function of B_1 and off-resonance frequency (Fig. 2b,c), illustrate BEAR's insensitivity to off-resonance over the effective bandwidth of the refocusing pulses. For $\delta = 0.7$ and $B_{1nom} = 0.175$G, the phase sensitivity was 80 rad/G, exceeding that of the BS method of 52 rad/G (Fig. 2a).

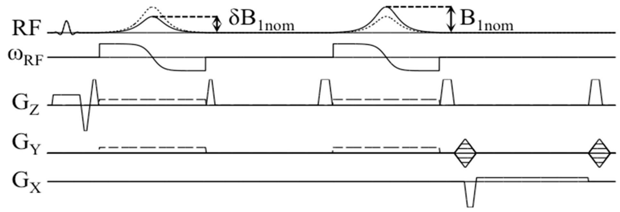

Figure 1: The BEAR sequence: two sech pulses generate a twice-refocused spin-echo. The refocusing pulses can be made selective in Z or Y for slice- or volumetric- imaging.

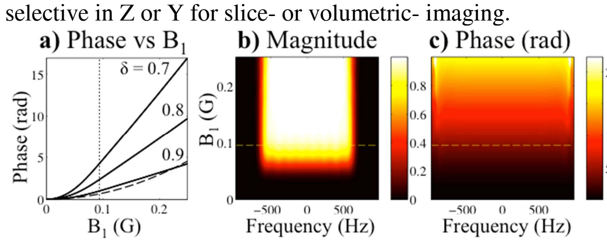

Figure 2: **(a)** BEAR's signal phase dependence on B_{1nom} and δ determined by Bloch simulations (solid). The BS phase dependence on B_1 for an 8-ms 4kHz offset Fermi pulse is shown for reference (dashed). **(b)** Magnitude and **(c)** phase plots for Bloch simulations of the slice profile for BEAR.

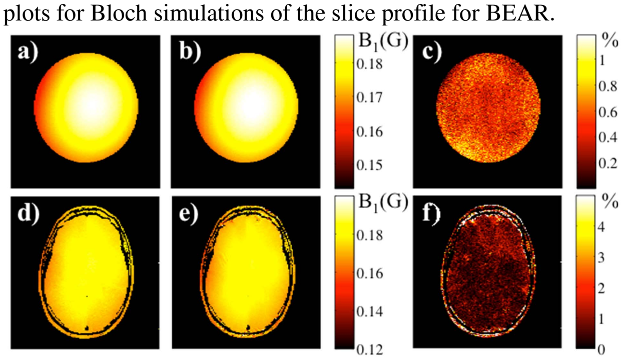

Figure 3: A comparison of B_1 maps: **(a)** BEAR phantom to **(b)** BS phantom, and **(d)** BEAR in vivo to **(e)** BS in vivo, with respective BEAR deviations from BS **(c,f)**. Average deviations: 0.14% **(c)** and 1.5% **(f)**.

BEAR B_1 maps closely match BS B_1 maps (Fig. 3), with an average deviation from BS of 0.14% (phantom) and 1.5% (*in vivo*). Note, the BS method has B_1 map variations in areas of high B_0 inhomogeneity, causing increased deviation between the methods near the perimeter of the head. Scans repeated with a TR of 100ms showed similar results. Fig. 4 shows that B_1 projections acquired with BEAR are in agreement with projections of 2D B_1 magnitude maps, with less than 1.6% difference.

Discussion and Conclusion: The BEAR method is a novel method of B_1 mapping that can be localized to a slice or 3D block volume with a spin-echo acquisition that is appropriate for fast projection measurements. As the method measures transverse magnetization phase perturbation, it is insensitive to T_1 and T_2. The method has a large dynamic range as long as the AFP pulses operate over their adiabatic threshold. Its sensitivity increases with increasing ratio ($1/\delta$) of the refocusing pulse magnitudes. With the parameters used here, BEAR has sensitivity that is 153% of the BS method. However, the BEAR method has high SAR which can limit TR, and imposes a moderately long TE which can result in low signal for regions of short T_2. Nevertheless, BEAR's high dynamic range, insensitivity to B_0, T_1, and T_2, ability to make fast projection measurements, and linear quantitative relationship between phase and B_1 make it an ideal candidate for use in robust transmitter gain calibration.

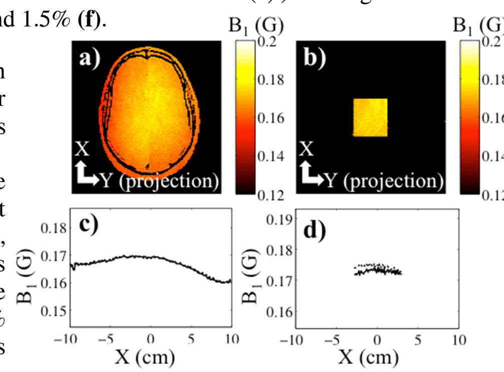

Figure 4: *In vivo* B_1 maps for: **(a)** slice and **(b)** volumetric scans. **(c,d)** B_1 projections (solid) and averages (dashed) of **(a,c)**, with difference < 1.6%.

References: [1] Sacolick *et al.*, MRM 63:1315–1322, 2010 [2] Conolly *et al.*, MRM 18:28-38, 1991 [3] Silver et. al, JMR 59:347-351, 1984 [4] Conolly *et al.*, JMR 83:549-564, 1989