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\(^1\) AFP pulses of magnitude $\delta B_{1\text{nom}}$ and $B_{1\text{nom}}$, where $\delta$ is a scaling factor and $B_{1\text{nom}}$ 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 $T/\mu = 12\text{ms}$ and $800 \text{rad} \cdot \text{s}^{-1}/5.5$ giving a BW of 1.4kHz. The adiabatic threshold $B_{1A}$, which we define as the minimum $B_1$ that ensures refocusing of 90% $M_x$, for this pulse is 0.095G. Assuming a $B_{1\text{nom}}$ of 0.175G, then $\delta B_{1\text{nom}} > B_{1A}$ for $\delta > 0.54$. The BS method used an 8-ms Fermi pulse, with off-resonant frequency of $\pm 4 \text{kHz}$. 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 $\delta$, with approximately linear phase dependence on $B_1$ for $B_1 > B_{1A}$. The simulated magnitude and phase of the refocused $M_x$, 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 $B_{1\text{nom}} = 0.175G$, the phase sensitivity was $80 \text{ rad/G}$, exceeding that of the BS method of 52 rad/G (Fig. 2a).

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.

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%.