Fast Spin Echo Bloch-Siegert B1 Mapping

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INTRODUCTION: Here, we present the modification of a fast spin echo (FSE) sequence to perform Bloch-Siegert B_1 mapping (1). Two off-resonance RF pulses are added symmetrically around the first refocusing pulse of a spin echo train. These pulses induce a static phase shift in the signal that is B_1^2-dependent, creating a allowing the phase difference between two FSE images to be used for B_1 mapping. The static Bloch-Siegert phase shift from the off-resonance RF pulses φ_{BS} act similarly to the non-CPMG case of a static phase shift from a mismatch between the excitation RF pulse and the subsequent refocusing pulses (2,3). Although it causes signal loss and an oscillation of the signal phase every other echo, the static Bloch-Siegert phase shift is preserved in the phase difference between the two images. The signal loss is a function of both phase shift and refocusing flip angle, but even for $\varphi_{BS} = 90°$, enough SNR remains to calculate B_1 accurately, and the method is shown to be viable even for $\varphi_{BS} > 90°$. B_1 mapping is presented here in-vivo with a spin echo train of 16 refocusing pulses, resulting in 64x64 in-plane B_1 mapping with excellent SNR, minimal off-resonance or T_1 sensitivity, and a scan time of 12 sec/slice.

METHODS / RESULTS: The Bloch-Siegert FSE sequence was implemented on a single drive 3T GE DVMR, and an 8-channel parallel transmit GE Signa Excite HD scanner. Scans on the single channel scanner were performed with a birdcage head T/R coil, and a saline phantom. Scans on the parallel transmit scanner were performed with an 8-channel Tx/Rx head array. The FSE sequence was modified as shown in Figure 1 with two 6 msec, 4 kHz Fermi pulses.

For the single channel phantom experiment, the amplitude of the two Fermi pulses was sequentially increased to give φ_{BS} over the range of 0 to 120°. For the 8-channel parallel transmit B_1 mapping, the Fermi pulses were played sequentially on 7 channels at a time, and the B_1 field for each channel was calculated by B_1 field interference (4). The excitation and refocusing pulses were played on all 8 channels. All RF pulses in this sequence used a circularly polarized phase configuration, without any additional B_1 shimming or optimization. All refocusing pulses used to acquire the images had identical (CPMG) phase.

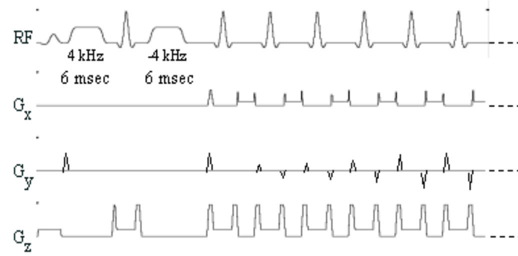
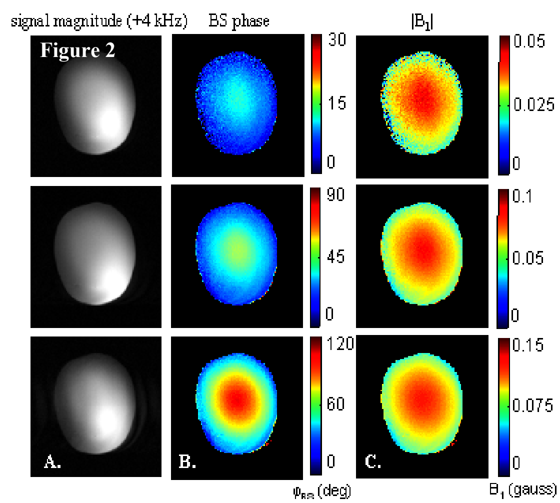


Figure 1: Fast spin echo Bloch-Siegert B_1 mapping



Signal amplitude and phase were simulated for a fast spin echo train of up to 64 echoes, for φ_{BS} = 0, 45, 90, with refocusing pulses having flip angles of 180, 160, 140°. Ideal B_0 homogeneity, and no T_2 loss is assumed in the simulations. For these simulations, the refocusing pulses have a phase that is modulated quadratically as described by Le Roux in (5).

Figure 3

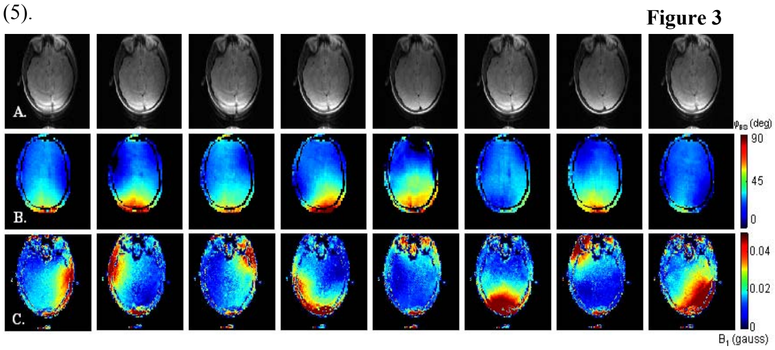
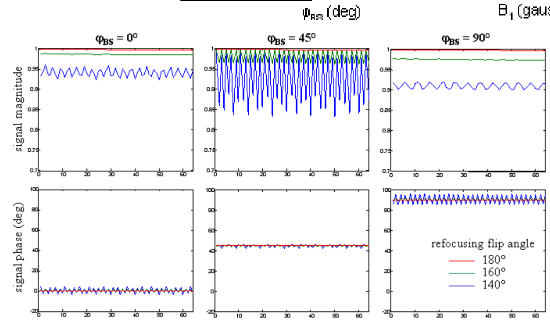


Figure 2: a. Signal magnitude of one of the two images used to reconstruct a FSE Bloch-Siegert B_1 map. TR = 1.8 sec, echo train length = 16, in plane resolution 128x128. **b.** Bloch-Siegert phase shift (0.5 * phase difference between the two +/- 4 kHz scans). **c.** $|B_{1,peak}|$ of the Fermi pulses. From top to bottom, the B_1 of the Fermi pulses was scaled to give an average B_1 over the slice of 0.037, 0.073, and 0.11 gauss. The colormaps for **c.** are scaled to reflect the changing B_1 scaling.

Figure 3: a. Signal magnitude (+4 kHz images). **b.** Composite 7-channel Bloch-Siegert phase shift (degrees)- each B_1 map is acquired with one channel not transmitting. **c.** Reconstructed B_1 maps for the 8 individual parallel transmit channels. TR = 1.5 sec, echo train length = 16.



DISCUSSION: Despite the non-CPMG conditions induced by the static Bloch-Siegert phase shift, a simple fast spin-echo can be used as a base sequence for Bloch-Siegert B_1 mapping. Signal loss is a function of both phase shift and refocusing flip angle, but one can reconstruct a high SNR B_1 map even with a 90° Bloch-Siegert phase shift. Although we present only a simple CPMG fast spin echo here in our in-vivo and phantom data, one may apply any of the non-CPMG techniques to recover signal and reduce ghosting artifact as long as signal phase is preserved. Figure 4 shows simulated signal magnitude and phase remains stable for long echo trains and large Bloch-Siegert shift when using Le Roux's quadratic non-CPMG sequence (5). Gradient echo-based Bloch-Siegert B_1 mapping sequences have problems when T_2^* causes signal loss. In these cases spin echo based B_1 mapping sequences can provide better SNR. Overall, in a fast spin echo versus a single spin echo Bloch-Siegert B_1 mapping sequence, SAR is reduced by having to use only two off-resonance RF pulses per echo train, rather than per each echo.

ACKNOWLEDGEMENTS AND REFERENCES:
1. Sacolick LI, Wiesinger F, Hancu I, Vogel MW. Magn Reson Med 2010; 63:1315-22. **2.** Pipe JG, Farthing VG, Forbes KP. Magn Reson Med 2002;47:42-52. **3.** Norris DG, Bornert P, Reese T, Leibfritz D. Magn Reson Med 1992;27:142-164. **4.** Brunner DO, Pruessmann KP. Magn Reson Med 2009;61:1480-1488. **4.** LeRoux P. J Magn Reson 2002;155:278-292.