Single-Shot Spiral Based Bloch-Siegert B_1^+ Mapping

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Purpose: B_1^+ mapping has a variety of applications in high field MRI such as designing parallel transmit RF pulses or correcting quantitative relaxometry maps such as those produced by DESPOT [1]. Bloch-Siegert B_1^+ mapping was recently introduced as a fast and accurate B_1^+ mapping method [2], however, due to the long high-amplitude Bloch-Siegert off-resonant RF pulse, this method suffers from high RF power deposition (SAR) at high field, and this limitation leads to long TR and scan time. We have implemented a Bloch-Siegert B_1^+ mapping method with a single-shot spiral acquisition to minimize SAR and scan time, with the goal of whole brain B_1^+ mapping at 7T in seconds rather than minutes.

Methods: An optimized off-resonant Bloch-Siegert (BS) pulse [3] with 4 ms pulse width and frequency offset of $\Delta\omega_{BS}$=4000 Hz was added to a spiral-out sequence, with the BS pulse placed after the excitation pulse and before the readout gradient. The refocusing part of the slice select gradient was moved after the BS pulse to act as a crusher for any direct excitation caused by the BS pulse. Fig. 1 shows the complete pulse sequence. The BS-spiral combination was repeated with BS pulse shifted symmetrically above and below resonance by +/- $\Delta\omega_{BS}$ for phase difference processing [2]. On each scan, an additional frame was collected at a longer TE (differing by 2ms) for B_0 mapping. The phase difference between the 2nd frames of the two scans was obtained as the BS phase shift. Due to high sensitivity of the optimized off resonance pulse, the BS phase is more than 2π so we used a Fourier based phase unwrapping method [4]. Using the BS phase shift map and the B_0 map in a full Bloch equation solution, we calculated the B_1^+ map. We compared spiral BS B_1^+ maps with those produced by a conventional gradient echo based BS B_1^+ mapping sequence using the same off-resonant BS pulse.

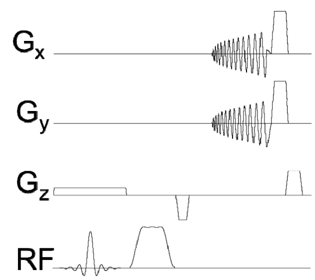

Fig. 1) Spiral PSD with BS Pulse

Results: A multi-slice B_1^+ map of a head-neck phantom was acquired by spiral and GRE based BS sequences on a 7T scanner (GE Healthcare, Waukesha). The scan parameters for the GRE sequence were selected as: TE=8.7 ms, TR=50 ms, FOV=24, slice thickness=5 mm, matrix 128×128, FA=40, NEX=1, bandwidth=15.6 kHz, readout=4.096 ms, which led to a 33 s scan time. The scan parameters for the spiral sequence were selected as: TE=8.7 ms TR=80 ms, FOV=24, slice thickness=5 mm, bandwidth=65 kHz, readout=39.708 ms, # interleaves= 1, Freq= 96, kmax=0.5, variable density [5], 128×128 reconstruction matrix, which led to 0.48 s scan time. The BS pulse amplitude was set to the excitation pulse amplitude in BS GRE sequence and it was increased by a factor of 2 in BS Spiral sequence. The B_1^+ mapping was repeated 20 times for each sequence. The average of B_1^+ maps is shown in Fig 2 and the ANR map is shown in Fig. 3. We increased the # slices in both sequences to 32 to cover the entire brain using an interleaved slice acquisition, which required the following parameter changes: TR to 425 ms and matrix size to 32×32 for GRE and TR to 1700 ms and matrix to 128×128 for spiral. For the GRE sequence, the total scan time was 64 s with measured SAR=2.5 W/Kg; for the spiral sequence scan time was 12 s with measured SAR=1.4 W/Kg. In another experiment Spiral BS and GRE BS were compared in head with the same parameters and the result is shown in Fig. 4. As expected, the spiral B_1^+ maps have better SNR compared to GRE BS due to 2× higher amplitude of BS pulse.

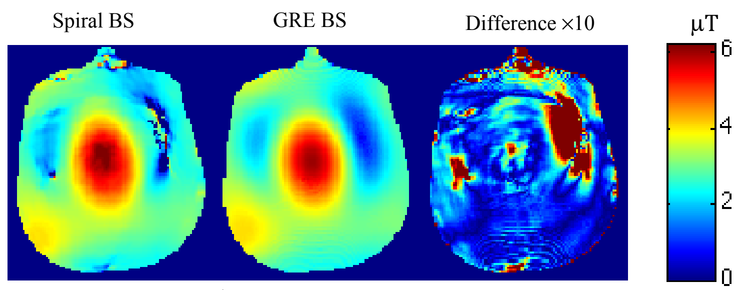

Fig. 2) Mean of B_1^+ map by Bloch-Siegert Spiral and GRE

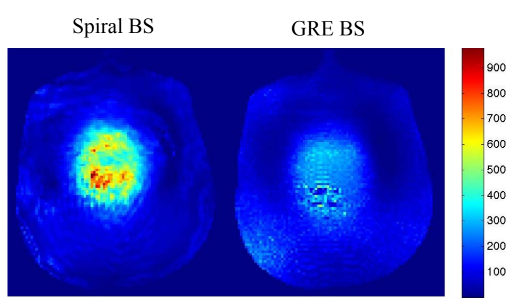

Fig. 3) ANR of B_1^+ map by BS Spiral and GRE

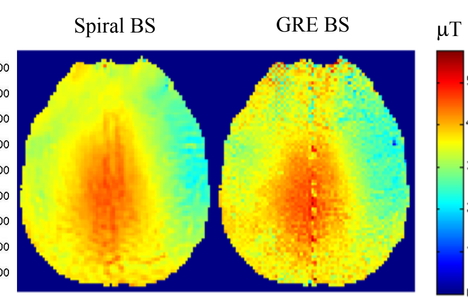

Fig. 4) In vivo B_1^+ maps by BS Spiral and GRE

Discussion: This novel single-shot spiral BS sequence is a fast B_1^+ mapping method with minimum RF deposition. We have shown here that it can be used for whole brain B_1^+ mapping at 7T in a 10 s timeframe, which makes it a good candidate for time-efficient whole-brain B_1^+/B_0 calibration for multi-transmit applications. It could also be used as part of prescan to optimize transmit gain quickly and accurately, even in single-transmit applications. Comparison between spiral and GRE sequences shows that the spiral method has a better ANR than GRE method because of its higher sensitivity due to higher BS pulse amplitude (which was not possible with GRE because of SAR limit) but suffers slightly from B_0 artifacts in the area with low B_1^+. Due to the slow variation in B_1^+ maps in the brain, these high frequency artifacts can be easily suppressed by filtering. In addition, the application of improved higher order B_0 shimming may reduce these artifacts. The spiral method is easily adaptable to lower field strengths, where the artifacts and overall performance should be even better.

References: [1] Deoni et al., MRM 60:1372:1387, 2008. [2] Sacolick et al., MRM 63:1315-1322, 2010. [3] Khalighi et al., Proc. ISMRM 18:2842 (2010). [4] Bagher-Ebadian et al., JMRI 27:649-652, 2008. [5] Chang et al., "Variable-Density Spiral-In/Out Functional MRI", MRM, 2010 (in press).

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