Fast Simultaneous B_0/B_1 Mapping by Bloch-Siegert Shift with Improved Gradient Scheme and Pulse Design

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Introduction

- B_1 mapping techniques provide a way to quantify B_1^+ inhomogeneity, and mitigate its effect on image quality [1-4].
- Recently, a method based on the Bloch-Siegert (BS) effect [5] has been shown to be robust to variations in experimental conditions.
- However, the acquisition time is generally limited by the allowable Specific Absorption Rate (SAR), which may become quite restrictive for human scanning at 7T and above.
- Based on theoretical analysis of the dependence between mapping sensitivity and SAR levels, we developed an approach to reduce SAR levels and further improving insensitivity to B_0 inhomogeneity compared to the original implementation [5].
- The effectiveness of the new scheme is demonstrated in human brain at 7T.

Methods

- For a BS pulse with constant frequency offset, the phase shift is:

$$\phi_{BS} = \gamma^2 / (2\omega_{RF}) \cdot \int_0^T (B_1(t))^2 \, dt$$

- By rearranging the equation:

$$SAR \propto \int_0^T (B_1(t))^2 \, dt = 2\phi_{BS}\omega_{RF} / \gamma^2$$

- Since ϕ_{BS} directly determines the signal strength in the final B_1 map, the only way to reduce SAR without affecting mapping sensitivity is to reduce ω_{RF}, which requires following changes.
- Using crusher gradients
  - A bipolar crusher pair sandwiches the BS pulse
- Optimizing the “stop-band” of the pulse (similar to [6])
  - The BS shift is maximized for a fixed peak B_1 value, for each pulse shape generated by the stop-band response minimization using the method proposed in [7]
  - Detailed design parameters are: the pulse duration 8ms (same as the original Fermi pulse); ω_{RF}=2kHz, passband ripple tolerance is set to a high value (e.g. 50%), bandwidth 1kHz; maximum stop-band ripple tolerance 1e-4
- Simultaneously map B_0 distribution to correct B_1 calculation
  - A second echo is added to the sequence to map B_0
- Extending the pulse duration (not explored)
- Final optimized sequence is shown in Fig. 1.

Results

- The effectiveness of the proposed sequence was demonstrated both with an oil phantom scan and an IRB approved volunteer study
- Hardware: a Siemens Magnetom 7T (Erlangen, Germany) scanner based on an Agilent 7T-830-AS (Oxford, UK) magnet, with a 32-channel head coil (Nova Medical Inc., Wilmington, MA, USA)
- The phantom data showed that the improved gradient scheme reduces the direct excitation effect of a 2kHz Fermi pulse by 250-fold (or 48dB)

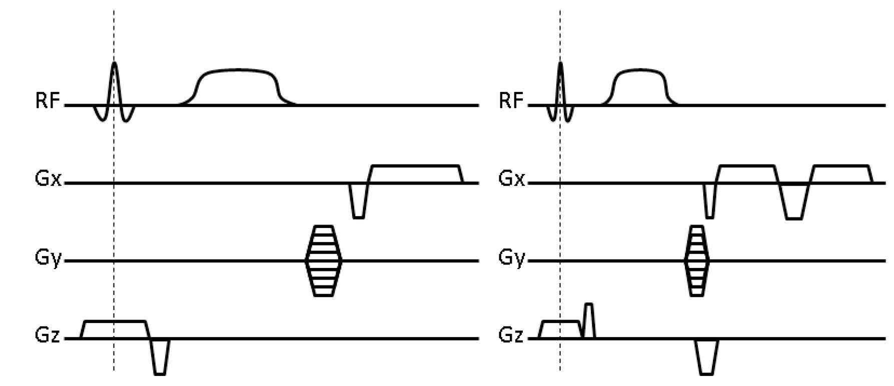

Fig. 1: Original (left) and proposed (right) GRE based BS B_1 mapping sequence diagram

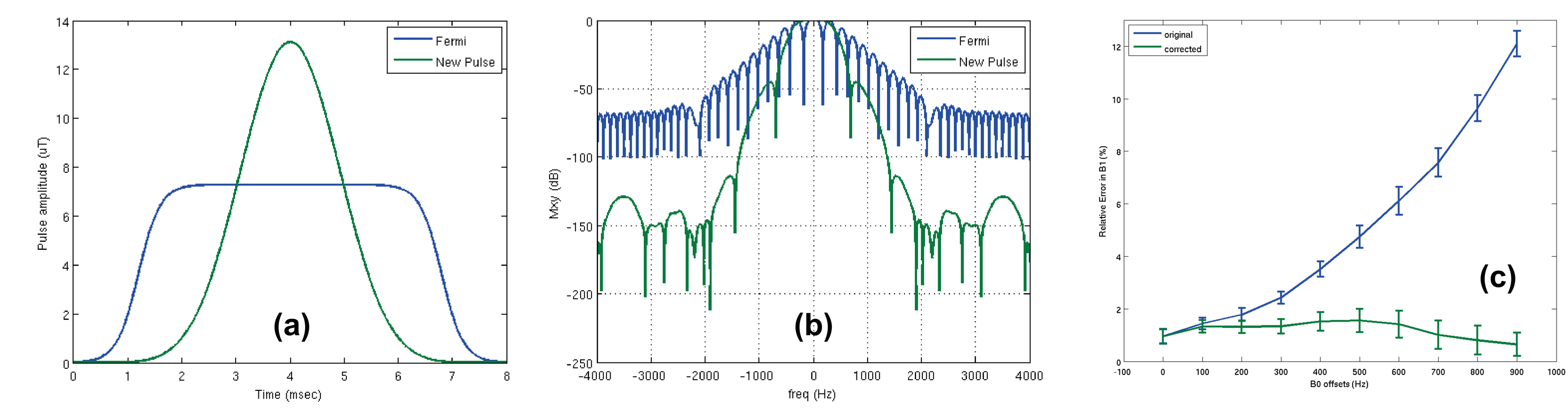

Fig. 2: (a) Pulse shape and (b) simulated frequency response of the Fermi (blue) and the new pulse (green). (c) relative errors of measured B_1 with B_0 offset with (green) and without (blue) simultaneous correction.

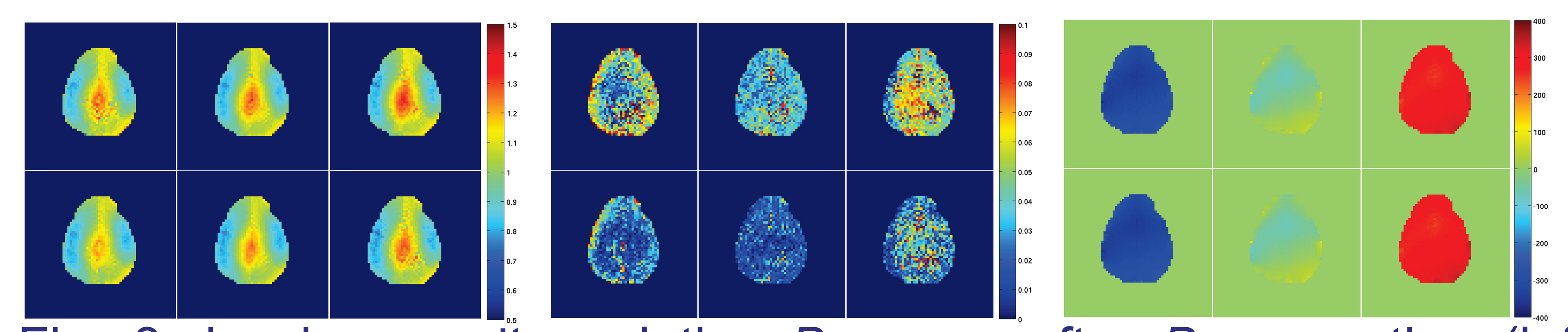

Fig. 3: in vivo results: relative B_1 maps after B_0 correction (left panel, scaled from 50% to 150%), relative error maps (middle panel, scaled from 0% to 10%), and B_0 maps (right panel, scaled from -400Hz to 400Hz). The top row images were acquired with 2kHz 8ms Fermi pulse and the bottom row with the new pulse. The B_0 offset was -300 Hz in left column, 0 Hz in the middle, and +300 Hz in the right column of each panel.

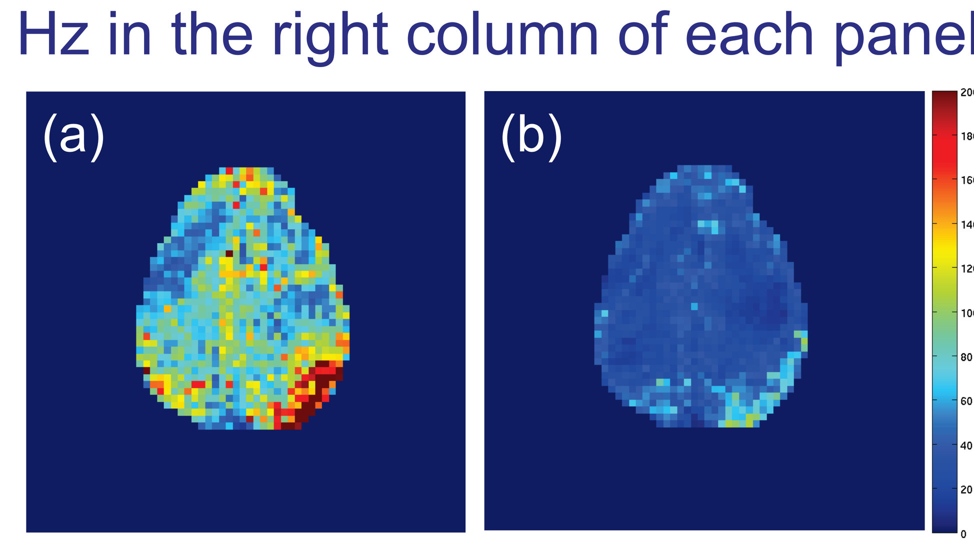

Fig. 4: *in vivo* results: angle-to-noise ratio maps (scaled from 0 to 200) acquired by (a) 2kHz the new pulse and (b) 8kHz Fermi pulse with 10 repetitions. SAR = 98% and TA = 3m50s.

Table 1: Mean relative errors in B_1 map

B_0 Offset (Hz)	-300	0	300
Mean Error (Fermi)	4.5%	3.5%	5.1%
Mean Error (New Pulse)	2.4%	1.6%	3.1%

Conclusion

- Efficiency of ϕ_{BS} /SAR only depends on ω_{RF}
- An optimized pulse shape used in BS B_1 mapping techniques combined with a modified gradient scheme and simultaneous B_0 mapping allow much reduced frequency offsets to be used
- This increases the energy efficiency, as demonstrated in both phantom and human studies
- The proposed scheme can be combined with other optimization scheme, e.g. EPI readout, to further reduce acquisition time

[1] Sacolick, et al, MRM 2011. [2] Hoult, et al, JMRI 2000, 12(1):46-67. [3] Zhu, et al, MRM 2004; 52(4): 869-77. [4] Katscher, et al, MRM 2003, 49(1):144-50. [5] Sacolick, et al, MRM 2010; 63(5): 1315-22. [6] Khalighi, et al, ISMRM 2011: 4431. [7] Selesnick, et al, IEEE TSP 1996; 44(8): 1879-92.