Optimization of Amplitude-Modulated Pulses for Bloch-Siegert Based B_1 Mapping

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Target Audience MR physicists, engineers.

Purpose

Reducing RF power deposition with Bloch-Siegert (BS)-based B_1 mapping[1] is an active area of research[2-6]. The recent realization that both the sensitivity and the SNR of BS methods are proportional $\gamma^2 SAR/\omega_{RF}$ has suggested that BS pulse optimization should be done under a constant energy assumption rather than a fixed amplitude assumption. Here, we followed this approach, while simultaneously considering the effectiveness of gradient crushers in minimizing signal excitation and saturation effects associated with the BS pulse.

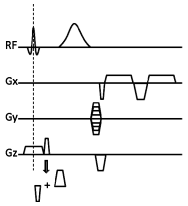

Fig. 1: Modified GRE based BS B_1 mapping sequence

Methods

Pulse Optimization: We focused on and amplitude-modulated BS pulse and gradient-echo (GRE) readout[3] (Fig.1), and considered the effect that increased BS pulse and crusher duration minimize signal excitation, while increasing signal loss due to T_2* decay. This optimization depends on the scanner gradient specs, as well as on background field gradients. The following three-step optimization is proposed: 1) design of BS pulse shape under constant-energy assumption for varying pulse duration (simulation); 2) crusher optimization for each of the optimal pulses at each pulse duration (using *in vivo* MRI for realistic background fields); 3) angle-to-noise ratio (ANR) measurement of each optimal pulse-crusher combination (*in vivo* for realistic background fields, and because of effects such as drift and motion). Below, we demonstrate this optimization for Δf_{RF}=500Hz.

Pulse optimization under constant energy assumption is mathematically equivalent to a spectrum concentration problem, whose solutions are prolate spheroidal sequences[7] (only 0th order, DPSS, demonstrated here). A fixed number (1000) of pulse support points was used, while the time-half-bandwidth product (*thbw*) was varied from 0.1 to 10. For each pulse duration (2ms to 9ms with 1ms step), the pulse shape generating the least amount of direct excitation in the 200-800Hz band (based on estimated B_0 variations in the head at 7T[3]) via Bloch-simulation. For each optimal pulse at a particular duration, the minimal crusher duration was found *in vivo* by setting the RF excitation pulse to zero and incrementally reducing crusher moment until signal became visible above background noise. Finally, ANR was measured for each pulse-crusher combination by calculating the ratio of mean and standard deviation of 10 repeat measurements.

MRI experiments: IRB-approved MRI experiments were performed on a Siemens Magnetom 7T using FOV 256mm, imaging matrix 64x64, slice thickness=5mm. The reference B_1 map was acquired with a 8ms 8kHz Fermi pulse (nominal ϕ_{2BS}=60°, TR = 615ms, 10 averages, maximum SAR). For demonstration purpose, both DPSS pulses and a previously optimized pulse under constant amplitude assumption (QDAPX)[3] went through crusher optimization and ANR measurement, with Δf_{RF}=500Hz, 2-9ms, 64% of maximal SAR, nominal ϕ_{2BS}=60°, minimum TE, TR=60ms. The ANR of an 8ms 8kHz Fermi pulse under the same conditions was used as reference. The nominal flip angle was set to the Ernst angle. Data were collected from five healthy volunteers.

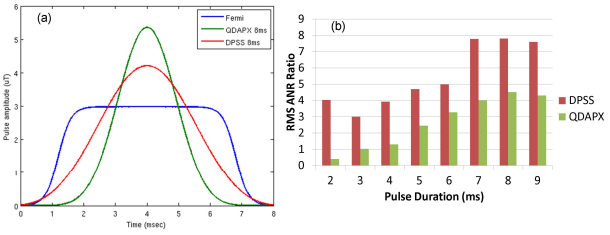

Fig. 2: (a) pulse shapes; (b) RMS ANR ratio

Results and Discussion

DPSS pulses generally required smaller crushers than the QDAPX pulse for all pulse durations. ANRs of DPSS pulse and QDAPX pulse from one subject, relative to the Fermi pulse, are shown in Fig.2b. For both DPSS and QDAPX pulse, RMS ANR ratios were maximized with 8ms pulse duration (7.8 and 4.5 respectively), with corresponding relative errors in B_1 as 1.0%, 1.1%, and 1.5% respectively. This suggests that the 8ms DPSS pulse is optimal terms of ANR. This is confirmed by relative B_1 maps, relative B_1 errors, and ANR maps (Fig.3). Results from other subjects are very similar.

We find that shorter TE does not necessarily translate into a higher SNR in the B_1 map, because of competition between T_2^* decay and the saturation effect from the BS pulses. This suggests that in the BS pulse design, the effect of different pulse duration cannot be simply considered as a T_2^* penalty on imaging SNR. Such disassociation between TE and SNR in the B_1 map suggests that proper evaluation of the SNR performance for different BS pulses has to be done *in vivo* after proper crusher optimization. BS pulse optimization under a constant energy assumption decouples the direct excitation minimization from the optimization of BS shift. It also removes the need to predefine an arbitrary threshold for the stop-band response. In fact, the optimal 8ms DPSS pulse found by the experiments has higher stop-band response than the Fermi and the QDAPX pulse for most of the high frequency spectrum. This is not only suggesting that tailoring the boundary of the stop-band in optimization could further improve the pulse, but also shows the difficulty in properly defining a threshold that is sufficient for applications. This further stresses the point that BS pulse optimization, and choice of frequency offset, require careful consideration of the actual B_0 variations in the object under study. Although an *in vivo* calibration of crushers is necessary in this proposed method, we found the optimal solution was quite consistent across a group of five subjects for a particular choice of B_1 SNR and measurement time. In the current optimization, the range of TE was not limited. It is also possible to reformulate the optimization problem under a constant TE assumption. This, however, generally requires the pulses operate at different energy level, which is out of the scope of this study.

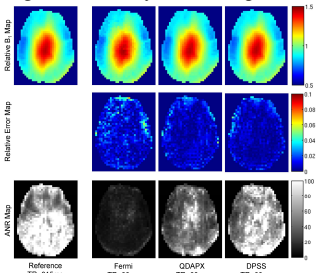

Fig. 3: *In vivo* B_1 mapping, errors, and ANR

Conclusion

A new BS pulse optimization framework under constant energy assumption with consideration of crushers is proposed and a resulting sensitivity improvement is demonstrated *in vivo*.

Reference

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