Broadband refocusing pulses with B<sub>r</sub>, robustness and energy constraints

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Introduction

Broadband refocusing pulses are of great interest in localized spectroscopy for improving spatial selectivity, reducing chemical-shift displacements, and reducing anomalous J modulation. In practice the bandwidth of amplitude modulated pulses is limited by the maximum B<sub>r</sub> amplitude produced by the RF coil. Broad bandwidth is achieved by amplitude and phase modulated pulses designed with the Shinnar-Le Roux optimized (SLR) [1], optimal control theory (OCT) [2], or with adiabatic pulses [3]. This work extends the OCT approach to limiting pulse energy, which can be necessary under constraints of specific absorption rate (SAR).

Results and Discussion

Optimizations are performed for different energy limits, while keeping T, BW, FTW, and B<sub>max</sub> fixed. This gives a curve of pulse quality for different pulse energies. Error of quality is plotted against pulse energy, using the quality function for exact B<sub>r</sub> calibration (Fig. 1a) and with B<sub>r</sub> miscalibration of ±20% (Fig. 1b). The standard SLR pulse with the same B<sub>max</sub> is given for comparison. Its quality is low because it is not broadband.

The quality increases with larger pulse energy. Pulses optimized without considering B<sub>r</sub> deviations (S-BUBOP-0%) reach a slightly better quality with slightly less energy compared to BB-SLR (see cross and square in Fig. 1a). For the same energy, pulses optimized with robustness against B<sub>r</sub> inhomogeneity perform worse for exact B<sub>r</sub> calibration (see circle and plus sign in Fig. 1a), compared to S-BUBOP-0%. For the same quality, pulses with better B<sub>r</sub> robustness need more energy. When looking at pulse performance under B<sub>r</sub>±20%, the BB-SLR pulse and S-BUBOP-0% pulses perform worse (see cross and square in Fig. 1b). Optimizing for B<sub>r</sub>±10% gives good robustness against B<sub>r</sub>±20%. For B<sub>r</sub>±20% the best pulse quality of 0.995 is reached with relative pulse energy of 6.8.

In a PRESS experiment the S-BUBOP-20% pulse with energy 4.5 is compared to SLR and BB-SLR (Fig. 2). The chemical-shift displacement between oil and water resonances is reduced with S-BUBOP-20% and BB-SLR (Fig. 2g). With a B<sub>r</sub> miscalibration of 20% the BB-SLR shows signal loss, while S-BUBOP-20% performs well (Fig. 2h).

Conclusions

Broadband pulses generally require more energy than non-broadband pulses. Compared to a standard SLR pulse, the exemplary S-BUBOP-20% pulse increases the bandwidth by a factor of 3 using a factor of 4.5 larger pulse energy, and with a smaller transition zone. Unlike BB-SLR pulses, S-BUBOP are robust against B<sub>r</sub> miscalibrations.

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References: