Selective excitation of metabolite signals for 1H MRS

Mirjam Holbach[1], Joerg Lambert[2], and Dieter Suter[3]
[1]Physics, Technical University Dortmund, Dortmund, Germany, [2]Leibniz-Institute for Analytical Sciences – ISAS, Dortmund, Germany, [3]Technical University Dortmund, Dortmund, Germany

Introduction:

Selective excitation of metabolite signals in *in vivo* MRS is important for the correct and robust quantification of the content of some key metabolites. This is of special importance under conditions of relatively low field strengths in common clinical MRI scanners, where considerable signal overlap combined with low signal intensities impedes the correct quantification of *in vivo* MRS signals. It is not clear wether the standard techniques for metabolite quantification can, in the case of low signal intensities and overlapping signals, produce reliable results. Many techniques for selective excitation exist, but they suffer from the presence of hardware imperfections and other experimental non-idealities, which may impede a robust performance of these methods. Here we develop RF pulses for the selective excitation of metabolite signals that are robust against hardware imperfections as for example RF inhomogeneity or static field inhomogeneity. With the use of optimal control (OC) theory we calculated pulse shapes that allow for a robust selective excitation in the presence of experimental imperfections. A Krotov-based[1] OC procedure with smoothing monotonic convergence[2] was used for the pulse design and simulations and experimental tests of the resulting pulses were carried out.

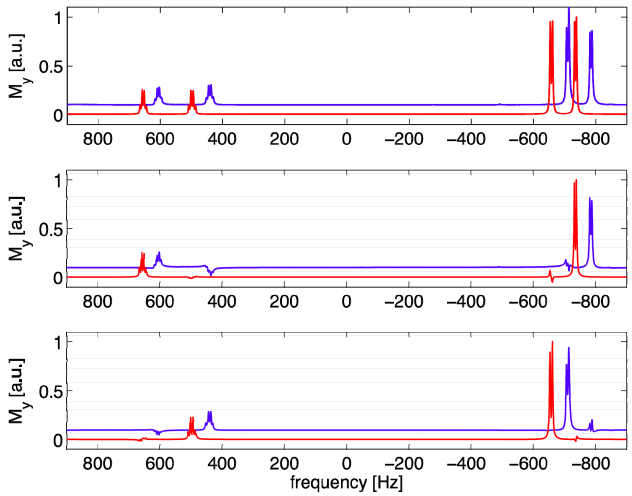

Fig. 1: *Simulated NMR spectra (red) of metabolites lactate and alanine as a model system and experimental results (blue).* ***Top****: Equilibrium spectrum,* ***middle****: Selective excitation of lactate signal and suppression of alanine signal with pulse 1,* ***bottom****: Selective excitation of alanine signal and suppression of lactate signal with pulse 2.*

Material and Methods:

Optimal control theory enables the calculation of RF pulses that transform a given initial state of a spin system into a target state (state to state transfer) by minimizing the difference of the reached target state and the desired ideal target state. Additionally experimental constraints on the pulse shape can be incorporated into the calculation. The Krotov algorithm with a smoothing substep was used in this work[2]. The properties of the algorithm are an improved optimization stability, global extremum searching, fast convergence and independence of the time discretization in terms of convergence[2]. We applied the algorithm with modifications to calculate pulses that act simultaneously on separated molecules (Fig. 2). Further variations of parameters such as RF amplitude or resonance frequency corresponding to non-ideal experimental conditions were incorporated into the calculation. To characterize the pulses and pulse sequences we calculated numerical simulations of the pulse performance with Matlab (Fig.1 and 3) and carried out experimental tests on a Bruker 500 MHz Avance II+ NMR spectrometer (Fig. 1). The model systems contained lactate, alanine and lipid molecules, which have overlapping signals in human tissue.

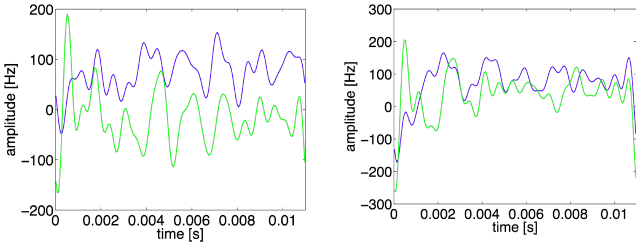

Fig. 2: *Real (blue) and imaginary (green) part of the RF-waveform of pulse 1 for selective excitation of lactate (left) and pulse 2 for selective excitation of alanine (right) calculated with a Krotov-based approach[2] resulting in relatively smooth amplitudes.*

Results and Discussion:

In this study we successfully showed the first application of Krotov-based OC algorithms to the pulse design for selective excitation of homonuclear spin systems. With modifications of the calculation we optimized pulse shapes that excite selectively lactate or alanine of the model metabolite system (Fig. 2). The perfomance of the resulting pulse shapes was simulated with Matlab. The experimental data closely resemble the simulations (Fig. 1). In Fig. 3 the robustness of the new pulse shapes compared to former pulse shapes was investigated by simulation of the efficiency profiles of the pulses. The optimized pulse shapes show a significantly better performance in the presence of hardware imperfections.

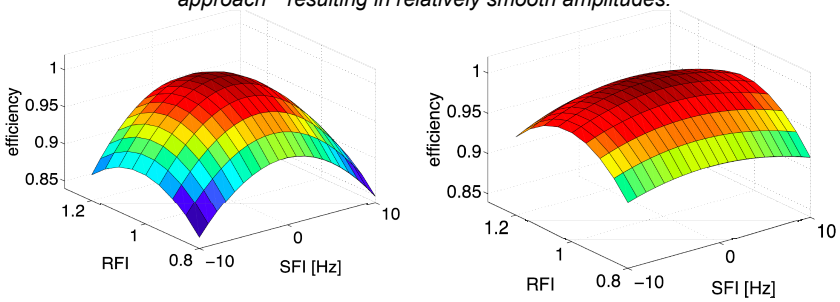

Fig. 3: *Efficiency profiles of RF pulses as a function of static field inhomogeniety (SFI) and RF-inhomogeniety (RFI). The RFI-values are given as a fraction of the nominal RF-value.* ***Left****: Simple Krotov pulse without consideration of RFI/SFI. The pulse performance is affected by shifts in the resonance frequency and by RF-miscalibration.* ***Right****: Efficiency profile of a robust pulse calculated with a Krotov-based optimal control procedure[1,2] with consideration of SFI. The pulse performance is less sensitive to shifts in the resonance frequency.*

References: [1] V. F. Krotov, *Global Methods in Optimal Control Theory*, Dekker **(1995)**; [2] I. I. Maximov et al., *J. Chem. Phys.*, **132**, 084107 (**2010**)