Design of complex RF pulse shapes for asymmetric excitation patterns via Optimal Control

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Introduction

Radio frequency (RF) pulses are used in magnetic resonance experiments to excite, invert and refocus magnetization. Computation of RF pulse shapes for a prescribed excitation profile is not trivial and therefore typically done by solving the simplified Bloch equation. Contrary to that, the presented design approach is based on the full time-dependent Bloch equations and allows a direct design of RF pulses that excite a specified target slice profile. While symmetric or antisymmetric magnetization patterns can be created with one component of the complex RF field, a fully arbritrary magnetization pattern requires both x- and y-components.

Theory

The efficient numerical solution of the optimal control problem is done by applying a Newton method which is embedded in a trust region framework using a matrix-free iterative solution of the Newton step. To achieve an accurate gradient information and application of the Hessian, the principles of adjoint calculus are used to compute exact derivatives by solving forward and backward in time. The described approach is implemented in MATLAB and uses a constant trapezoidal slice selective gradient shape for the optimization of B1x and B1y.

Results and Discussion

The extension to control both components of the RF field simulataneously allows to create predefined arbitrary excitation patterns – e.g. simultaneous multislice pulses for three slices with different flip angles. The pulse shapes for both components are used to compute a complex RF shape and imported to a GRE sequence on a Siemens 3T Skyra MR scanner to validate the simulations with phantom and in-vivo experiments.

Conclusion

Typically, simultaneous multislice pulses are used to accelerate imaging experiments by an aliased acquisition of different slices with an identical flip angle. However, asymmetric excitation patterns with different flip angles could be used to accelerate (e.g. T1, T2) quantitative parameter identification in multipulse experiments where each slice encodes a different temporal magnetization evolution.

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