From the central and peripheral nervous system to cardiac conduction: biomagnetic field detection using rotary excitation

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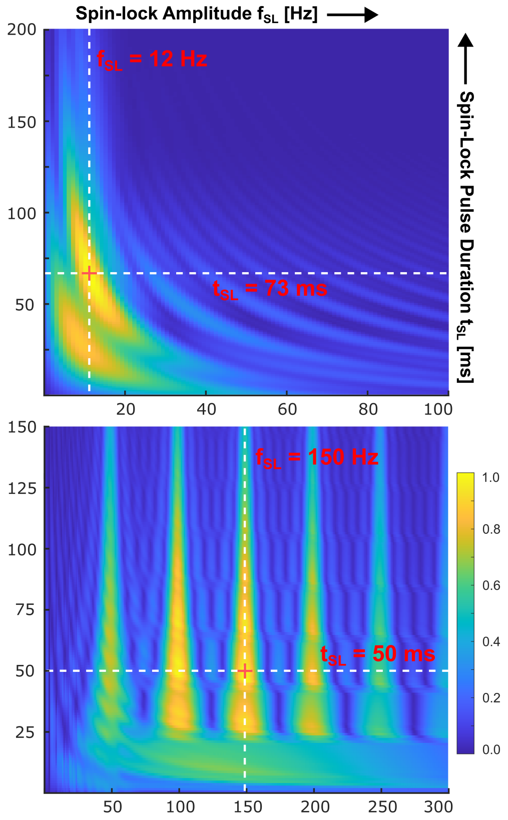
Introduction: Rotary Excitation (REX) is a phenomenon that occurs during the spin-lock (SL) state, enabling the detection of oscillating magnetic fields in the pico- to nanotesla range [1]. Originally proposed for detecting neural activity (low-frequency oscillations in the Hz range), REX has been applied for imaging alpha activity [2] and for the clinical localization of the seizure onset zone in focal epilepsy [3]. In this study, we demonstrate that the REX detection concept can be extended to non-sinusoidal fields, such as those arising in the peripheral nervous system (PNS) and cardiac conduction.

Methods: Physiological models of biomagnetic fields were generated from electromyography data acquired during 50 Hz electrical stimulation of the median nerve, as well as from magnetocardiography data of the cardiac QRS complex [4]. For both scenarios, optimal SL preparation parameters (SL duration t_{SL} and amplitude f_{SL}) were determined by means of Bloch simulations. Field detection was validated experimentally using a clinical 3T MRI system. The time-varying biomagnetic fields were emulated using the scanner's built-in gradient system within a spherical calibration phantom.



Bloch simulation: maximum REX response for cardiac QRS (top) and PNS fields (bottom).

Results: Optimal SL durations and amplitudes were determined for both applications. For detecting cardiac fields with a QRS duration of 100 ms, the maximum REX response was observed at 73 ms and 12 Hz. For the electrical 50 Hz PNS stimulation, maxima occurred at 50 ms and integer multiples of 50 Hz, with the global maximum at 150 Hz. The manifestation of global maxima in the millisecond range can be explained since the REX effect induces magnetization components, while relaxation effects counteract and reduce these components. Experimental validation confirmed the detectability of both field types using the optimized parameters, with minimum detectable field magnitudes of 1 nT and a spatial resolution of 2×2×5mm.

Conclusion: REX-based field detection was originally developed for purely sinusoidal waveforms. However, the potential applications are considerably broader, as REX is a resonance phenomenon that generates detectable magnetization whenever the SL amplitude matches a main frequency component of the temporal waveform. In this context, REX can be interpreted as spectral Fourier analysis for magnetic fields. Future studies will aim to transfer the optimized and phantom-validated protocols to ex vivo models and subsequently to in vivo detection of biomagnetic fields.

References: **[1]** Witzel et al.42(4):1357-65 (2008) **[2]** Truong et al. Magn Reason Med. 81(6):3462-3475 (2019) **[3]** Kiefer et al. Radiology. 280(1):237-43 (2016) **[4]** Jensen et al. Sci Rep. 8:16218 (2018)