Characterization of time-varying magnetic fields via spin-lock based magnetic resonance fingerprinting

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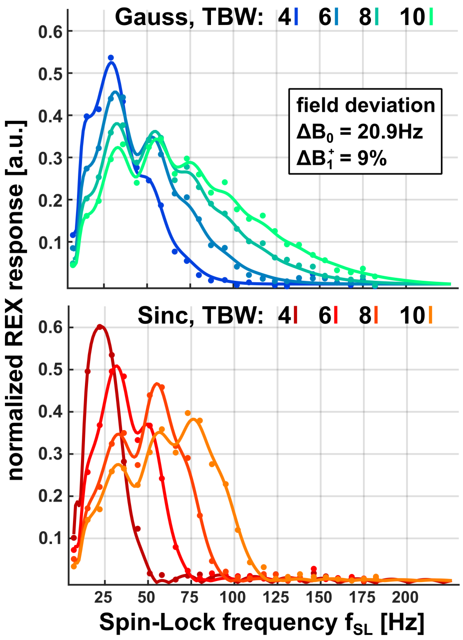
Introduction: Spin-locking (SL) can be used to effectively reduce the Larmor frequency in the rotating frame [1]. Under SL conditions, relaxation processes such as $T_{1\rho}$ and $T_{2\rho}$ show sensitivity to low-frequency interactions and can be exploited to analyze macromolecular remodeling [2]. Besides relaxation, spin dynamics slow down, allowing magnetic oscillations in the Hz to kHz range to be absorbed [1]. This phenomenon, known as Rotary Excitation (REX), can be utilized for the direct detection of biomagnetic fields [3]. In this study, we demonstrate that REX, in combination with Magnetic Resonance Fingerprinting (MRF), can be used more broadly to characterize temporally varying magnetic fields.

Methods: The REX effect was modeled using numerical simulations of the Bloch equations via a fourth-order Runge-Kutta integration. Simulations were conducted for 10^5 combinations of relaxation times, static field deviations, and different magnetic waveforms. Gaussian- and Sinc-shaped fields with a maximum magnitude of 100 nT and varying time-bandwidth products (TBW) were simulated, and their REX responses were analyzed for different SL field strengths. The resulting dictionary was matched against experimental data acquired on a clinical 3T MRI system (Siemens Magnetom Skyra). The goal was to identify the controlled stimulus fields by means of a pattern matching algorithm.

Results and discussion: A strong agreement was observed between the simulated and measured REX signals. Gaussian and Sinc fields could be reliably distinguished in 97% of voxels within the field of view, and TBW values were identified with at least ±1 accuracy in 94% of cases. The mean inner product used for the pattern-matching algorithm was 0.997. For accurate matching, it was essential to include static field deviations (ΔB_0 and ΔB_1) in the model. ΔB_0 introduced additional oscillations in the REX response, while ΔB_1 altered the effective SL amplitude, leading to spectral shifts in the acquired signals.



Measured (dots) and matched (lines) REX responses for Gauss- and Sinc-shaped field variations.

Conclusion: This work demonstrates that spin-locking combined with MRF concepts enables spectral analysis and temporal characterization of magnetic fields using a standard clinical MRI system. This approach also indirectly enhances the temporal resolution of SL-based field detection sequences. Future studies will explore whether this method can be applied to assess and calibrate implanted devices such as deep brain stimulators. For imaging biomagnetic fields - such as those associated with epilepsy [4] or cardiac conduction [5] - the presented approach could offer new perspectives for improved and accelerated detection.

References: **[1]** Redfield. Phys Rev. 98;1787 (1955) **[2]** Bustin et al. JCMR. 25;34 (2023) **[3]** Gram et al. Sci Rep. 13;12(1) (2022) **[4]** Kiefer et al. Radiology. 280(1):237-43 (2016). **[5]** Albertova et al. Magn Reson Med. 92(5):1965-1979 (2024)