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## Overview

Quadrature Phase RARE (QP-RARE) is a fast spin-echo technique that uses **quadratic phase modulation** of the refocusing pulses to achieve robust echo trains even under **non-CPMG conditions**.  
This makes it particularly suitable for diffusion-weighted imaging and other applications where phase coherence is disrupted.

This repository includes:

* **JEMRIS-compatible sequence generation** (XML files)
* **Extended Phase Graph (EPG) simulations** for S1/S2 signal components
* **Flip angle & phase optimization** based on SNR and k-space weighting
* Integration of **crusher gradients** and **prepulse schemes**
* Tools for evaluating **robustness to phase offsets**

## Features

* **QP-RARE sequence design**:
  + Configurable number of preparation pulses (e.g., 3 or 7)
  + Adjustable flip angles and phase increments
  + Optional k=0–only acquisition mode
* **Optimization framework**:
  + Based on Rahbek et al. (2023) SNR–PSF optimization approachRahbek
  + Supports target k-space weighting functions and filter generation
  + Robustness evaluation under φ=0 and φ=π/2 phase offsets
* **Simulation capabilities**:
  + **JEMRIS** Bloch simulations for realistic gradient/RF effects
  + **EPG** simulations for rapid parameter sweeps
  + Output of S1 (in-phase) and S2 (quadrature) component evolution

## Requirements

* MATLAB R2020a or later
* JEMRIS for MRI sequence simulation
* (Optional) Access to HPC cluster for large-scale optimizations
* Toppe framework for image reconstruction of MRI data

**Usage**

1. **Generate a QP-RARE sequence**:

generate\_QPRARE\_XML('QPRARE\_7prepulses.xml', params);

1. **Run EPG simulation**:

run\_QPRARE\_EPG(params);

1. **Optimize flip angles**:

[flips\_opt, txdev\_opt, rxdev\_opt] = FA\_optimization\_QPRARE();

1. **Simulate in JEMRIS**:
   * Load the generated XML sequence
   * Run simulation for φ=0 and φ=π/2 offsets
   * Analyze reconstructed images

**References**

* **Le Roux P.** Non-CPMG Fast Spin Echo with Full Signal. *J Magn Reson*, 155:278–292, 20021-s2.0-S109078070292523…
* **Bastin ME, Le Roux P.** On the Application of a Non-CPMG Single-Shot Fast Spin-Echo Sequence to Diffusion Tensor MRI of the Human Brain. *Magn Reson Med*, 48:6–14, 2002Magnetic Resonance in M…
* **Rahbek S, et al.** Optimized Flip Angle Schemes for the SPLICE Sequence and Application to Diffusion-Weighted Imaging. *Magn Reson Med*, 89:1469–1480, 2023