# Quadrature Phase RARE (QP-RARE)

## 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

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## 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 approach

- 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

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## Requirements

- MATLAB \*\*R2020a\*\* or later

- [JEMRIS](https://sourceforge.net/projects/jemris/) for MRI sequence simulation

- [Toppe](https://github.com/toppeMRI/toppe) framework for MRI image reconstruction

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## Usage

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

```matlab

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

```

2. \*\*Run EPG simulation\*\*:

```matlab

run\_QPRARE\_EPG(params);

```

3. \*\*Optimize flip angles\*\*:

```matlab

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

```

4. \*\*Simulate in JEMRIS\*\*:

- Load the generated XML sequence

- Run simulation for φ = 0 and φ = π/2 offsets

- Analyze reconstructed images

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## References

- \*\*Le Roux, P.\*\* Non-CPMG Fast Spin Echo with Full Signal. \*J Magn Reson\*, 155:278–292, 2002.

- \*\*Bastin, M.E., 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, 2002.

- \*\*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.

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