M229 Advanced Topics in MRI, Spring 2025
Homework 1: Pulse Sequence Simulations
Assigned: 2025.04.10; Due: 5 pm, Mon, 2025.04.21 by email
Questions? Email HoldenWu@mednet.ucla.edu

Turn in (1) a PDF with your simulation results and discussions, and (2) your MATLAB code. Include comments in your code to improve readability.

1. Bloch Equation Simulations

In the first part, we will take a closer look at the transient and steady states of rapid gradient echo (GRE) sequences using Bloch equation simulations. Follow Dr. Brian Hargreaves's tutorial that was shared through our class email list. The MATLAB scripts xrot.m, yrot.m, zrot.m, throt.m, and freeprecess.m will be especially helpful.

1A. *Steady state signal comparison*. Simulate the steady state signal levels for bSSFP (center of pass band), SSFP-FID, and SSFP-Echo.

(i) Follow Brian's tutorial to implement sssignal.m, gresignal.m, and gssignal.m. For bSSFP, you can use sssignal.m. For SSFP-FID/Echo, start with gresignal.m and gssignal.m, and then add an option to specify the position of gradient spoiling in TR for SSFP-FID/Echo.

(ii) Read and use the provided template HW_1A_bSSFPandGRE_SS_v0.m, which calls the scripts sssignal.m for bSSFP, and gresignal.m and gssignal.m for SSFP-FID/Echo.

(iii) Assume the parameters: bSSFP TE/TR = 2.5/5 ms, SSFP-FID TE/TR = 2/10 ms, and SSFP-Echo TE/TR = 8/10 ms. Plot and compare the steady state signal levels over a range of flip angles (0-180^o) and different tissue T_1 and T_2: (a) T_1 = 1000 ms and T_2 = [100, 200, 500, 1000] ms, (b) T_2 = 40 ms and T_1 = [100, 200, 500, 1000] ms. (See slides for Lectures 2 and 3.)

(iv) Discuss your observations.

1B. *Catalyzation for bSSFP*. Simulate the approach to steady state for a bSSFP sequence.

(i) Read and test the provided templates HW_1B_bSSFP_main_v0.m and bSSFPprepfunc_halfTheta.m, which simulate the (θ/2-TR/2 preparation) scheme we introduced in class.

(ii) Implement linear ramp catalyzation with N TRs and excitation angles [1:N]/N.

(iii) Assume the parameters: RF θ = 70^o and $\Delta\phi$ = π, TR = 5 ms, 200 TRs, tissue T_1/T_2 = 600/100 ms. RF phase cycling (e.g., $\Delta\phi$ = π) should be consistently applied throughout the catalyzation and regular TRs. Compare no preparation, θ/2-TR/2 preparation, and linear ramp catalyzation with number of TRs = [5, 10, 20]. For each preparation scheme, plot the transition to steady state for a range of off-resonance frequencies (±400 Hz) as an image (magnitude) and specifically for spins in the center of the pass band and stop band (magnitude and phase). (See slides for Lectures 2 and 3.)

(iv) Discuss your observations.

2. Extended Phase Graph Simulations

In the second part, we will use the extended phase graph (EPG) formalism to simulate rapid GRE sequences. Use the MATLAB scripts sent to the class email list as a starting point.

2A. *Gradient-spoiled GRE.* Simulate the evolution of phase states for a gradient-spoiled GRE (SSFP-FID) sequence.

(i) Review epg_cpmg_hhw.m, which simulates turbo spin echo (TSE). Modify the script to simulate SSFP-FID by looping through each TR, which consists of an RF excitation at the beginning of TR and one gradient spoiler at the end of TR.

(ii) Assume the parameters: RF $\theta = 30^{o}$, TR = 10 ms, 200 TRs, tissue T_1/T_2 = 1000/100 ms. Plot the evolution of all F and Z states as an image (magnitude), as well as the specific evolution of F_0 (magnitude and phase). (See slides for Lecture 4.)

Bonus: Compare the EPG simulations of gradient-spoiled GRE with Bloch simulations.

2B. *RF-spoiled GRE.* Simulate the evolution of phase states for a gradient-spoiled and RF-spoiled GRE sequence.

(i) Based on your work in 2A, add quadratic RF phase spoiling to simulate an RF-spoiled GRE sequence. Remember to demodulate the received signal by the same phase as the RF pulse.

(ii) Assume the parameters: RF $\theta = 60^{o}$ and quadratic $\Delta\phi$ based on $\phi_0 = [2, 5, 117^{o}]$, TR = 20 ms, 400 TRs, tissue T_1 = 1000 ms and T_2 = [100, 500, 1000] ms. Plot the evolution of all F and Z states as an image (magnitude), as well as the evolution of F_0 (magnitude and phase), for these parameter choices. Compress the dynamic range of your images (e.g., |Img|^p, p<1.0) for better visualization. Compare with Fig. 11 in Scheffler's paper (Concepts in MR, 1999).

(iii) Discuss your observations. Which choice of ϕ_0 allows RF-spoiled GRE to achieve T_1-weighted contrast?

Bonus: Compare the EPG simulations of RF-spoiled GRE with Bloch simulations.