BME 599 – Advanced Topics in MRI

Assignment #1

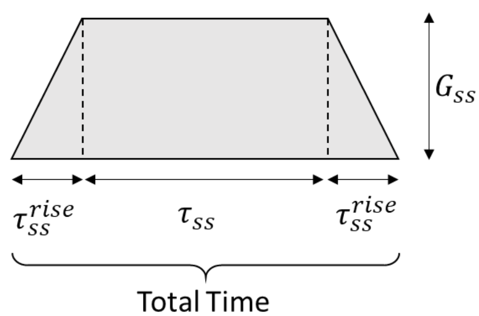
Due Date: 9/28/23

Submission Instructions: Access the class GitHub page at https://github.com/UMICH-BME-AdvMRI. Create your own repository with your UM uniqname and upload your assignment here. Please include all the code needed to reproduce your results! We should be able to run your code using the files you provide.

Problem 1: Spatial Encoding

Suppose you want to collect a 2D bSSFP image at a spatial resolution of 1.2 x 1.2 x 3.0 mm^3 with 256 x 256 matrix size. The receiver bandwidth is 750 Hz / pixel. You are imaging on a 1.5T scanner with maximum gradient amplitude 25 mT/m (for one axis) and maximum slew rate of 180 T/m/s. In the following problems, you will design gradients for slice-selection, phase encoding, and frequency encoding and calculate the shortest possible TR and TE.

1a. You decide to use a sinc-shaped RF pulse with time bandwidth product 4 and a duration of 1 ms. Calculate the amplitude and total duration of the slice-select gradient. Note that the total duration includes both the flat-top time (τ_{ss}) and the time needed to ramp-up and ramp-down the gradient (τ_{ss}^{rise}), as shown in the figure below.



1b. Calculate the shortest possible duration of the phase encoding gradient. As in part a, consider both the flat-top time and rise time when calculating the total duration.

1c. Calculate the amplitude and total duration of the frequency encoding gradient. As in part a, consider both the flat-top time and rise time when calculating the total duration.

1d. Based on your results in parts a-d, calculate the shortest possible TE and TR. Please draw a sequence diagram and label the timings and amplitudes of all RF and gradient events. It is okay to submit a handwritten diagram.

- HINT #1: You can assume that the duration of the slice-rephasing gradient equals half the duration of the slice-selection gradient, and likewise that the duration of the read pre-phasing gradient is half that of the readout gradient.
- HINT #2: You can let certain gradients overlap to minimize the TE and TR.

1e. List three ways you could further decrease the TE and TR by maintaining the same spatial resolution and FoV.

Problem 2: Balanced and Spoiled Steady-State Sequences

2a. Simulate the steady-state frequency response of a bSSFP sequence with a flip angle of 60° using Bloch equation simulations. Show results for (1) TR=5ms and TE=2.5ms, (2) TR=10ms and TE=5ms, and (3) TR=20ms and TE=10ms.

2b. Modify the bSSFP sequence to generate a FLASH sequence by adding a gradient spoiler along the slice selection direction. You can assume TR=10ms and TE=5ms.

> i. Assuming the spoiler gradient as a “perfect spoiler” that completely eliminates transverse magnetization components, please calculate the steady state signal at T1 = 1000 ms, T2 = 100 ms and the flip angle = 10° using a Bloch equation simulation
>
> ii. Rather than assuming ideal spoiling, now let us examine the effect of a gradient spoiler using a Bloch equation simulation. Simulate the steady state signal with the gradient spoiler achieving 2π, 4π, 8π, and 16π dephasing (1 cycle, 2 cycles, 4 cycles, and 8 cycles) per voxel (each with the same TR). Plot the signal as a function of dephasing moment.
>
> iii. Now simulate the effects of *both* the gradient spoiler and RF spoiling. Simulate the steady-state signal by sweeping RF phase from 0°-180° with a reasonable step. Plot the signal as a function of RF phase. Please list your choice of RF phase that best eliminates transverse magnetization.

Problem 3: Slice Profile Simulation

1. Design an RF pulse and its corresponding slice selective gradient to excite a slice thickness of 5 mm
    - RF: 2-msec truncated Sinc pulse with a time bandwidth product of 8
    - Slice selective and rephasing gradients with the following gradient specifications:
        - The maximum gradient strength: 25 mT/m
        - The maximum gradient slew rate: 180 mT/(m*ms)

2. Simulate the slice profile of your RF pulse with a flip angle of 90° (i.e., Mz is tipped into Mxy) at 0 Hz and 200 Hz off-resonance using a Bloch equation simulation with a T1 of 1000 msec and a T2 of 100 msec. Plot the RF waveform (in µT), corresponding gradient waveform (in mT),and m_x, m_y, m_z and m_{xy} vs position.

3. Now that you have a 90° pulse, we will look at producing different flip angles.
   - Generate an RF pulse for a flip angle of 30° and simulate its slice profile.
   - Generate a 10° RF pulse and simulate its slice profile.
   - Now take your results from the 90° and 10° pulses, and on the same plot at the slice profile show the slice profile approximation you would obtain by simply Fourier transforming the RF pulse. Note the differences and similarities between the Fourier transform and Bloch equation simulation at the small and large flip angles.
   - How do your results change if the T2 is 2 ms?

4. For one of the pulses you generated, simulate m_x, m_y, m_z and m_{xy} at the point in time between the slice selective gradient and the slice rephasing gradient. Explain the purpose of the slice rephasing gradient.

5. Based on one of RF pulses you generated for exciting one slice, design an RF pulse to excite 5 slices for a Simultaneous Multi-slice acquisition.
   - 5 slices with a 5-mm slice thickness and 20 mm gap.
   - Simulate the slice profile of your SMS pulse.