BE280A, Principles of Biomedical Imaging 11/18/08
Fall Quarter 2008

BE280A Final Project Assignment

Due Date: As agreed upon in class, the completed project (hard copy) will be due in my office on Tuesday, December 9, 2008 by 5 pm. In addition to the hard copy, please submit a PDF version of the report and MATLAB code (*.m file) via e-mail by 9pm on that day. For full credit, the subject line of your e-mail should read **BE280A08 Final Project**. The report filename should follow the following format mri_{initials of partner 1}_{initials of partner 2}.pdf – e.g. mri_lk_pb.pdf. The oral exam component of the project (10 minutes per student) will occur during the final exam period for this course (Thursday, December 11, 2008 from 8 am to 11 am).

Guidelines:

1) Select a partner to work with (there are 18 registered students, so that there will be 9 groups). Your partner for the final project should **not** be the same as your partner for the midterm project.
2) Discussion of **general ideas** is encouraged between groups, however, each report submitted should reflect each group's own understanding of the material. Figures and MATLAB code should be **unique** to each group. Significant discussions with other groups should be given appropriate credit (e.g. we discussed part (a) with so and so).
3) An electronic copy of the MATLAB code should be submitted with the PDF of the report. The code file should be named in a similar fashion to the *.pdf file, except with a *.m extension.
4) The MATLAB code should follow the following criteria: (a) All figures in the report can be generated just by typing the name of the *.m file (e.g. no further manipulation of the files by the instructor should be required); (b) The numbering and labeling of the Figures generated by MATLAB should **exactly match** what is in the report. (c) If you use functions, they should be named such that the main file can recognize them; or else, just include functions within the main file (the main program will then need to be a function).
5) Use a word-processing program to write the report, including all equations (no handwritten reports! Use an equation editor.). Neatness and clarity of exposition will play a **significant** role in the grading of the report. Other grading criteria include technical correctness and originality. **Clearly** indicate how each section of your report corresponds to each question – it's usually best to break your report into clearly delineated sections.
6) You may use external references (print or electronic). If you do so, please cite them at the end of your report.
7) Title and label the axes on all plots and images.
8) For all problems, use $\gamma/(2\pi) = 4257 \ Hz/G$
9) In addition to answering the questions below, please be as **quantitative** as possible. Also provide additional details and original insights as appropriate. If you noticed something interesting or learned something new in doing this project, please comment on that.

Preliminaries

(**5 pts**.) Label your e-mail, PDF file, and MATLAB code as indicated above.

(**5 pts**.) Make sure that your MATLAB code executes without errors. In addition, all figures should be generated simply by typing the name of the main MATLAB code provided. The number of your figure should **exactly** match the number in your report. Extra figures are okay, but these should be given additional figure numbers.

(**5 pts)** Clarity. Make sure to label all sections in your report clearly. Also indicate clearly how you have addressed the questions.

Description of Problem

Part 1 (50 pts)
Design an echoplanar imaging (EPI) pulse sequence to meet the following requirements: FOV_x= 192, FOV_y = 192 mm, matrix size = 64x64 (i.e., resolution in x = 3 mm; y = 3mm); maximum available gradient = 4.5 G/cm; minimum rise-time from zero gradient to full amplitude = 200 μsec (i.e. maximum slope or slew-rate = 22.5 G/cm/msec = 225 mT/m/msec). Assume that each gradient waveform duration must be an integer multiple of 4 μsec. Also assume that the ADC is only on during the readout gradient, and that the sample rate of the ADC is 250 KHz (i.e., Δt = 4 μsec).

Your design should use trapezoidal and/or triangular gradients, where the maximum slope of your gradients is limited by the slew-rate specification. Your design should make full use of the gradient strengths and slew rates to cover k-space ***in the shortest time possible***. For consistency, when there are two gradients occupying the same space, stretch the shorter gradient out when possible. That is, make the total lengths of the readout and phase encode dephasers the same; and make the total lengths of the readout ramps and the phase blips the same. For the readout ramps and phase gradient blips that occur between readout flats, round the overall time to the nearest multiple of 4 usec. Do **not** have the phase encode dephaser overlap with the initial positive ramp of the readout gradient. Have the dephasers move to an initial position of $k_x = -W_{k_x}/2$ and $k_y = -W_{k_y}/2$.

Assume that the readout gradient corresponds to the x-axis and the phase encode gradient corresponds to the y-axis.

In your design, the 33rd k_y line (phase-encode direction) should go through the $k_y = 0$ origin, so that you end up with a slightly asymmetric coverage of k-space, with 32 k_y lines below the origin and 31 k_y lines above the origin. Similarly, the coverage in the readout direction is asymmetric, so that either the 33rd or 32nd ADC sample of each line (depending on odd or even line) coincides with $k_x = 0$.

(a) (20 pts) Determine the pulse sequence parameters that accomplish the above design parameters. Be explicit in your derivations. Use MATLAB to plot out your gradient trajectories (e.g. G_x and G_y versus time) and the corresponding k-space trajectories (e.g. k_x and k_y versus time). Also make a parametric plot showing the 2D k-space trajectory (e.g. Make sure to label all axes of your plots correctly). As necessary, show zoomed-in views of the critical parts of the trajectories. **NOTE:** Once you have a vector representation of your

gradients in MATLAB, you may want to use the *cumsum* function to calculate your gradient trajectories – this will provide a good check of your answer.

(b) (30 pts) Write a **short** MATLAB program to calculate the pulse sequence parameters. Document the program **clearly** to explain your logic. Use the following input/output format for your program:

[gxr, gxd, gyp, gyd]= epi(fovx,fovy,dt,maxG,trise,nx,ny)

where gxr, gxd, gyp, and gyd are MATLAB structures that have the following elements (amp, trise, tflat). For example, gxr.amp, gxr.trise, gxr.tflat are the amplitude, risetime, and flat time of the gxr gradient. Note that for triangular gradients, the flat time will be zero. The gradient structures gxr, gxd, gyp, and gyd correspond to the readout gradient, readout dephaser, phase gradient, and phase dephaser, respectively. The inputs should be in units of mm for FOV, μsec for dt and trise, and G/cm for maxG. The outputs should be in units of G/cm for the gradients and μsec for the timing parameters. For example:

```
fovx= 192;%mm
fovy = 192;%mm
dt = 4; %usec
maxG = 4.5;%G/cm
trise = 200;% usec
nx = 64;ny = 64;
[gxr0,gxd0,gyp0,gyd0]=epi_tl(fovx,fovy,dt,maxG,trise,nx,ny);
```

Name your function epi_{initials of partner 1}_{initials of partner 2}.m. Your code should produce the answers in part (a). In addition, your code will be tested on an array of input parameters that vary the parameters in different combinations. The **grade** for this portion will depend partially on the number of tests that your code successfully passes. **NOTE:** It is important that you test your program on different parameters to make sure that it does not crash when you change the parameters (e.g. vary one or two parameters at a time by about 20%). Also, make sure that your units are correct!

NOTE: You will turn in two MATLAB files – one with the prefix "epi" for this part. The second file begins with the prefix "mri" and applies to all parts of the project – this second file will call the first file to generate all of the figures for the project.

Part 2 (20 pts)
Use MATLAB to generate the following 64x64 image: a uniform square of water that is 20x20 pixels and located in the lower lefthand quadrant such that the upper righthand corner of the square just touches the center of the image. For the purposes of simulation, you may assume that there is a spin located at each point within the square. Also assume that at t=0, all the spins within the object are in phase.

Assuming that you are using the gradients from Part 2, plot out the MR signal as a function of time. Remember that the signal is complex so you will want to plot the real and imaginary parts or the magnitude and phase of the signal. Comment on the features of the MR signal. When does the signal reach a peak? Is the functional form of the signal what you would expect from the object? You may want to show zoomed-in views of the MR signal to help make your point.

Use the quiver command in MATLAB to show the relative phases of the spins at different points in the trajectory. In particular, show and comment on the spin phases at the following points: (a) $\left(k_x = -W_{k_x}/2, k_y = -W_{k_x}/2\right)$; (b) $\left(k_x = -W_{k_x}/4, k_y = -W_{k_x}/4\right)$; and (c) $\left(k_x = W_{k_x}/4, k_y = W_{k_x}/4\right)$. You may also choose other points that demonstrate your understanding of how the phases of the spins correspond to the Fourier transform of the object.

Part 3 (20 pts)
Reconstruct the object from the MR signal. Take into account the fact that the EPI sequence zig-zags through k-space. Also note the MATLAB ifft function assumes that the center of k-space is acquired as the first indexed point, so you will want to make judicious use of the fftshift function. Show what happens if you do not take into account the zig-zag. You will need to decide if the image is best displayed in magnitude/phase or real/imaginary form.

Part 4 (25 pts)
Now assume that the square object is completely composed of fat, which has a resonant frequency (at 1.5T) that is 220 Hz lower than that of water. This can be modeled by introducing an off-resonance term of the form $\exp(-j\Delta\omega t) = \exp(-j2\pi\Delta f t)$ into the MR signal equation (remember that Hz does **not** equal radians/sec!)

(a) Plot the MR signal from this object. How does this differ from the signal observed from the water object in Part 3?
(b) Reconstruct the object. Explain what you see with mathematical expressions. Be explicit and rigorously justify each step of your derivation. Show that your theoretical expression matches the images. Make good use of the modulation/shift theorem. The complete answer will also need to take into account the zig-zag nature of the k-space trajectory.
(c) Now reverse the sign of the phase-encode gradients (e.g. from negative to positive or vice versa). Repeat parts (a) and (b) and explain what you find. Be as quantitative as possible.

Part 5 (20 pts)
In this part you will experiment with Partial Fourier reconstruction of the data. As a reference for this section, use the sections from Bernstein et al. handed out in class. Assume that you will only collect 40 lines in k-space starting at an initial position of $k_x = -W_{k_x}/2$ and $k_y = -W_{k_y}/2$.

(a) Assume the water phantom from part 2. Reconstruct the image using zero-filling of k-space. How does your image compare to the full k-space reconstruction?
(b) Assume the water phantom from part 2. Reconstruct the image using homodyne reconstruction. Use the filter with smooth transitions given in Bernstein et al. How does your image compare to the full k-space and zero-filling reconstructions?

Part 6 (25 pts) Now assume that there is an error in the MRI pulse sequence, such that the sequence actually starts at $k_y = -W_{k_y}/2 - \Delta k_y$ instead of $k_y = -W_{k_y}/2$. However, your image reconstruction still assumes that the sequence starts at $k_y = -W_{k_y}/2$.

(a) Show that the error is equivalent to multiplying the original object by a linear phase term. The resultant object is now complex. Apply this linear phase term to your complex object, compute the MR signal assuming a perfect pulse sequence (e.g. no errors), and reconstruct the object. Compare this reconstruction to the one you found in part 3.
(b) For parts b and c, perform partial Fourier construction using the same number of lines as in part 5. Reconstruct the complex object using zero-filling. How does your image compare to the full k-space reconstruction?

(c) Reconstruct the complex object using homodyne reconstruction and proper use of phase correction. For this part, assume that you don't know *a priori* what the phase term is and that it must therefore be estimated from the MR signal. Use the smooth version of the lowpass filter given in Bernstein et al. How does your image compare to the full k-space and zero-filling reconstructions?

Part 7 (30 pts) Oral exam component (10 minutes). Be prepared to explain in detail all aspects of the project. Exams will be performed on an individual basis, with partners scheduled to take their exams in contiguous time slots.