BE280A, Principles of Biomedical Imaging 11/21/06
Fall Quarter 2006

BE280A Final Project Assignment

Due Date: Completed project (hard copy) is due on Thursday, December 7, 2006 at 11 a.m. in my office at the Center for fMRI. In addition to the hard copy, please submit a PDF version of the report via e-mail by 12 p.m. on that day.

Guidelines:

1) Select a partner to work with (there are 38 registered students, so that there will be 19 groups).
2) Discussion of **general ideas** is encouraged between groups, however, each report submitted should reflect each group's own understanding of the material.
3) MATLAB code should be **unique** to each group.
4) 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.
5) You may use external references. If you do so, please cite them at the end of your report.
6) For all problems, use $\gamma/(2\pi) = 4257 \ \ Hz/G$

Part I (40 pts)

Design an echoplanar imaging (EPI) pulse sequence to meet the following requirements: FOV_x= 256, FOV_y = 192 mm, matrix size = 64x64 (i.e., resolution in x = 4 mm; y = 3mm); maximum available gradient = 3 G/cm; minimum rise-time from zero gradient to full amplitude = 150 μsec (i.e. maximum slope or slew-rate = 20 G/cm/msec = 200 mT/m/msec). In other words, the gradient cannot change instantaneously, but takes 150 μsec to go from 0 G/cm to 3 G/cm. Assume that the ADC is only on during the flat parts of the readout gradient, and that the sample rate of the ADC is 125 KHz (i.e., Δt = 8 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 8 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 $k_y = -W_{k_y}/2$.

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) (15 pts) Determine the pulse sequence parameters that accomplish the above design parameters. Be explicit in your derivations. Plot out representative sections of the pulse sequence with important parameters clearly labeled. Make a plot of the k-space trajectory. You may want to use MATLAB for the plot.

(b) (25 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, usec for dt and trise, and G/cm for maxG. The outputs should be in units of G/cm for the gradients and usec for the timing parameters. For example:

```
fovx= 256;%mm
fovy = 192;%mm
dt = 8; %usec
maxG = 3;%G/cm
trise = 150;% usec
nx = 64;ny = 64;
[gxr0,gxd0,gyp0,gyd0]=epi_tl(fovx,fovy,dt,maxG,trise,nx,ny);
```

Please submit an electronic version of your MATLAB program via e-mail by 11 AM on 12/07/06. Name your function epi_{your initials}.m. For example, your instructor would name his program epi_tl.m. Also, hand in a well formatted **print-out** of your code with your report. Your code should produce the answers in part (a). In addition, your code will be tested on a wide array of input parameters that vary the parameters in different combinations. The **grade** for this portion will depend on the number of tests that your code successfully passes.

Use MATLAB to generate the following 64x64 image: a uniform disk of water with radius of 16 pixels.

For the following parts, use the gradient values and timing parameters (e.g. echo time, gradient amplitudes) derived for the EPI sequence in part 1a. Also, you may assume that the true-k-space data for each object is given by the MATLAB's Fourier transform of the object you constructed in part 2 (i.e. use the *fft2* command to obtain the 2D FT and then use *fftshift*). When you do this, you will note that the center of k-space is at the 33rd row and 33rd column of the resulting matrix. Assume that rows correspond to the y-direction (phase-encode) and columns correspond to the kx-direction (readout). Also, to keep things simple, assume that increasing row numbers correspond to increasing ky-values. Thus, the first row in the k-space matrix will correspond to the first acquired k-space line.

Part II (30 pts + 10 optional bonus points)

(a) *(10 pts) Nyquist Ghosts due to time delays.* Assume that the ADC is delayed by either 8 μsec or 16 μsec with respect to the gradient waveforms. For example with an 8 μsec delay, the first data point acquired by the ADC corresponds to the 2^{nd} point in each k-space line. Assume that the reconstruction computer thinks that either the 32^{nd} or 33^{rd} sample of each ADC line corresponds to $k_x = 0$, so that the delay of the ADC introduces alternating shifts in the k-space data. To keep things simple, you may assume that k-space data acquired on the gradient ramps is equal to zero. For both delay values, use MATLAB to **reconstruct** the image with the assumed delay.

(b) *(20 pts)* Derive a mathematical expression that explains what you see in the images. Be explicit and rigorously justify each step of your derivation. Discuss how your theoretical expression compares with the images. **HINT:** Think about what happens when you divide k-space into odd and even lines and reconstruct the odd and even images separately before adding them together. Make good use of sampling/aliasing theory and the modulation/shift theorem.

(c) *(Bonus Problem 10 pts).* In practice, the delay between the ADC and the gradients is not known but needs to be measured. One approach is to acquire two calibration k-space lines along $k_y = 0$ in two directions (e.g. $k_x = -W_{k_x}/2$ to $W_{k_x}/2$ and $k_x = W_{k_x}/2$ to $-W_{k_x}/2$). Sketch the pulse sequence that accomplishes this measurement process. Discuss how the data might be used to estimate the delay. In particular, how would you measure a delay that is not an integer multiple of Δt? Make good use of the modulation/shift theorem.

Part III (30 pts + 10 optional bonus points)

Consider an object in which the uniform disk of water is surrounded by a 2 pixel thick ring of fat. At a field strength of 1.5 Tesla, the resonant frequency of fat is about 220 Hz lower than the resonant frequency of water. This can be modeled by introducing an off-resonance term of the form $\exp(-j\Delta\omega t)$ into the MR signal equation.

(a) (10 pts) Introduce an off-resonance term into the k-space data and reconstruct the resultant image. Note that your simulation should simulate what is happening to the k-space data. **Hint:** Split the image into fat and water images and reconstruct the two images separately and then combine at the end. Make sure you take into account the exact timings of your EPI pulse sequence.

(b) (20 pts) 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.

(c) (Bonus Problem 10 pts) Now consider what happens when the sign of the phase-encode gradient is inverted (e.g. from positive to negative). Repeat part (a) assuming the sign is inverted and explain what you find using the expressions developed in part (b).