ECE 5206 Spring 2020 Homework Set 3
Due: 5:00PM Tuesday March 23, 2021

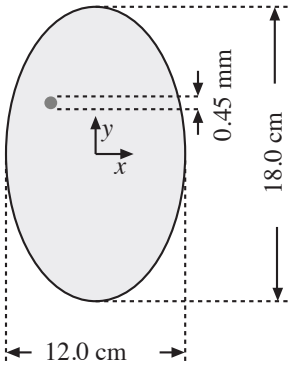

Figure 1: Axial slice of head with embedded cylindrical structure

1.) (80 pts) A cross section of patient's head is roughly an oval. Assume that a slice of a subject's head contains two tissue types of interest: the background (Tissue A) and a cylindrical structure (Tissue B) as shown in Figure 1. The cylindrical structure has its long axis parallel to $\hat{z}$ and has a length of 1.8 mm. The diameter of the cylinder is 0.45 mm. The cylinder is inside the cranial cavity, which has a height (orthogonal to the plane shown) that is 10.0 cm. We do not know where in the head the cylindrical structure sits other than the direction orientation of the long axis. MRI properties of the tissues are given in the table below. Note that the concentration density of protons has been normalized for convenience.

Tissue properties at 7.0 T			
Tissue Type	concentration (cm^{-3})	T_1 (ms)	T_2 (ms)
Tissue A	1.03	1350	75
Tissue B	0.99	1250	67

To maintain an adequate signal from each voxel, we need to assure that the minimum voxel volume is at least 0.02 mm^3.

a.) Assume a standard (2-D) *spin echo* imaging sequence that images a sequence of slices perpendicular to $\hat{z}$. We need to make sure that at least one voxel in the image is entirely Tissue B (that is, in at least this one voxel there is no mixture of Tissue A and Tissue B), so design a voxel size $\Delta x \times \Delta y \times \Delta z$, and a scanning geometry strategy with the number of columns (N_x), the number of rows (N_y) and the number of slices(N_z) that will guarantee this condition. Note that some slices may not have any Tissue B and some slices may have a mixture, but one slice must have a "purely Tissue B" pixel in it. Also note the voxel dimensions are not required to be isotropic (that is, Δx can be different from Δy, etc.). This part is mostly about geometry and the sampling pattern in object space.

b.) Assume an MRI system with a background field strength of $B_o = 7.0$ T. The maximum gradient strength possible (for each gradient coil) is ± 5.5 G/cm (1 T = 10000 G). Assume

that $\gamma = 42.65$ MHz/T (note units are in Hz). Determine the shape of the RF excitation (90^o) pulse envelope if a *symmetrical* pulse is formed of the complete main lobe and only q sidelobes on each side of the main (total of $1 + 2q$ lobes). Determine what you consider an appropriate number is for q for signal excitation, taking into consideration the quality of the excitation profile through the slice, the ability to keep out-of-slice excitation small, and how q affects the timing of the acquisition sequence for the whole imaging scan. Justify your choice in your report. *Note in your report the timing of the zero crossings of your pulse envelope relative to the peak of the main lobe of the pulse.* Determine quantitatively the distortion of the excitation profile through the depth of the slice that occurs due to the truncation of the pulse envelope (you can use either Matlab or hand calculations for this, but you should describe the distortion as a function of z either with an accurate plot or with an analytical expression of z). Give a qualitative explanation of the effect of this type of distortion on the images produced by the scanner. **You can use the arbitrary strength of "1.0" for the main lobe magnitude of the envelope of the 90^o excitation pulse.** (The 180^o pulse would have the same shape but would be twice as strong.)

c.) Assuming a *standard 2-D spin echo sequence*, use phase encoding in the x-direction and readout in the the y-direction. *Explain whether or not this is a good choice for the readout and phase encoding directions and why.* Determine the step size and duration for changes in the phase encode gradient (Δg_x and T_p) and the strength of the readout gradient (G_y) and the sampling period during readout (Δt). Note that the data arrays for k-space samples must have dimensions that are powers of 2 (or you will lose points). It is okay if some of the image samples are outside of the head (contain only air).

d.) One standard definition for (normalized) image contrast is

$$C = \left| \frac{I_A - I_B}{(I_A + I_B)/2} \right|$$

where I_A is the intensity (strength) of a pixel entirely in Tissue A and I_B is the intensity of a pixel in entirely in Tissue B. This is based on the fact that we can always "amplify" the image by multiplying the individual intensities by the same factor to improve the display. On the other hand, noise would also be amplified by the same factor. Using the above definition and what you know about the spin echo imaging timing sequence (including possibly interleaving slice selection pulses during data acquisition) and practical considerations for imaging a patient (like how long a patient can remain still during the image acquisition), choose values of T_E and T_R that give the "best" contrast between the two types of tissues listed above. Note this may not be the maximum contrast. Give the contrast for your values of T_E and T_R and explain why you chose these values. Note that this "normalized" contrast is not the only measure of image quality because it does not include the effects of noise (noise does not change with T_E and T_R even though the signal strength from Tissue A and Tissue B are both strongly affected by T_E and T_R).

e.) Estimate the total time required to collect the entire set of k-space data for one entire slice using your sequence designed above. How long would it take to image the entire brain for your sequence?