Georgia Institute of Technology

The George W. Woodruff School of Mechanical Engineering
Nuclear & Radiological Engineering/Medical Physics Program

Ph.D. Qualifier Exam

Spring Semester 2009

_______________ Your ID Code

Imaging (Day 3)

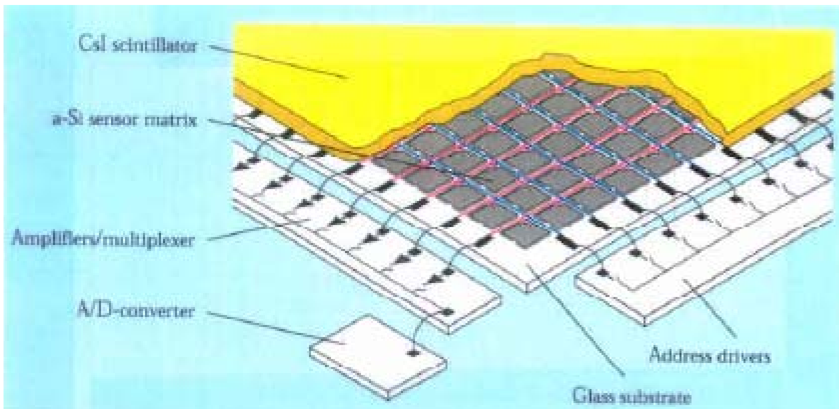
Instructions

1. Use a separate page for each answer sheet (no front to back answers).
2. The question number should be shown on each answer sheet.
3. ANSWER 4 OF 6 QUESTIONS ONLY.
4. Staple your question sheet to your answer sheets and turn in.

NRE/MP - Imaging

Answer 4 of the following questions.

1. Refer to the picture below - a flat-panel digital x-ray radiography system is based on a microcolumnar CsI(Tl) scintillator optically coupled to an amorphous-Silicon (a-Si) array. The a-Si array has 3000 x 3000 pixels. The size of each pixel is 100 μm x 100 μm. The thickness of CsI(Tl) scintillator is also 100 μm. Given that the incident x-ray flux is 10^7 photons sec^{-1} cm^{-2} and that the linear attenuation coefficient of CsI(Tl) for the incident x-ray is 45 cm^{-1}, what will be the exposure time needed in order to achieve a signal-to-noise ratio (SNR) of less than 0.05 for each pixel? List your assumptions if necessary.

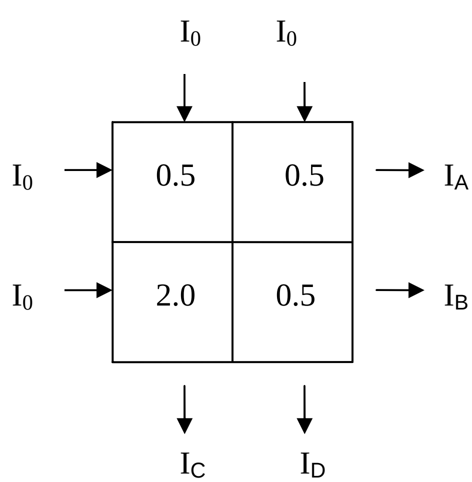


2. To test which of the two x-ray CT image reconstruction methods gives better image, 2 projections were acquired from a known squared test object. The dimension of each square is 1 cm x 1 cm. The true value of μ (in cm^{-1}) is shown in each square.

   a. Calculate I_A, I_B, I_C, and I_D, and then use these values with the simple back projection method to "back calculate" the μ value for each square.

   b. Similarly, use the values of I_A, I_B, I_C, and I_D obtained in (a) with the iterative method to obtain the μ value for each square. Limit the number of iterations to two.

   c. Which method gives the better image in this test? Justify your answer.



3. A medical generator contains 250 mCi of X_1 (half-life = 11.6 day) producing the daughter X_2 (half-life = 9.7 day). You are given the following decay scheme for this question:

$$X_1 \xrightarrow{\lambda_1} X_2 \xrightarrow{\lambda_2} X_3 \xrightarrow{\lambda_3} X_4 \text{ (stable)}$$

   a. Derive an equation as a function of time for X_2 using the following initial conditions: $X_1 = N_{10}$, $X_2 = N_{20}$, $X_3 = 0$, and $X_4 = 0$. (The decay constants for radioactive nuclides are given as λ_n where *n* is associated with radioactive nuclide).

   At t=0, the daughter is completely removed.

   b. How many becquerels of X_2 can be removed (assuming 100% removal efficiency) when the daughter activity equals that of its parent?

   c. The daughter product is then administered to the patient for a single-photon emission computed tomography scan (SPECT). Explain the principles of gamma cameras and SPECT imaging for producing both planar images and tomographic image sets.

   d. The following 3x3 image representation with the horizontal and vertical projection data (2x3 sinogram) is obtained from the gamma camera. Explain and apply <u>additive</u> algebraic reconstruction technique (ART) for <u>TWO</u> complete iterations to the image matrix with 2x3 sinogram. Show each step in box form.

15	5	14	
?	?	?	16
?	?	?	13
?	?	?	5

4. a. What is the temporal pulse duration of a 5 MHz ultrasound transducer that transmits 3 cycles per pulse?

   b. What is the spatial pulse length?

   c. What is the approximate axial resolution of this transducer/pulse?

   d. If the spacing between pulses is 60 microseconds, what is the pulse repetition rate (in Hz)?

   e. If the field of view of this transducer operating in B-mode is defined by a 90º sweep and a depth of 5 cm, what is the maximum refresh rate (frame rate) if the beam width is 2.1 cm at 5 cm. Ignore beam focusing and assume no overlap in beam positions.

   f. What could you do to increase the frame rate in part e)?

5. a. What is the procession frequency of hydrogen protons (ω) at a location 3 cm (in the x-direction) from the iso – center of a magentic field when G_x is 40 mTesla/meter and B_0 = 0.1 Tesla?

   b. What would (ω) be for a point at x=0, but, z = 3 cm using G_x and B_0 for part a)?

   c. What RF bandwidth would be needed to excite a 5 mm slice using a gradient slice excitation G_z = 20 mTesla/meter?

   d. What would be the period (time in msec) of the pulse in part c)?

   e. What is a disadvantage of using a higher gradient G_z to get a thinner slice? What is a disadvantage of using a narrow bandwidth RF pulse to get a thinner slice?

6. Given the following tissue properties constants and relations:

   Tissue 1: T1 = 600 msec, T2 = 90 msec
   Tissue 2: T1 = 1500 msec, T2 = 200 msec

   γ_H =Gyromagnetic ratio for ^{1}H= 42.58 x 10^6 MHz/Tesla

   $M_{xy} = M_0 \cdot \sin(\alpha) \cdot e^{-t/T2}$

   $M_z = M_0 \cdot \left(1-\left(1-\cos(\alpha)\right) \cdot e^{-t/T1}\right)$

   a. Calculate the ratio of M_{xy} of Tissue 1 to Tissue 2 at a point 45 msec after a 60° excitation pulse. Assume no T2* effects.

   b. What would be the value of M_z (as a function of M_0) be 100 msec after a 45° RF excitation pulse for Tissue 1?

   c. Explain why T1 is always longer than T2.