NTNU

Department of Physics

Examination paper for TFY4320 Physics of Medical Imaging

Academic contact during examination: Pål Erik Goa
Phone: 959 08 026

Examination date: Tuesday June 6th 2017
Examination time (from-to): 09:00-13:00
Permitted examination support material: Code C

- Karl Rottmann: Matematisk Formelsamling.
- Barnett and Cronin: Mathematical Formulae.
- Øgrim og Lian: Størrelser og enheter i fysikk og teknikk.
- A specified, simple calculator is permitted.

Other information: Each sub-question (1a, 1b, etc) carries equal weight in the evaluation. Exam might be answered in English or Norwegian.

Language: English
Number of pages (front page excluded): 5
Number of pages enclosed: 0

Informasjon om trykking av eksamensoppgave
Originalen er:

1-sidig □ **2-sidig** □

sort/hvit □ **farger** □

skal ha flervalgskjema □

Checked by:

Date Signature

Some useful expressions and values.

$$
\begin{aligned}
I &= NE \\
I &= I_0 e^{-\int \mu(x)dx} \\
S &= \varepsilon A(I_P + I_S) \\
C &= \frac{I_1 - I_2}{I_1} \\
k &= \frac{S_1 - S_2}{STD_s} \\
D &= EN_0(\frac{\mu_{en}}{\rho}) \\
\varepsilon &= \frac{N_{out}}{N_{in}} \\
p(s,\theta) &= -ln\frac{I}{I_0} = \int_A^B \mu(s,t)dt \\
HU &= 1000 \cdot \frac{\mu - \mu_w}{\mu_w} \\
R_c &= \frac{d(L+z)}{L} \\
g &= \frac{d^2}{4\pi L^2}\frac{d^2}{(d+t)^2} \\
t &= \frac{6d}{\mu L - 3} \\
S &= S_0(1 - e^{-TR/T1})e^{-TE/T2} \\
S &= \frac{S_0(1 - e^{-TR/T1}) sin\theta e^{-TE/T2}}{1 - cos\theta e^{-TR/T1}} \\
f\lambda &= c \\
c &= c_0 + v\beta \\
\beta &= 1 + B/2A \\
f_d &= \frac{\pm 2 f_0 v cos\theta}{c}
\end{aligned}
$$

Table 1: Linear attenuation coefficients [1/cm]

keV	Water	Soft Tissue	Bone	Calc.	Se
20	0.81	0.87	7.68	9.29	216
511	0.097				

Problem 1: X-ray mammography

1 a

Start from the definition of the visibility k and derive the expression of k given below for a small object of dimension x with linear attenuation coefficient μ_2 inside a large object of thickness t and μ_1. State any assumptions or simplifications you do as part of this derivation as well as the definition of the additional parameters required.

$$k = (1 - e^{\Delta\mu x})\sqrt{\frac{\varepsilon A N_0 e^{-\mu_1 t}}{1+R}} \quad (1)$$

1b

Calculate the resulting surface dose to the patient in units of mGy, given the following values:

- Breast tissue thickness: 2 cm.
- Dimension of calcification: 0.1 mm.
- Scattering ratio: 0.5.
- Detector: Amorphous Se, 0.1 mm thickness.
- Visibility $k = 5$.
- X-ray effective energy 20 keV.

The soft tissue mass energy absorption coefficent at 20 keV is $0.56 cm^2/g$.

1c

Describe how a suitable X-ray spectrum can be generated for the above situation, including choice of anode material, acceleration voltage and possible filters. Draw the approximate shape of the resulting spectrum.

Problem 2: Nuclear Medicine Imaging

2a

The following simplified expression/model for the number of counts in a gamma camera was discussed in the course:

$$\#counts \propto \int_0^{t_S} A_0 e^{-\lambda t} dt \cdot Y_\gamma (1 - \bar{\phi_\gamma}) \cdot g \cdot \varepsilon_D(E_\gamma) \tag{2}$$

- Use a figure to illustrate the process described by this model, and define/explain each of the terms.
- Based on the model, discuss problems/challenges in order to reconstruct quantitative SPECT images (images with activity instead of counts).
- Identify one additional effect that needs to be corrected for in quantitative SPECT imaging (not included in the model).

2b

Given a PET-ring with diameter 80 cm and filled with one ring of detectors consisting of 9x9 LSO crystals, each with dimensions 4x4x25 mm.

- Calculate the geometric efficiency of the PET-ring.
- Calculate the maximum spatial resolution.
- Estimate the coincidence detection probability for a point source. State any assumptions made as part of your estimate.
- Estimate the coincidence detection probability for a points source positioned in the center of a water-filled cylinder with diameter of 20 cm.

The non-colinearity effect is 2.2 mrad and the linear attenuation coefficient of LSO at 511 keV is 0.88 1/cm.

Problem 3: Magnetic Resonance Imaging

3a

Explain the two physical interaction processes expressed by the following equations:

$$\vec{N} = \vec{\mu} \times \vec{B} \tag{3}$$
$$\frac{d\vec{J}}{dt} = \vec{N} \tag{4}$$

Use the above to derive the equation of motion for the magnetic moment in an external field, and define the gyromagnetic ratio γ.

3b

Given a 2D spin-echo MR-sequence with the following parameters: TE = 20 ms, TR = 1200 ms, field-of-view = 256x256 mm, image matrix 128x128, slice thickness = 5 mm, number of slices = 10, rf-pulse bandwidth: 2 kHz. Answer the following questions, and justify your answers:

- What is the total duration of the MR-scan?
- What is the spatial resolution?
- What is the amplitude of the slice-select gradient (in units of mT/m)?
- Estimate the maximum number of slices that can be included without increase in scan-time.

The gyromagnetic ratio for protons is 42.58 MHz/T.

3c

Draw up the complete sequence diagram for the above MR-sequence. Include one line for each of the following parameters:

- rf-pulses.
- Slice-select gradient.
- Frequency-encoding gradient.
- Phase-encoding gradient.
- Transverse magnetization, including the position of the spin-echo.
- Signal acquisition.

Problem 4: Ultrasound Imaging

4a

- Describe the two main effects that governs the choice of frequency in normal pulse-echo imaging.
- Describe the main contrast mechanisms in pulse-echo imaging.

4b

In figure **??** below you see an ultrasound image before and after the signal-processing applied as part of matlab-exercise 7 in the course.

- Describe and explain the origin of the noise as seen in the left image.
- Describe the physical mechanism of how it is possible to reduce this noise.
- Describe the post-processing procedure used in order to achieve this effect.

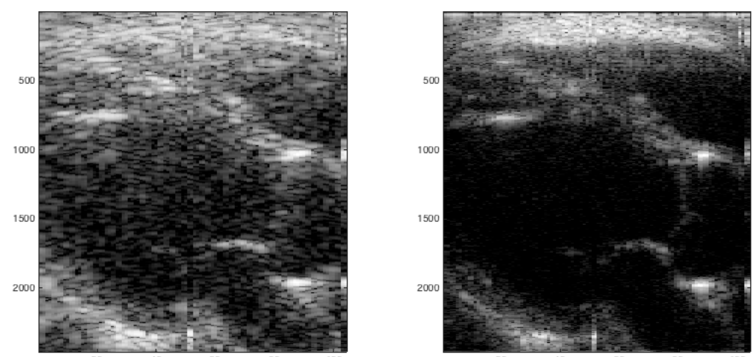

Figure 1: Ultrasound Image before (left) and after (right) signal processing.