# UNIVERSITY OF OSLO

## Faculty of Mathematics and Natural Sciences

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| Exam : | INF-GEO4310 – Imaging |
| Date : | Friday 17. December 2010 |
| Time : | 09.00 – 13.00 (4 hours) |
| Number of pages : | **10** pages |
| Added material : | None |
| Allowed aid : | **Pocket calculator and one A4 sheet with your own text** |

## Your candidate number:

- Please make sure that the exam paper is complete before you begin answering it. For each task, read carefully through the complete text before starting to solve it. If you feel that some information is missing, you may make your own assumptions, as long as they are not contradictory to the "spirit" of the exercise. In such a case, you should make it clear what assumptions you have made. This also goes for the multiple-choice questions.

- Enter your answers to the multiple-choice questions on these sheets of paper.
- The rest of the questions should be answered on separate sheets of paper.
- We recommend that you make calculations on a separate sheet of paper, and then enter your result into the proper place on the exam paper.

- 21 exercises are multiple-choice questions where five alternatives are given, and only one alternative is the correct one. Here you will get 4 points for a correct answer, -1 for an incorrect answer, and 0 if you do not answer. Choosing alternatives at random will on the average give you 0 points here! If you mark the right answer, and guard with some extra crosses, you will loose 1 point for each incorrect cross.

- If you have placed a cross in one of the boxes, and afterwards find that you do not want a cross there, you may write "REMOVE" to the left of the box.

- In the last 4 exercises you are to find the answers yourself. The maximum number of points to be obtained for a good answer is indicated for each exercise. These exercises have a total of 14 questions.

- **If you spend about 3 minutes on each of the 21 multiple-choice questions and then about 10 minutes for each of the 14 last questions, you will have about three quarters of an hour left to recheck your answers.**

- **Answer the questions that you find easiest and least time consuming first!**

Remember to enter your candidate number!

## *Multiple choice – geometrical optics*

1. **What do we mean by "hyperfocal distance"?**
   - ❑ The smallest focus distance at which the near limit of the DOF extends to zero
   - ❑ The largest focus distance at which the near limit of the DOF is the focal length
   - ❑ The smallest focus distance at which the far limit of the DOF extends to infinity
   - ❑ The largest focus distance at which the extent the DOF is infinite
   - ❑ The smallest focus distance at which the DOF equals the circle of confusion

2. **What is the angular magnification of a telescope where the objective and the eyepiece are placed at a distance equal to the sum of their focal lengths?**
   - ❑ The product of their focal lengths
   - ❑ The sum of their focal lengths
   - ❑ The difference between their focal lengths
   - ❑ The ratio of their focal lengths
   - ❑ The product divided by the sum of their focal lengths

3. **The Moon is about 400 000 km away. What is the smallest distance between two resolvable points on the Moon if we use a lens having a diameter D = 0.2 m at $\lambda$ = 410 nm?**
   - ❑ 10 m
   - ❑ 100 m
   - ❑ 1 km
   - ❑ 10 km
   - ❑ 100 km

## *Multiple choice – remote sensing*

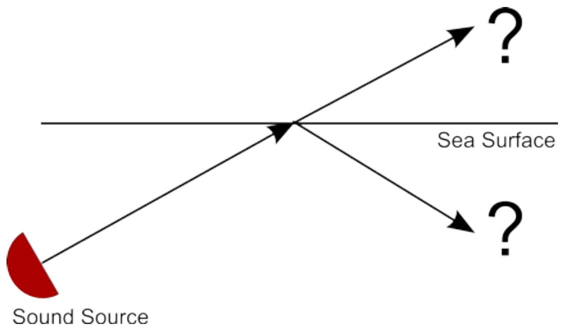
4. **Which of the following wavelengths is not in the visible range of the electromagnetic spectrum?**
   - ❑ 500 nm
   - ❑ 700 nm
   - ❑ 0.4 μm
   - ❑ 1100 nm
   - ❑ 0.7 μm

5. **Which statement below is NOT correct?**
   - ❑ Communication satellites typically use geostationary orbits.
   - ❑ Geostationary orbits rotate at the same speed as the earth.
   - ❑ Geostationary orbits have an inclination angle close to 90 degrees relative to the equator.
   - ❑ Polar orbits give varying coverage depending on latitude.
   - ❑ Polar orbits typically have a speed of 8 km/s.

**6. Why does vegetation look green?**

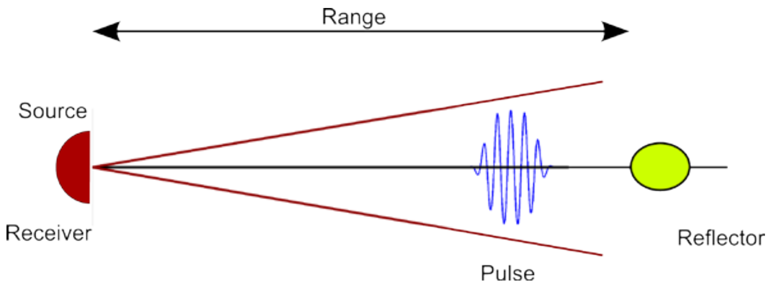
- ❑ Because chlorophyll has equal reflectance properties independent of wavelength.
- ❑ Because green light has higher wavelength then blue light.
- ❑ Because vegetation absorbs light in the green part of the spectrum.
- ❑ Because vegetation absorbs lights in the red and blue part of the spectrum.
- ❑ Because the atmosphere absorbs light corresponding to red and blue wavelengths.

## *Multiple choice – sonar*



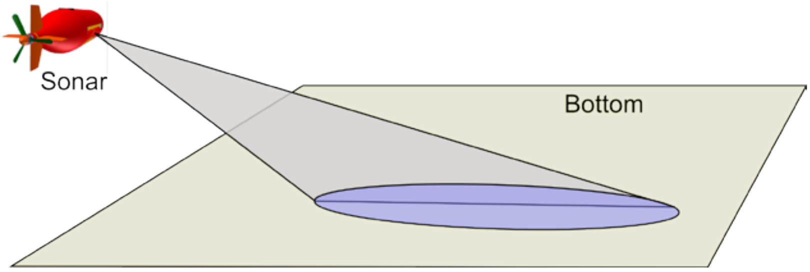

**7. For any underwater sound source near the sea surface, the sea surface might affect the transmitted signal. In what way?**

- ❑ The sea surface is perfectly absorbing, and all sound energy disappears.
- ❑ The sea surface is transparent. All sound energy goes through to the air.
- ❑ The sea surface is (almost) a perfect reflector, and all sound is scattered into the ocean again.
- ❑ The sound is refracted away from the sea surface and trapped into an underwater sound channel.
- ❑ The sound is transported by the surface waves over long distances.




**8. A critical component in sonar is estimation of range (or distance) to a reflector. What is the basic principle of range estimation all sonars use?**

- ❑ The range is calculated from the angular size of the object (angular spread).
- ❑ The range is calculated from the measured pulse length.
- ❑ The range is calculated from the estimated target strength (or reflectivity).
- ❑ The range is calculated from the estimated travel time (or time delay).
- ❑ The range is calculated from the signal bandwidth.




**9. A sidescan sonar is a sonar that images the seafloor (bottom). The simplest version of a sidescan sonar has only one sonar element (or transducer). What is the basic imaging principle for such a sonar?**

- ❑ The sonar measures the angle of arrival to the seafloor and thereby the topography.
- ❑ For each transmitted ping, the sonar measures backscattered reflectivity along a range line. Then the range lines for each ping are stacked to make an image.
- ❑ For each transmitted ping, the sonar makes a two dimensional image of the seafloor.
- ❑ The sonar estimates the reflectivity (or the target strength), and the range to the seafloor is calculated from the target strength.
- ❑ The sonar detects all the objects on the seafloor from the angular spread of the backscattered intensity.

## *Multiple choice - ultrasound*

**10. In 2D imaging it is usually easier to interpret the images if the resolution is the same everywhere in the image and in both dimensions. How is this for a medical ultrasound system? Assume that transmission and reception take place with a constant aperture size. Which statement is then correct?**

- ❑ Radial and lateral resolution are both constant with depth and equal
- ❑ Radial resolution varies with depth, lateral resolution is constant
- ❑ Lateral resolution deterioates with greater depth
- ❑ Both resolutions deterioate with greater depth
- ❑ Lateral resolution improves with greater depth

**11. Medical ultrasound imaging transmits and receives the following wave type(s)**

- ❑ Shear waves
- ❑ Compressional waves (Longitudinal)
- ❑ A mix of shear and compressional waves
- ❑ Rayleigh waves
- ❑ A mix of Rayleigh and shear waves

**12. A phased ultrasound array for 2D imaging consists of equal-width elements with a total aperture D. Assume a center frequency f and a speed of sound c. Which angular distance between beams is the optimal one, i.e. neither too high nor too low, for proper sampling of the image?**

- ❑ 4c/(f D)
- ❑ fD/c
- ❑ 2c/(f D)
- ❑ c/(2 f D)
- ❑ 2 f D/c

## *Multiple choice – seismic*

**13. If the the centre frequency of the seismic pulse is 20Hz and the velocity is 2000m/s, the dominant wavelength is :**

- ❑ 10 m
- ❑ 20 m
- ❑ 100 m
- ❑ 2 000 m
- ❑ Infinite

**14. Consider a NMO-corrected CMP-gather and assume that each seismic trace is contaminated by Gaussian or 'white' noise. If the fold is increased from 5 traces to 50 traces how much will the stacking process improve the signal-to-noise ratio, i.e. a factor of :**

- ❑ 5
- ❑ $\sqrt{10}$
- ❑ 50
- ❑ 0.5
- ❑ 3.16

**15. The two main principles of seismic migration are :**

- ❑ Forward extrapolation and stacking
- ❑ Imaging and stacking
- ❑ Downward extrapolation and imaging
- ❑ Deconvolution and imaging
- ❑ Muting and stacking

## *Multiple choice – medical imaging*

**16. Which one of the following statements is true ?**

- ❑ X-ray Computed Tomography Imaging requires that the object to be imaged is placed in a static magnetic field. For medical imaging the typical magnetic flux density of the field is around 1-3 Tesla.
- ❑ During X-ray Computed Tomography Imaging particles containing a positron emitting isotop are injected into the patient. An isotop often used is fluorodeoksyglucosis (FDG). This is utilized to essess the metabolism in for example cancer tumors and the brain.
- ❑ X-ray Computed Tomography Imaging is the imaging technique routinely used for mammography in the Norwegian screening program where all females in the country between the ages of 50 and 69 are screened every second year.
- ❑ In a typical X-ray Computed Tomography Imaging examination the patient is subject to a lower dose of radiation than in a conventional transmission X-ray examination.
- ❑ In X-ray Computed Tomography Imaging a 2D section of tissue of the object being imaged is subject to repeated radiation from different angles. By combining the received signals an image is then made of the local gamma ray absorption in the section.

**17. Which one of the following statements is true ?**

- ❑ Two mechanisms typically used in MR imaging are the spin lattice relaxation time $T_1$ and the spin-spin relaxation time $T_2$.
- ❑ Functional Magnetic Resonance Imaging (fMRI)is typically used to image tumor growth in inner organs, e.g., liver and colon.
- ❑ MR imaging is based on a ressonance phenomenon where interaction takes place between a RF wave and a strongly focused sound wave..
- ❑ MR imaging is one of the major sources of exposure to ionizing radiation in the Norwegian population.
- ❑ MR imaging is not suited to produce 3D images of the human body.

**18. Which one of the following statements is true ?**

- ❑ In SPECT imaging one detects high energy gamma photons emitted from a radioactive substance.
- ❑ In SPECT imaging one detects high energy protons emitted from a radioactive substance.
- ❑ In SPECT imaging one detects high energy alpha particles (helium atom nuclei) emitted from a radioactive substance.
- ❑ In SPECT imaging one detects high energy magnetons emitted from a radioactive substance.
- ❑ In SPECT imaging one detects high energy beta-particles emitted from a radioactive substance.

## *Multiple choice – seismology*

**19. P-wave tomography gives us images of the P-wave velocity. The magnitude of the P-wave velocity variation in the mantle is on the average of:**

- ❑ 10%
- ❑ 1%
- ❑ 0.1%
- ❑ 0.01%
- ❑ 0.001%

**20. Which one of the following statements is correct?**
**Damping in seismology results in …**

- ❑ The amplitude of the waves decreasing with propagation distance
- ❑ Long wavelengths in the model are not well recovered
- ❑ Short wavelengths in the models are not well recovered
- ❑ If we have lots of data, the models get too smooth
- ❑ Data errors will strongly contaminate the models.

**21. Which of these statements is false?**

- ❑ P-wave tomography is based on ray theory.
- ❑ Normal modes analysis requires strong earthquakes.
- ❑ Earthquake location can be done with one station only.
- ❑ Refraction does not occur in the Earth.
- ❑ P-waves always convert to S-waves at the Core-Mantle boundary.

# Part II: Find the answers yourself.

**Indicate how you are thinking – don't just write down an answer.**
**Give brief answers, but give reasons for your answer.**

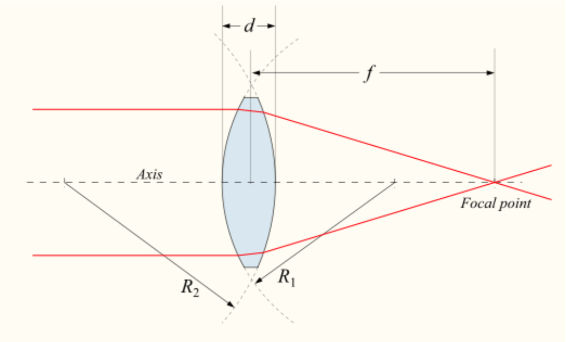
## 22. Geometrical optics (30 points).

We have been told that the focal length of a thin lens is given by the radii of curvature of the two lens surfaces, $R_1$ and $R_2$, and the index of refraction, n, of the lens material relative to the surrounding medium. We have been given the equation

$$\frac{1}{f_0} \approx (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

But this is just an approximation, based on the assumption that the thickness of the lens, t, is small compared to $R_1$ and $R_2$. A more precise equation is

$$\frac{1}{f_1} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)}{n}\frac{t}{R_1 R_2}\right]$$



*Positive (converging) lens*

**a)** Given a bi-convex lens where the absolute value of the two radii of curvature are $|R_1|$ = 10 cm and $|R_2|$ = 5 cm, n = 1.5, and the lens thickness, t, is 4,5 mm, what is the relative error in focal length, given as $(f_0-f_1)/f_1$?

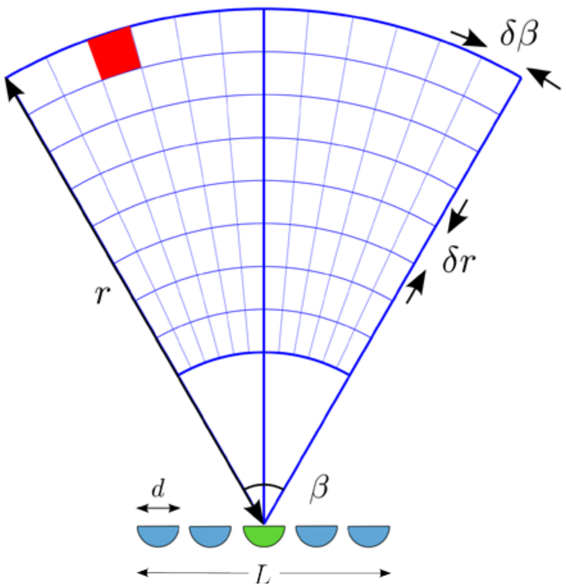
**b)** If we use a combination of two thin lenses separated by a distance d, the distance from the second lens to the focal point of the combined lenses is called the back focal length (BFL). This is given by:

$$BFL = \frac{f_2\,(d-f_1)}{d-(f_1+f_2)}$$

If the first lens is bi-convex and the second bi-concave, all four surface radii are 5 cm, and the distance between the lenses is 0.5 cm, what is then the BFL?

**c)** If the object is far from the lens, the image of the object will be smaller than the object. Now say that you are going to give a lecture in a big auditorium. Is it possible, using a converging lens system of a given focal length f to produce a 2.5 meter tall real image on a screen of a 2.5 cm tall object? If so, what are the distances from the lens to the object and image, respectively?

## 23. Sonar (30 points)




Assume a sonar transmitter (green) and a receiver array (blue and green). For each transmitted pulse, the received signals are logged on all receiver elements. Assume the following parameters:

- Element size $d = 3.75$ cm
- Center frequency $f = 100$ kHz
- System bandwidth $B = 30$ kHz
- Sound velocity $c = 1500$ m/s
- Array size $L = 1.2$ m
- Number of elements $N = 32$

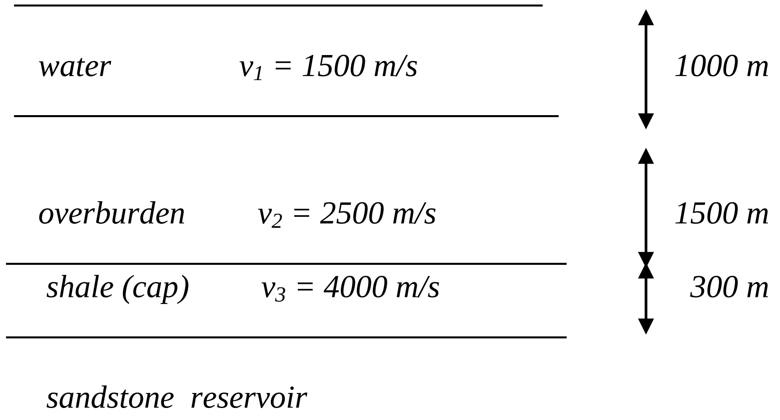
**a)** What is the field of view $\beta$ of any sonar of this type (written as a function of parameters)?
What is the field of view $\beta$ for this particular sonar (given in degrees)?

**b)** What is the angular resolution (or beamwidth) $\delta\beta$ of any sonar of this type (written as a function of parameters)?
What is the angular resolution (beamwidth) $\delta\beta$ for this particular sonar (given in degrees)?

**c)** How can the angular resolution be improved (made smaller) for a fixed array size?
Name two negative consequences of improving the angular resolution for fixed array length.

## 24. Seismic (30 points).

A simplified earth model above a sandstone reservoir is given as:




**a)** What is the density of the overburden if the zero-offset reflection coefficient at the seafloor is 0.4?

**b)** Define what we mean by a refracted wave, and find the critical angle associated with the seafloor.

**c)** Consider the reflection from the interface between the shale and the sandstone, and compute the NMO-coerrection if the offset is 1000 m

## 25. Medical ultrasound imaging (30 points).

Consider an ultrasound system for imaging of the carotid in the neck. Assume that the speed of sound is c=1500 m/s.

**a)** An echo is received after 20 microseconds, which depth does this echo originate from?

**b)** Assume that the system is designed to image up to 5 times deeper than the echo in a) without ambiguites.
What is then the maximum value for the pulse repetition frequency?

**c)** Assume an attenuation in the tissue of 0.5 dB/cm/MHz and a frequency of f=10 MHz. How much more attenuated will the received signal from the maximal depth of b) be compared to that from the depth of a), expressed in dB?

**d)** Assume that in order to do 3D imaging one must have 100 beams in each dimension (azimuth and elevation). What is the resulting 3D image update rate with the PRF found in b)?

**e)** What can be done to increase the 3D update rate if the frequency f is constant? Discuss also the changes in image quality which may result from your proposals.

***Good Luck!***