

EECE4646 Final Exam

Prof. Charles A. DiMarzio
Department of Electrical and Computer Engineering
Northeastern University

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Logistics

Schedule In fairness to all, I must insist on adhering strictly to the schedule. The exam is due electronically by 6:00PM Thursday 24 April. To avoid any confusion, that is 18:00 Eastern Standard time.

Format: Please email exactly one .pdf file with all the problems answered in sequence. Other formats can lead to font variations, lost artwork, and other unpleasant events.

Filename: Please include some recognizable portion of your name in the filename.

Copy: Please keep a copy yourself, in case any electronic problems occur. I plan to download your work and check that I can open your file shortly after the submission deadline, and I will contact you if there is any problem.

General Instructions

Please do not collaborate with other students or seek help from outside experts. However, you may use any reference book, journal articles, or other readily available resources. Please cite references if you do so.

Please contact me if you are confused about the wording of a problem. I will clarify the wording of the problems, or correct an error in the questions if someone should find one. Keep an eye on the announcements on the course web site for such updates. Obviously, I cannot give you the level

of help I would on homework, but I can clarify or correct.

Draw a figure for each of the problems. Usually in my problems, the first step is to generate a layout of the optical system. I give points for figures.

You will want to use a computer for some of the problems. You may use any language you like, but make sure that the equations and graphs are presented in such a way that I don't need to look at your code. When I ask for a plot, I am looking for a correctly labeled one, with correct numerical values. A sketch is not sufficient.

Present your work as clearly as possible. I give partial credit if I can figure out that you know what you are doing. I do not give credit for putting down everything you know and hoping I will find something correct in it. In the past, some students have typeset the whole exam in Word or L^AT_EX, which made it easy to follow. Others submitted excellent hand-written exams that were as easy to read as the typeset ones. These exams were the easiest to grade, particularly when I sought to understand the reasoning in order to assign partial credit.

1 Maltese Cross

Vertically (x) polarized laser light is collimated and is incident on the plane surface of an uncoated plano-convex glass lens with a radius of curvature of 7.5 cm. The light then forms an image at the back focal plane of the lens. Note that we are using the lens backward according to our rules for minimizing spherical aberration. This will have the advantage of making the problem simpler to solve.

1.1 Setup

First, compute the angle ζ between the x direction and the plane of incidence, and the angle of incidence θ . See slides for Chapter 6, Page 68 to become familiar with the geometry.

If you are using Matlab, you can set up the coordinates using

```
[x,y]=meshgrid([-5:0.02:5],[-5:0.02:5]);rc=7.5; % Radius of curvature rc
r=sqrt(x.^2+y.^2);
Ex=ones(size(x)).*(r<5);Ey=zeros(size(x)); % Lens radius is 5
```

Display (imagesc) the angles to make sure you did this right. Hint: Use atan2.

1.2 Fresnel Coefficients

Calculate the Fresnel reflection coefficients for the air–glass interface. Image them (imagesc) as functions of x and y . These should be functions of radius only. Right?

1.3 Transmission

Convert the incident light to P and S components (I haven’t found a way to do this using matrices in Matlab with the data in an array like this. I just wrote out the equations). Then compute how much light is transmitted through both interfaces (air–to–glass and glass–to–air) in each polarization.

1.4 Output

Convert the P and S polarization back to x and y components. Image (imagesc) the irradiance of the vertical (x) and horizontal (y) component.

Let these functions be the transfer function in the pupil plane of the optical system. Compute the resulting incoherent point–spread function for the reflected light. It’s enough just to get the shape. You don’t need to put correct spatial frequency or x and y axes on it. Just compute the Fourier transform. It might be a good idea to use decibels in the display.

2 Gaussian Beams

Here, we’ll consider some issues regarding Gaussian beams in a laser radar.

2.1 Laser Cavity

First, design a cavity for a carbon–dioxide laser ($\lambda = 10.59 \mu\text{m}$) with a collimated output beam having a 1 cm diameter. The length of the gain medium is 1 m. Determine the radii of curvature to use for the mirrors and their diameters.

2.2 Telescope

Model the telescope as two perfect lenses (In reality, we’d probably use reflectors for this). Pick two focal lengths that will magnify the beam to 30 cm. Choose lenses to keep the system over $f/3$ to keep aberrations small.

2.3 Transmitter Beam

Using matrix optics, determine the location of the transmitter waist, its diameter, and beam divergence (angle).

3 Mode-Locked Laser

Here we take a look at the properties of a wide-bandwidth laser. The laser has a pulse-repetition frequency of 80 MHz and a pulse width of 50 fs.

3.1 Free Spectral Range

The pulse repetition frequency is equal to the free spectral range. This is generally true of mode-locked lasers. What is the length of the laser cavity?

3.2 Gain Line

What is the bandwidth of the laser in frequency units? The laser gain line must be wide enough to accommodate this bandwidth. Express the line width in nanometers. Note that I can measure the laser spectrum with a spectrometer. If the line width is narrow, the laser is operating in CW mode, and if it is as wide as you determined, it is mode-locked.

3.3 Modes

How many cavity modes are operating?

4 Light-Emitting Diode

Let's look at the radiometric parameters of a light-emitting diode. We place the LED in an integrating sphere and measure a total power of 50 mW, when the LED is drawing a current of 100 mA. On a spectrometer, we measure a Gaussian-looking spectrum with a center wavelength of 830 nm and a full width of 40 nm. We measure the LED chip and find the illuminated area to be a square 0.5 mm on a side, more-or-less uniformly bright. There no lens on the output of this LED, as there is on many.

4.1 Efficiency

What is the ratio of photons emitted by the diode to electrons passing through it?

4.2 Radiant Exitance

What is the radiant exitance?

4.3 Intensity

We place a detector with a diameter of 1 mm at a distance 30 cm in front of the diode, and measure 140 nW. What is the intensity of the LED in this (forward) direction?

4.4 Radiance

Assuming the diode emits as a Lambertian source, what is the radiance?

4.5 Spectral Radiance

Estimate the spectral radiance. A filter selects a 5 nm wide band, and delivers it to an optical system that ends with a camera. The overall optical transmission is 10%. The camera has a pixel size of 7 μm square, and a numerical aperture of 0.5. How much light is incident on the pixel?