EE119 Homework 7: Microscopes, Projectors and Photomultiplier Tubes

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Due Monday, March 30, 2009, or by the end of spring break

1. Design a simple (single lens) microscope to resolve an object size of 3 microns such that the image can be viewed with a fully relaxed eye. Assume normal visual acuity of the user.

2. Compound Microscope

   A microscope consists of an objective and an eyepiece. The total magnification is 20. The eyepiece has a focal length of 5 mm, and the tube length of this microscope is the standardized 160 mm. The working distance of a microscope is the distance between the sample and the objective lens, or s_1 in the lecture notes. What is the working distance of the microscope?

3. Microscope Design

   Design a compound microscope with the following characteristics:

   - It can resolve 0.5 micron feature size (or lower)
   - The working distance should be greater than 5 mm
   - Standardized Tube Length (160 mm)
   - The microscope is not diffraction-limited

   Provide in your solution your reasoning, a ray trace of your system, the focal lengths of the optics and Numerical Aperture (NA) of the objective. Show that your design meets specifications. Assume normal visual acuity.

4. On his voyage last week through the South Pacific, Captain James Cook encountered some pirates and barely survived the attack. He decides to scare off the pirates while he sails around Tahiti by projecting a big skull and crossbones on the sail of his ship. Fortunately, he has brought you along, and you have a transparency of a skull and crossbones, as well as a lightbulb and some lenses. The focal length of your lenses is 30 cm and 8 cm. The lamp has a coil filament, so you will have to design a projector to illuminate the slides uniformly. Assume that you need a magnification of M = -100 in order to project the skull and crossbones onto the sail.

   (a) Draw a picture of the illumination system with the two lenses. The picture does not need to be to scale, but rays should be included to indicate where the filament of the lamp imaged. Label the lamp, the projector lens, the condenser, the slide and the screen in your diagram. Which lens will you use as the projector and which will you use as the condenser? Put the slide in contact with the condenser lens.

   (b) Find the distance between the slide and the projector lens.

(c) Find the distance between the projector lens and the screen.

(d) The light from the filament should be focused on the projector lens–in other words, the image of the filament should be on the projector lens. Find the distance between the filament and the condenser.

Also: See section 8.12 in Hecht for a description of liquid crystal displays, if you're interested

5. For a photo-multiplier tube, assume constant quantum efficiency and constant light power.

   (a) Plot the variation of cathode current as a function of wavelength between 200 nm and 1000 nm. Assume a current of 10nA at 200nm.

   (b) If the photocathode material has a work-function of 1.7 eV, what is the maximum wavelength it can detect?

6. A certain PMT has 12 stages. In the first five stages, each primary electron can stimulate four secondary electrons. In the next seven stages, each primary electron can stimulate five secondary electrons.

   (a) What is the gain of this PMT?

   (b) The pulse width is 9 nsec, and the rise time is 3 nsec. The load resistance is 50Ω. What is the approximate peak voltage observed for the single photon?

   (c) **This problem is optional.** Choose a coupling capacitor that is suitable for this photon counting system (ie. Choose a capacitor so that the pulse width is not broadened). Assume that both the PMT load resistor and the input impedance of the amplifier are 50Ω.

7. A PMT has a cathode dark current of 2×10^4 electrons per second at 300K (room temperature).

   (a) What is the equivalent shot noise to this dark current? Assume the bandwidth is 1Hz.

   (b) We can distinguish a light signal if it just barely exceeds the shot noise level of the dark current. Based on this criterion, what is the minimum power that can be detected? Assume the quantum efficiency is 50 % at $\lambda = 630$ nm.

   (c) If the PMT is cooled down by 80 °C (down to to 220 K), what are the cathode dark current and the minimum detectable power? Assume the work-function is 1.4 eV.