MAS450 Spring 2003 Problem Set #1 Solutions

1. (8pts) What characteristics of holograms make them potentially interesting in the following applications? Elaborate as needed.
   a. Microscopy/metrology
      Holograms “store” a three-dimensional field of light from objects that may no longer exist, may not be visible to a human observer, or may be too dangerous to observe directly. This light is (ideally) an exact 3D replica of the original object, making it possible to measure object properties using just the holographic record.
   b. Non-destructive testing
      In addition to the properties listed in (a) above, holograms are very sensitive to the position (or position change) of objects. Repeated holographic exposures or overlay of holographic and original objects can display interference patterns the show movement or stress of objects.
   c. Holographic optical elements
      Several holographic optical elements can be superimposed in a single hologram (unlike refractive optics). A hologram can simulate the behavior of complex collections of lenses. Holographic lenses can also be computed rather than recorded optically, permitting more freedom and accuracy for some lens designs.
   d. Data storage
      Holograms have extremely high storage capacity, can be written and addressed optically and in parallel, and have associative memory properties.

2. (5pts) What precautions should you take when working around the types of lasers we use in class? What laser class are they? What are the do's and don'ts? What are the potential threats or risks? -- See safety guide for details.

3. (5pts) You’re exposing a hologram in the holography lab, and you hear the crashing sound of breaking glass coming from the darkroom? What should you do?

DON’T PANIC. Effective help depends on you thinking, not freaking. Alert and consult your TA if possible. Evaluate risk based on what you know about the situation (who is in the lab and what they are doing). Learn more by asking the person what has happened, if they need any help, and if it is okay to enter the room without danger. Do not compound the situation by exposing yourself or others to added or unknown dangers. For instance, are there chemicals on the floor (slip hazard, toxicity through skin or eyes)? Is there glass on the floor or elsewhere (particularly bad in a dark room)? Is the door physically blocked? If there is any question whether the situation will get worse by entering the room, get help instead. Otherwise, make sure the person gets the medical help they need (first aid kit, MIT Medical Department). Appropriately deal with any chemical spills (clean up minor spills, get help for moderate spills, pull the fire alarm for the most toxic of spills). Clean up broken glass appropriately (put clean glass in broken glass container in darkroom). Report any injury, spill, or breakage to your TA or the lab staff.

If you feel entering the darkroom is too risky, it is best to get immediate help by dialing Campus Police emergency (100), or get other help as directed by the TA or staff. In this class of difficult-to-assess situations, there is no single correct answer about what to do. Use your knowledge about the situation and your best judgment to minimize the danger to yourself, the person in the darkroom, the rest of the lab, and the people in the rest of the building.

4. Try out the holography demo programs “sourcedemo” and “fringedemo”: http://www.spl.harvard.edu/courses/mas450/holodemos/
Now, answer the following questions:
    a. (2pts) Set up either program to display the e-field of two spherical sources. Animate the phases of both sources. Switch to intensity mode and observe. Now, repeat the process but animate the phase of only one source. What happens to the intensity fringes at the plate? What fundamental characteristic of holography can you observe from this experiment? Explain.

    Holograms are sensitive to incoherence due to the characteristics of the recording light sources or mechanical instabilities and vibrations. When the phase of two sources is coherent (changing at the same rate, statistically correlated…), the intensity pattern that results from the interference of the two sources is stationary. Stopping one source’s animation simulates incoherence between the sources (which in the real world can be due to two different sources, vibration of an optical element, etc). If the sources aren’t coherent, the intensity pattern isn’t stationary (it shifts proportional to the phase difference). Too much of a shift means that the time-average intensity a photosensitive plate records will not be a high-contrast recording. In the worst case, the image will be uniformly gray.

    b. (3pts) Set up either program to display intensity with both sources visible, and with the fringe pattern somewhat coarse (several fringes visible). Turn on phase animation of both sources. Position your mouse in the center of a dark area of the fringe. Without moving the mouse, press “e” to change to the electric field display. Where are you in the e-field? What happens over time? Go back to the intensity view (press “i”). Move the pointer to a bright fringe. Switch back the e-field. Write a brief summary of your observations.

    Dark areas of intensity correspond to areas of the field that have gray (zero value) areas throughout the e-field phase cycle. White areas of intensity correspond to areas of a high magnitude of e-field modulation.

    c. (2pts) Simulate the basic behavior of the Michelson interferometer that you’ll create in lab using both demos. Print out the results.

    In the Michelson interferometer, a single laser beam (a narrow, collimated, plane wave source) is split by a beam splitter into two beams that travel two different but equal-length paths. The two beams are recombined so that they are parallel or almost parallel. The beams then both pass through a lens, which focuses them down to two point sources very close together just beyond the lens. A coarse fringe pattern results from the interference of these two side-by-side sources.

    To simulate this configuration using the computer demo, the two sources should be side-by-side, equidistant from the plate, close enough to each other to produce coarse fringes (or perhaps one big fringe in the case of total extinction) and far enough from the plate so that the fringes are linear and linearly spaced.

5. (5 pts) Michelson interferometer: You have set up a Michelson interferometer as shown in Lab #1. Using a 10X objective, you project the fringe image onto a white surface half a meter away from the objective. You observe a pattern of vertical fringes where the distance between the centers of two adjacent dark fringes is 3cm. What is the spacing and orientation of the two point sources focused from the HeNe laser by the objective? State all assumptions/approximations you make.

The key to solving this problem is to forget as much as possible about the *apparatus* that is causing the interference, and concentrate on the *phenomenon* observed and the *geometry* that results in the effect. If you ever see linear, parallel fringes that result from interference, you should immediately think that there are probably two side-by-side sources at the heart of the interference pattern. This problem concentrates on the distance between those sources themselves (whatever caused them), instead of on the Michelson interferometer itself.

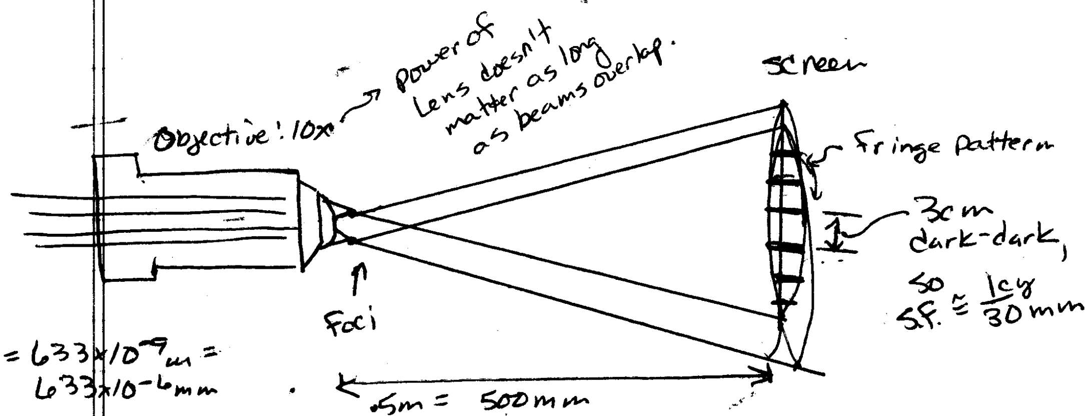
While the problem is under constrained, most reasonable approximations and assumptions produce similar results. The exact power of the objective, as we discussed in class, doesn't change anything (except shift the focus of the lens a millimeter or so in front of the actual objective, well under the significant figure limit of the distance from the objective to the white surface). We use different power objectives (10x, 20x, 40x) to *change the size of the projected beam*, not to magnify the fringes.
Here are some reasonable assumptions:

1. The small angle approximation holds, so tan(x) ~= sin(x) ~= x.
2. The white surface is close to perpendicular to the direction of both beams.
3. To make the calculations easier, assume that one source is some theta above the surface normal axis, and the other source is the same theta below the axis. Or, even better, one source is on axis.
4. HeNe lasers have a wavelength of 633nm.

Common pitfalls:

- The answer asked for a distance, not an angle.
- We're talking small here. Choose a reasonable unit. Yes, you could use meters, but the point is that the separation is small. Millimeters are usually our most appropriate general-purpose unit.
- Lots of text, no picture. Draw the picture! It helps you figure out the problem, and it helps others understand your answer if you got one, and whether or not you have some intuition if you didn't.
- Illegible calculations never make a grader happy. You don’t have to be "monks scribing in a cave" neat; just try for "someone can figure out the progression of the steps towards solving the problem" neat (see handwritten solution to this problem for an example).
- Significant figures. You might not have had to worry about them since high school or freshman chemistry, but you should watch them now. We're all a bit careless at times, but the phrase "half a meter away" implies a low accuracy measurement that does not justify multiple digits of accuracy for a result.

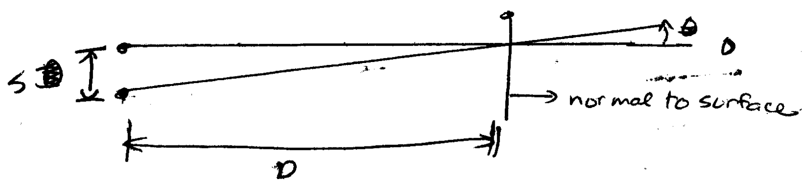
Here's an example solution, done the old fashioned way (which is fine):



$\lambda = 633\times10^{-9}m = 633\times10^{-6}mm$

find separation of foci...

assume small angle approx: $\tan\theta \cong \sin\theta \cong \theta$ (radians)
set one source on axis to surface, the other θ offset:



Use: $\dfrac{\sin\theta_1 - \sin\theta_2}{\lambda} = S.F. = \dfrac{1}{30}\dfrac{cy}{mm}$

$\cong \dfrac{\tan\theta}{633\times10^{-6}mm}$ $\qquad \tan\theta = \dfrac{S}{D}$

so:

$\dfrac{1}{30}\dfrac{cy}{mm}\cdot 633\times10^{-6}mm \cong \dfrac{S}{500mm}$

$$\boxed{S \cong 0.01mm}$$

(foci are negligibly closer to screen than $\frac{1}{2}$ meter; this fact would decrease separation slightly.)