Student Name ______________________________ Date ____________________

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.237 Modern Optics Project Laboratory

Laboratory Exercise No. 5 **Fall 2024**

Holography: An Application of Diffraction and Interference

The Pre-Lab Exercises must be completed BEFORE entering the Lab. In your lab notebook record data, explain phenomena you observe, and answer the questions asked. Remember to answer all questions in your lab notebook in a neat and orderly fashion. No data are to be taken on these laboratory sheets. Tables provided herein are simply examples of how to record data into your laboratory notebooks. Expect the in-lab portion of this exercise to take about 3 hours. **Please note that a written report is required for this Laboratory Exercise.**

PRE-LAB EXERCISES

PL 5.1 – Get Prepared to Start the Laboratory Exercises

Read the **entire** laboratory handout, and be prepared to answer questions before, during and after the lab session. Determine all the equations and constants that may be needed to perform all the laboratory exercises. **Write** them all down in your laboratory notebook before entering the Lab. This will ensure that you take all necessary data while in the Lab to complete the lab write-up. This preparatory work will also count toward your Lab Exercise grade.

PL 5.2 Preparation for Making Holograms

In Lab Exercise 5.3, your group will be making one type of hologram. You will have the option of making: (a) a Denisyuk single-beam white-light reflection hologram (simplest), (b) a two-beam or multiple beam reflection hologram, (c) a two-beam transmission hologram (must be viewed with a laser) or (d) a rainbow hologram (pseudo-color – but it takes quite a while to setup and develop). For those with little or no experience with optics or holography, this is a great opportunity to get your feet wet (pun intended).

For this section of the Pre-Lab it is your job to find out more about these types of holograms - everything about exposure of the holographic film, its development, and processing will be explained on lab day However, before coming to the Lab you are advised to do some outside research on how to configure the holographic recording and readout setups for each of the four types of holograms listed above.

After you have decided which hologram you want to make, make a detailed sketch of the recording system you will use. – This includes placement of the object, lenses, laser, mirrors, beam splitters, holographic plate, and any other items you might need (e.g., slits, wave plates, irises, etc…).

Here are some useful tips to consider before coming to the MOL to make holograms:

(1) You should bring some *interesting* objects from which we can make holograms. Such objects should not be dark in color, nor should they exceed a volume of 7 cm x 7 cm x 7cm.

(2) Those students whose objects we use will be able to take home a copy of their hologram. Otherwise, holograms made in the MOL will be archived for demonstration to future students. You will need your own laser to view the transmission holograms at home. Reflection holograms will be viewable in white light.

(3) Make sure to wear clothes that can handle stains. Also, you will not be able to leave to go to the bathroom while the plates are developing, so be sure to go beforehand.

(4) Be aware that it will be extremely dark at times in the laboratory, and that it can be fairly time-consuming depending on the complexity of the hologram you choose to make.

"'By-the bye, what became of the baby?' said the Cat. 'I'd nearly forgotten to ask.' 'It turned into a pig,' Alice answered."

– Lewis Carroll, *Alice in Wonderland*

LABORATORY 5A

IN-LAB EXERCISES

In the first holography lab session you will observe several holograms and participate in making one (or more) simple holograms. In the second session, you will have the opportunity to design and make a more difficult type of hologram. Some options are listed below. Your report (not more than 4 pages) for this section of the laboratory exercise will be graded by both the writing and laboratory staff. For this assignment assume your audience is a fellow 6.161 student. The Writing Coordinator will be looking at your grammar, at your sentence construction, for critical thinking on your part, and to see how clearly you can express your ideas in writing.

5.1 Viewing of Transmission, Reflection, White-Light and Computer-Generated Holograms

A collimated He-Ne laser beam (up to 10 cm in diameter) and a white-light source have been set up for viewing of four types of holograms.

(a) Illuminate the given laser-made **transmission holograms** first with the collimated beam. For each hologram, find the direction of propagation of the virtual image, and view it directly (i.e., no lens or screen is to be used to view this image). Move your head around and tilt the hologram to get the best view of the image. You may repeat your observations with a divergent laser beam by removing the large collimating lens to "see" if you obtain better results.

(b) In particular, for the **hologram of the clock or the hologram of the train**:

1. Draw a diagram of the setup that gives a virtual image with the best fidelity. In your diagram, show the location of the virtual image and any other beams that exit the hologram.

2. Referring to the geometry in (b) that gave the best virtual image, draw a new diagram of an orientation that would put the most output power into the real image. Now try your new readout geometry to see if it does indeed give a bright, real image. If it does not, rethink the problem, and retry other new readout schemes until you can see the real image. Record your final setup that works in your notebook, and explain why it works

3. Use the information from (a) and (b) to infer the geometry of the setup that was used to record the hologram (reverse engineering).

(c) Illuminate the **reflection hologram of the coins** with the divergent laser beam and view the image through the hologram in reflection. Is the image you see real or virtual? Draw a diagram of the setup showing the location of the image and any other beams that exit the hologram. Use this information to infer the geometry of the setup used to record the hologram.

(d) Illuminate the **white-light hologram of the owl** with white-light from the overhead lights in the Laboratory such that the light strikes the hologram and then reflects an image into your eye. Tip the hologram from side to side and up and down. Draw a diagram of your readout configuration showing the location of the image or images. Describe your observations from tipping the hologram in the beam. Re-illuminate the white light hologram with the divergent He-Ne laser beam. What differences do you observe? Explain these differences. Use your observations to infer the geometry of the setup used to record this hologram.

(e) Put the collimating lens back into the system so as to generate a collimated laser beam. Illuminate the **first computer-generated transmission hologram** (written on a 4"x5" plate) with the collimated laser beam and view the real image (it will spell a familiar acronym) on a distant screen. Draw a diagram of the setup showing the location of the real image and any other beams that exit the hologram. Use this information to infer the geometry of the setup used to record the hologram.

(c) Place the **second computer-generated hologram** (written on 2"x2" film) into the collimated laser beam. Now relocate the screen close to second computer-generated hologram. Move the screen away from the hologram slowly. What do you observe on the screen? How do you explain what you see on the screen with respect to what you see on the actual hologram? Ask the TA or LA to show you how this hologram was made.

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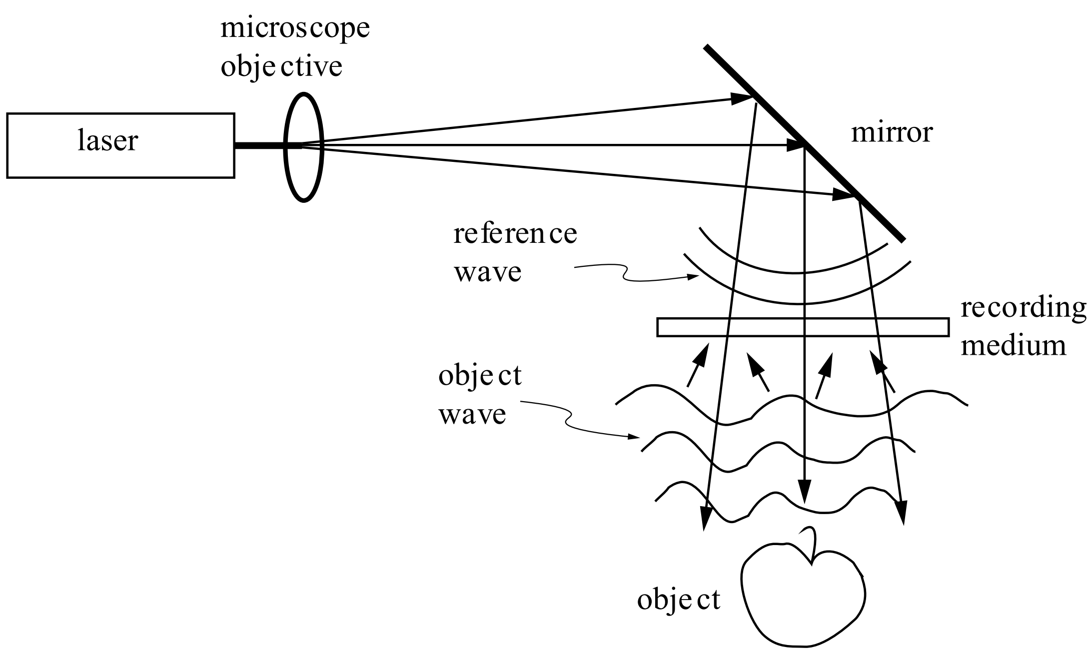
Laboratory 5B

5.2 Designing and Making Holograms

We encourage all the students in the class to make a few simple holograms. Recording holograms can be difficult, and it is possible you will not make a successful hologram with your system. In this case, your paper should address why you think the system you built did not work.

The Figure below shows an extremely simple and stable reflection hologram write geometry that can be set up quite quickly. Note that in this configuration, reference beam is incident on the recording medium from one side and the transmitted reference beam illuminates the object to produce a reflected object wave beam. This setup works well with photographic film as the recording medium, even though the reference wave is substantially stronger than the object wave.

The steps for post processing the photographic film so you can view the hologram are given below in Appendix I

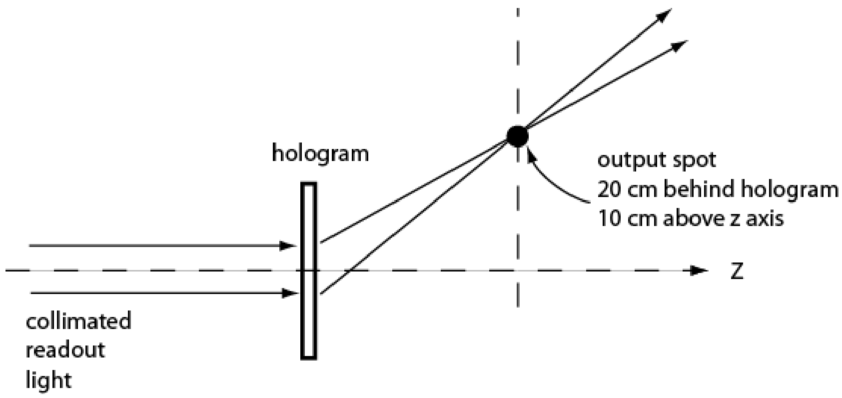


Hologram Options

(a) Make a Holographic Optical Element
In this session you will see an example of a holographic optical element. The element was designed to act as a reflection hologram, taking collimated light and producing a focused off axis beam. For this writing project you will use what you know about holography and the holographic writing process to design a Holographic Optical Element (HOE) with the following characteristics:

Goal: Focus a collimated beam to an off-axis spot
Read Wavelength: 514nm (Argon-ion laser green line)
Write Wavelength: 632.8 nm

A diagram of the desired system is shown below.



The most interesting aspect of this project is the complication introduced by using a different wavelength light to write the hologram than is used to read out the hologram. Detailing how you addressed this complication should be a major focus of your report.

(b) Make a hologram of a magnifying glass in front of an object

For this option you will make a multiple beam hologram of an object located beyond a magnifying glass. For the purposes of this assignment the position of the glass and object should be set to generate a virtual image of the object when observed from the location of the hologram plate.

An interesting question to ask about this system is what happens when you read out with a conjugate of the reference beam without the magnifying glass in the system? For a hologram made without a magnifying glass when the hologram is read out with a conjugate of the reference a real image forms at the location of the object. In the system described for this option do you form a real image when using a conjugate readout? What about when you return the magnifying glass to the system? Addressing these questions should be a major focus of your report.

(c) Make the RGB Hologram of Problem 1 in the homework

(d) Make a more complicated hologram

Most of the more interesting examples of art holography, at least from a technical point of view, are made using systems significantly more complicated than the two-beam hologram made in class. For this option you will design and make a more complicated hologram. Some examples include multi-beam reflection or transmission holograms (more than two beams), rainbow holograms, white light transmission holograms, multiplexed holograms, multiple exposure holograms, and pseudo-color holograms.

More complicated hologram geometries can result in more interesting holograms. In your report you should address why you chose the hologram geometry used to make your hologram. In particular, what does this hologram geometry allow you to achieve, either in readout or writing that you cannot duplicate with a simpler hologram. You should also present a brief summary of the history of the type of hologram you choose to make.

APPENDIX 1

Instructions for the Development of Photographic Film and Plates

For the holography lab we will normally use one of two developers, and one of two hologram emulsions. The two developers used are JD-2 and JD-4 kit developers, and the holographic emulsions commonly used are PFG-01 and PFG-03M.

Developer Details

JD-4 and JD-2 are developer kits (developer and bleach) made by Photographers Formulary (stores.photoformulary.com), and commonly purchased through Integraf (www.integraf.com). Either developer can be used with either holographic emulsion, but the JD-4 developer is normally used with the PFG-03M emulsion. The two major differences in the developers are: (1) the exposure energy and (2) the develop time. When using JD-4 developer the exposure energy is about one-tenth the energy required when using JD-2 developer. The develop time when using JD-4 is about 20 seconds, but the develop time when using JD-2 is about 2 minutes.

The kits contain the powdered chemicals that you will need to mix both the developer and associated bleach. The developer is mixed as two parts, A and B, which are kept separate until just before use. After mixing the A and B liquids the developer will 'go bad' in 20min (JD-4) to about 2 hours (JD-2), so we generally mix parts A and B just before loading a plate in the system.

Developer parts A and B will keep for a few months at room temperature, and longer in a refrigerator. Developer mixed for the holography lab can generally be used for final projects, but a new kit should be purchased each semester the class is run.

The JD-4 kits come with a copper-sulfate-based bleach that seems to work a little better than the Potassium Dichromate bleach in the JD-2 kits. Holograms bleached with JD-2 bleach tend to darken to brown over time faster than the holograms bleached with the JD-4 bleach.

Emulsion Details

The two most commonly used holographic emulsions for 6.161 are PFG-01 and PFG-03M. Both types are designed to be operated with red light. In this lab we will expose the plates using a red Helium-Neon laser (632.8nm). The emulsion layer in the PFG-01 plates is 7-8 microns thick, while the emulsion layer of the PFG-03M plates is 6-7 microns thick. The major difference between the two emulsions is the size of the silver halide grains used to record the holograms. The PFG-03M emulsion has finer grains of silver halide and these require higher exposure energy for proper hologram recording. The different recording energies for the two emulsions and two developers are given in the table below.

Table I. Exposure energy for developer/emulsion combinations. Note that the exposure for PFG-01 is given in microjoules/cm^2 while the exposure for PFG-03M is given in millijoules/cm^2.

Hologram Emulsion	JD-2 Exposure Energy	JD-4 Exposure Energy
PFG-01	80 microjules/cm^2	Unspecified
PFG-03M	1.5 mJ/cm^2	0.15 mJ/cm^2

Writing/Developing Process (JD-4 with PFG-03M)

1. The recording plate is mounted in the plate holder, and the system is allowed to stabilize for 1-3min.

2. The exposure is made. The exposure time is set to achieve ~300 microjoules/cm^2. This is twice the manufacturer specified exposure, but in practice seems to work well.

3. The plate is developed for 20s in JD-4 developer.

4. The plate is rinsed for 3min in a tray of distilled water (obtained in building 13).

5. The plate is bleached in JD-4 bleach. The plate is bleached until it is clear, and then ~20s longer.

6. The plate is rinsed again for 3min in a tray of distilled water.

7. The plate is dipped into a solution of ~1/2 capful of Kodak Photoflo + 0.5 L distilled water. The photoflo is a wetting agent that helps the plate dry without spots.

8. The plate is then air dried standing vertical (for as long as you can wait) and finished with a heat gun.

APPENDIX II

Further Instructions for your Report

For all options, your report should include:
(1) A brief (1-2 paragraph) discussion of holography in general
(2) A discussion of the design of your hologram including diagrams of the systems used to write and readout your holograms
(3) Experimental details of the exposures, beam intensities, and recording material
(4) Details of experiments you used to answer the questions posed by your chosen topic