MASSACHUSETTS INSTITUTE of TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.237 Modern Optics Project Laboratory
6.637 Optical Signals, Devices & Systems

Problem Set No. 5	**Holography**	Issued Thrs. 10/23/2024
Fall Term, 2024	-	Due Tues. 11/05/2024

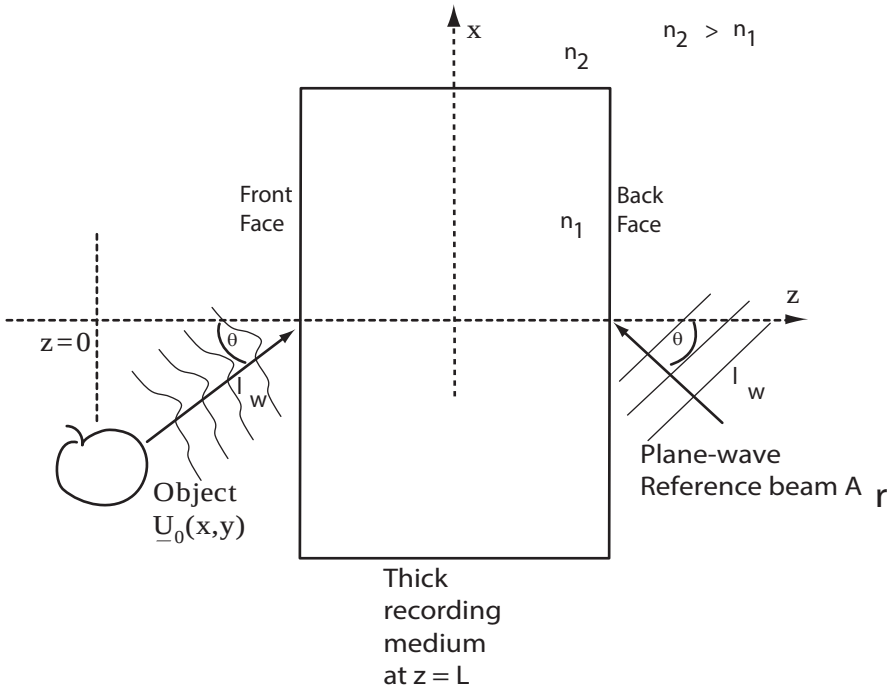
Reading recommendation: Class Notes, Chapter 5. Be neat in your work!

6.237 STUDENTS: Do any four
6.637 STUDENTS Do all five

Problem 5.1

You are given a red He-Ne laser ($\lambda = 0.63\mu m$), a white source (not necessarily collimated, but you can collimate it if you wish) and a thick holographic recording material. Describe with the aid of diagrams how you would make a high brightness hologram that employs the red, green and blue components of the white readout light to achieve maximum brightness in the image and simultaneously minimal misalignment of the output images.

Problem 5.2
Mutually coherent plane wave reference and object beams of wavelength λ_w traveling in a medium of refractive index n_2, enter a holographic recording medium of refractive index,n_1,from opposite faces with external angles of incidence θ as shown.



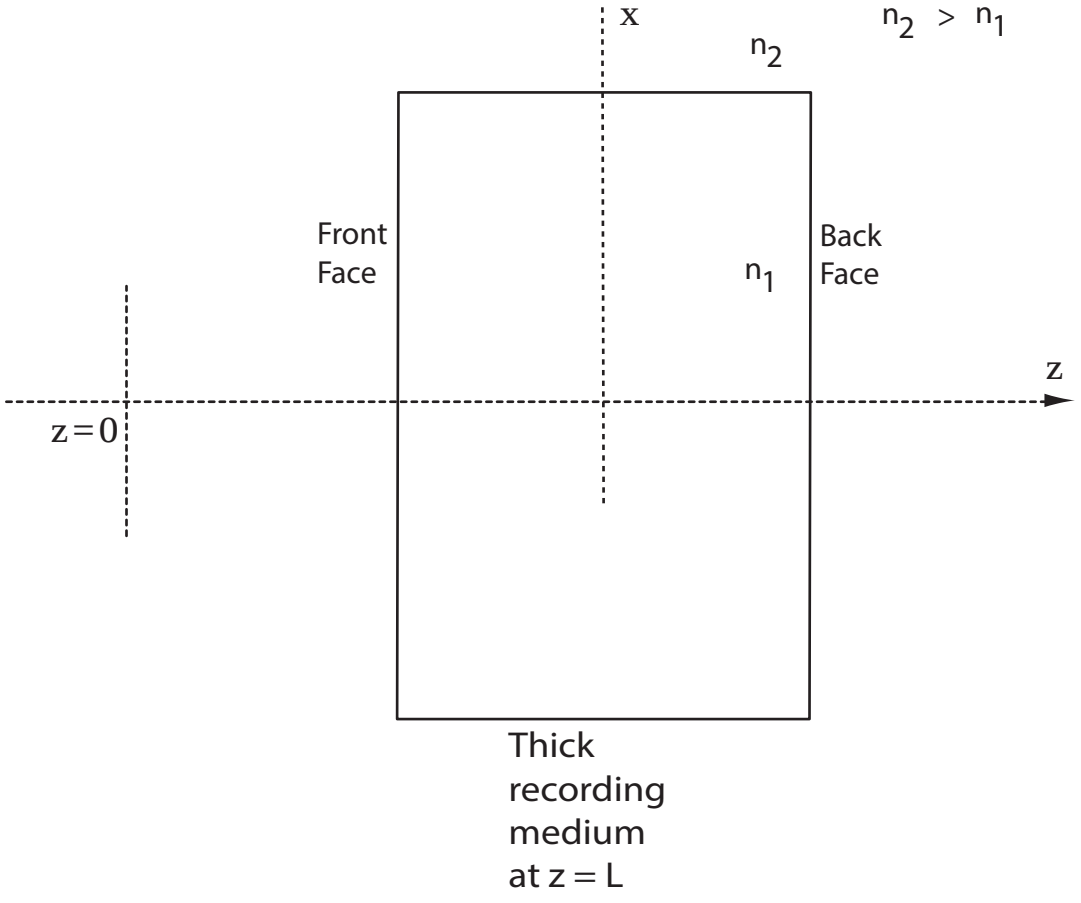
(a) On the figure above, sketch the interference fringes in the medium.

(b) For the case where $n_2 > n_1$ give the expression for the nominal fringe spacing Λ? in the recording material. When a hologram is written with this system, for readout with light of increasing wavelength beyond λ_w, should the external readout angle, ψ, be increased or decreased to remain Bragg matched? Explain your answer.

(c) For the case where $n_2 < n_1$ give the expression for the nominal fringe spacing Λ? in the recording material. When a hologram is written with this system, for readout with light of increasing wavelength beyond λ_w, should the external readout angle, ψ, be increased or decreased to remain Bragg matched? Explain your answer.

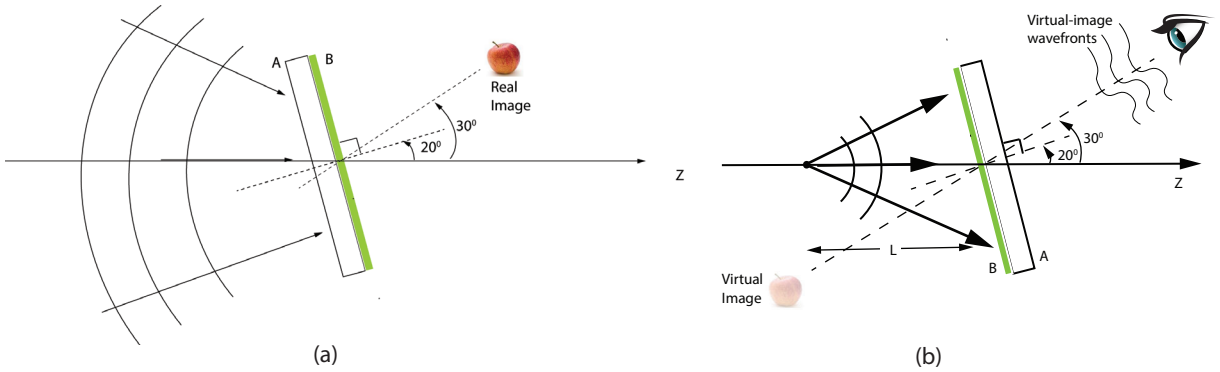
(d) For case (c) What special conditions must be imposed on θ to record a hologram?

(e For case (c) it is desired to readout the stored image as a real image with light of wavelength λ_r which has a shorter than λ_w. Draw the desired readout geometry on the diagram below and label all angles and show where the real image can be found.



Problem 5.3

A hologram of unknown origin is loaned to you and you would like to reverse engineer it so you could make one like it for yourself. You begin by reading it with a converging He-Ne laser beam of wavelength 0.63 μm traveling along the z-axis and focusing to a distance L behind the hologram as shown in Fig (a). The hologram has the emulsion on the side labeled B and the side labeled A is the glass substrate. With the hologram tilted at 20^0 to the direction of your readout beam, you observed a real image in transmission at 30^0 to the to the z axis, as shown in Fig. (a).



You rotate the hologram 180 degrees into the orientation shown in Fig, (b) and upon reading it out with diverging light of the same wavelength originating from a distance L in front of the hologram, you discover that there is a virtual image of the same object at the location shown in Fig (b).

(a) Is this a transmission hologram or a reflection hologram?

(b) Draw a diagram to show the recording geometry of this hologram. For full credit, you must show clearly **ALL** the waves (beams) that are writing the hologram,**ALL** the angles involved must be specified, and the specific orientation of the emulsion side of the hologram during the write process?

Problem 5.4

A hologram is made in a recording material of refractive index n by interfering a nominally on-axis object beam $\underline{U}_0(x, y)$ with a tilted plane-wave reference beam. The writing light has wavelength λ_w. The plane-wave reference beam has amplitude A_r and is incident from below in the $x - z$ plane at an angle θ as shown in the diagram below.

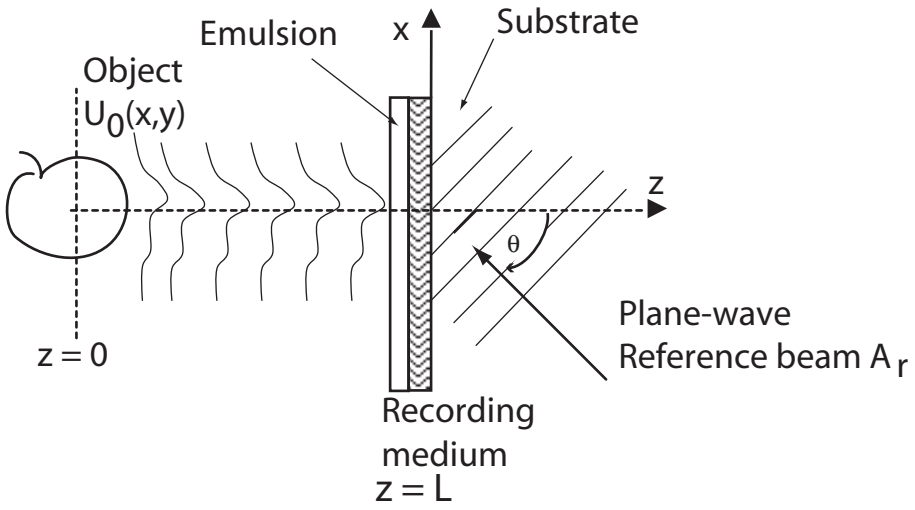


Figure 1: Hologram written with reference beam, A_r, and object beam, $\underline{U}_0(x, y)$

A. THIN HOLOGRAM CASE
First assume the recording medium is **thin**.

(A1) Does the writing geometry shown lead to a transmission or reflection hologram?

(A2) Assume that the hologram in Figure 1 is a thin hologram and that it is read out with a beam of amplitude B that has the conjugate phase of the reference beam. Derive the field expressions (amplitude and phase) of each beam exiting the hologram.

(A3) Draw a diagram of the readout geometry to show each entering and exiting beam with its appropriate field term [from (b)]. Also label the real and virtual images, if they exist.

B. THICK HOLOGRAM CASE
Now assume that the hologram is **thick** and that the write geometry is the same as that used in the Figure above. Thick reflection holograms are used for decorative purposes on credit cards, and are also worn (usually around the neck) as decorative jewelry. Large reflection holograms can also be found as art media in museums (e.g., MIT Museum).

(B1) Draw and describe the location of the images when the hologram is read out with the conjugate of the reference beam.

(B2) Next, the thick hologram is read out in an optimal way (Bragg matched) with a plane wave of wavelength $\lambda' = 3\lambda_w/2$ also incident from above on the emulsion side.

(a) What is the optimal angle, ψ, between the z-axis and this readout beam?

(b) The angle θ has a maximum value, θ_{max}, that should be respected if the intent is read out the hologram with light of wavelength $3\lambda_w/2$. What is this angle?

(c) Describe the characteristics of the images produced, and draw a diagram of this optical readout configuration showing the location of the images.

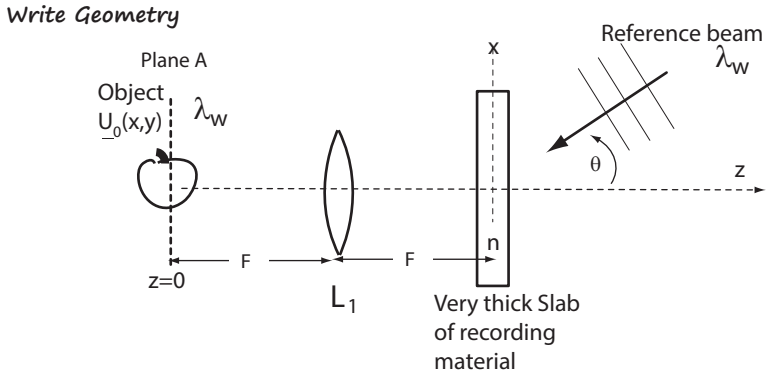
(B3) Using the results from part (B2), describe the output images that are obtained when this hologram is read out with collimated white light incident from above on the front side.

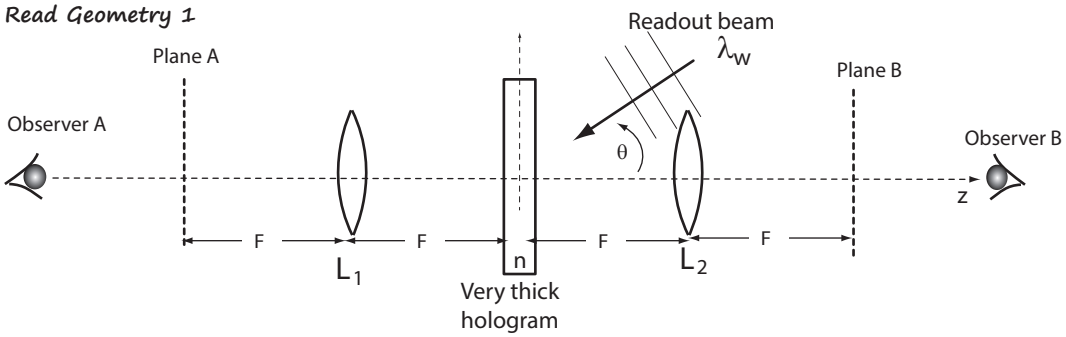
(B4) Describe the output images that are obtained when this hologram is read out with non-collimated white light incident from above on the front side.

Problem 5.5

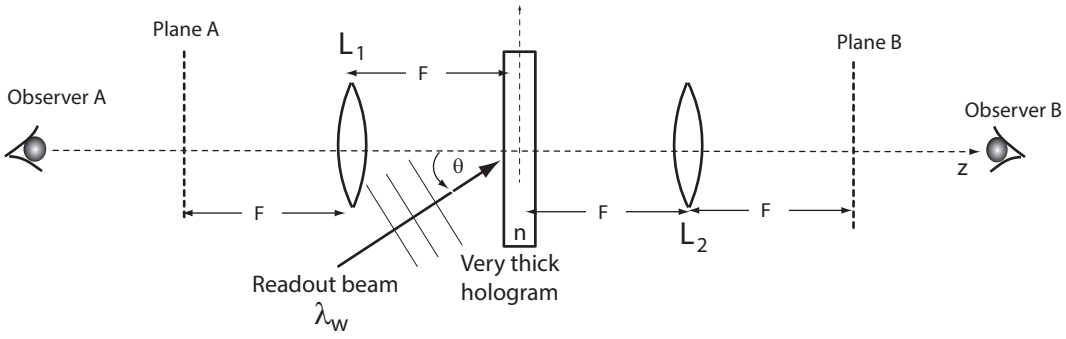
A hologram of an object is recorded through a lens L_1 of focal length f into a **very thick** slab of material of refractive index n using laser light of wavelength λ_w and the geometry shown. Note that the recording plane-wave reference beam is incident from the back side of the material at an angle θ as shown.

For the 4 readout geometries below, assume all lenses have the same focal length F. Draw in the dominant output images that emerge from the hologram. In each case state whether the image is real or virtual and show the angular direction of the output beams. **Also Comment on what Observers A and B see**.

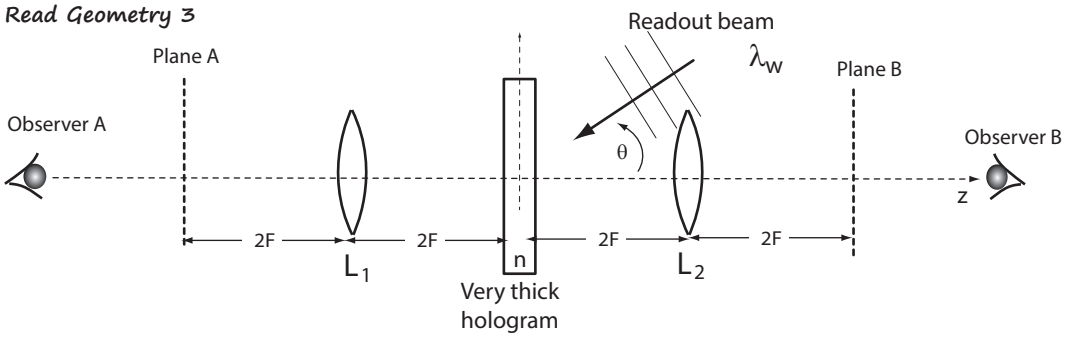




Read Geometry 2



Read Geometry 3



Read Geometry 4