UNIVERSITY OF TORONTO 2000

Department of Electrical Engineering

ECE 426F Introduction to Optical Engineering

Laboratory #4 INTRODUCTION TO OPTICAL PROCESSING

Purpose:

Basic Fourier transform characteristics of lenses are investigated, and elementary spatial filtering and optical processing concepts are demonstrated.

References:

Class notes and textbook by Hecht.

Experimental Arrangement:

Two similar arrangements are used with only slight differences in lens focal lengths. The optical arrangement is shown in Fig 1. The first part of the systems is a spatial filter which smoothes the transverse intensity variations of a HeNe laser (632.8nm) beam to produce a smoothly-varying (near-Gaussian) intensity profile. This filter consists of short-focus microscope objective lens, L_o, mounted on a precise xyz stage, and a small pinhole of ~10-μm diameter placed at the focal plane. *Do not touch the delicate foil pinhole surface—its expensive and tears easily.* Light from the pinhole is collimated by lens L_c when placed one focal length, f_c, away from the pinhole. The microscope objective and L_c share this common focal plane forming a backwards telescope that is called a beam expander. The pinhole only passes low-spatial frequencies of the intensity pattern, providing an ~2-cm diameter uniformly intense beam. Two additional lens, L_1 and L_2, provide two Fourier transforms of the now *clean* laser beam. Slides are placed in the object plane of L_1 following the filter, introducing spatial intensity variations in the HeNe beam which show up as a Fourier transform in the Fourier plane of lens L_1. A second Fourier transform is carried out by lens L_2, which reconstructs the slide object in the image plane. Suitable choice of aperture in the Fourier plane can selectively pass or remove spatial information contained in the object.

Precautions: Do not touch surfaces of the **pinhole**, **slide**s, front **surface mirrors**, or **lenses**. Please handle all equipment with care.

Procedures:

(1) Spatial Filter

In order to examine the diffraction images of various objects, it will be necessary to reduce the (spatial) optical noise on the laser beam. This noise is often produced by diffraction from various imperfections in the optical beam path.

1a Observe the beam from the He-Ne laser at a distance from the lens L_o. Describe the appearance of the beam.

1b Carefully position the pinhole at the focal point of the laser output lens L_o and try to pass the maximum light. This is not easy to do, and requires careful adjustment of all three axis of the xyz stage. With patience, you will obtain a fairly intense and circularly symmetric transmitted beam. Secure all parts solidly.

1c Describe the change in the appearance of the beam. Explain how the pinhole "cleans up" the beam. Calculate an optimum size for a pinhole for the parameters in your experiment.

A second lens, lens L_c, is used to collimate the beam (Fig 1). Position the collimating lens ~25 cm or 36.3 cm from the pinhole – a focal length to lens centre. Aberrations are minimized when the most curved surface (smallest radius) of the lens faces the collimated beam. Place a mirror one focal length beyond lens L_c and move lens L_c axially until the reflected beam appears to be focused on the pinhole plane. Remove the mirror and check the collimation by observing the output beam several meters away – the diameter should be constant.

(2) Optical Fourier Transform:

When collimated light is diffracted and passed through a lens, the lens optically performs a Fourier transform. The diffraction image at the focus of the lens is the Fourier transform of the incident waveform. You will place several different slides in the object plane to spatially modulate the uniform light beam. Predict how the Fourier transform should appear at the lens focal plane.

Place a slide holder in front of lens L_1 at a distance of one focal length (f_1 = ~25 or ~37 cm) as shown in Fig 1. Place a white screen at the opposite focal plane of lens L_1 to observe the Fourier image.

2a Place images of linear gratings (slides 4, 5, and 6) in the object plane, and record your observations of the Fourier images. Change the orientation of the gratings and observe the changes in the Fourier plane.

2b Place images of grids (slides 10, 11, and 12) in the object plane, and record your observations of the Fourier images.

Explain what is seen in the Fourier plane by considering the following:

Given a line-to-line spacing, d, grating interference maxima occur for specific angles satisfying the grating formula:

$$m\lambda = d \sin \theta.$$

In the Fourier plane of lens L_1, these peaks should be separated by $\sim f_1 \tan q$ from the optical axis where f_1 (= 25 or 35 cm) is the focal length of lens L_1. Use these relations to predict where the light appears in the Fourier plane.

(3) Introduction to image processing:

In order to complete the optical Fourier imaging set-up, a second lens, L_2, is used to re-image the object at the image plane (Fig 1). This lens is to placed one focal length (25 cm or 35 cm) from the Fourier plane to collimate the beam. An image of the object slide will then be sharply formed at the focal plane of this lens.

To check the set-up, use an object with fine structure such as slide 14, and make small adjustments to obtain maximum visibility of the fine structure. You will probably need to turn off the room lights to help you to observe the details of the image.

The term "spatial frequency" refers to number of times that a spatial pattern is repeated in a unit distance (e.g. number of lines / mm). From the observations in part 2, can you make some general statements regarding the dependence of the Fourier transform of an image on the spatial frequencies in the image?

3a Using slides 13, 14, and 21, perform the following experiment:

Place one slide in the object plane, and observe the image as the Fourier transform is gradually restricted by a variable iris in the Fourier plane. Record and explain your observations of the image changes. Do they conform to your expectations based on your answer to the question above?

Optical image processing can be used to accentuate or eliminate certain elements of an image. This is done by physically blocking (i.e. filtering) a portion of the light beam in the Fourier plane. We will observe this with two simple examples.

3b Typically cloud chamber photographs include a large number of relatively parallel tracks of incoming particles, and a few curved tracks caused by interactions. By filtering in the Fourier plane, we can change the relative intensities of these features in the image. Use slide 22, a cloud chamber photograph. Close down the iris in the Fourier plane and observe the image when the iris is on-axis, and off-axis (along the diffraction direction). You will need to use a small aperture in order to see the effects clearly. Repeat the process for a two-pin filter and compare the pros and cons of these approaches. Make a sketch of the Fourier-plane observations (light pattern and overlay the optical filter) and explain your observations.

3c Use the slide with a half-tone picture of Einstein. Note that the image is made up of a series of dots. By aperturing in the Fourier plane, show that you can obtain a continuous-tone image. Sketch the Fourier-plane observations (light pattern and overlay the optical filter) and explain your observations.

3d Use the slide of a sailing boat. Replace the pinhole with the two-pin filter on a magnetic mound and systematically filter the grid appearing in the sail. Repeat for the grid in the boat, then for the water, etc. What advantage does such a two-pin filter offer? Calculate theoretically an optimum separation distance (pin tip to pin tip) for the pin filter in this example.

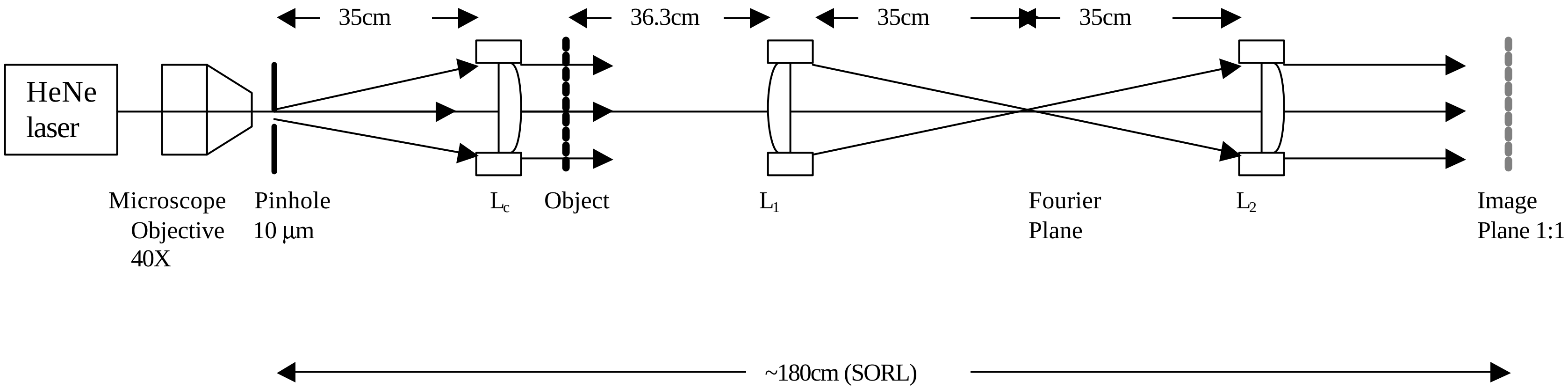

Figure 1 Fourier Optics Arrangement

Above arrangement is for SORL Fourier Optics (white lens housing), which have 35 cm focal length lenses. The lenses are achromatic-doublets designed for 633-nm HeNe laser light.

Arrangement with the open lenses is more compact due to 25 cm focal length lenses. The lenses are general-purpose singlets. All marked distances above should be reduced to ~25 cm for this arrangement.