**Lab 3 - Diffraction**

**Spring 2020**

*Objective* We begin an analysis of monochromatic waves, this week in the context of diffraction. We will investigate the diffraction of optical waves through apertures.

*Background* This week we will consider the diffraction pattern produced when light propagates through apertures. In summary, the far-field diffraction pattern produced by a plane wave propagating through an aperture is found to be the spatial Fourier transform (FT) of the aperture function. For example, a rectangular aperture would give rise to a diffraction pattern that is a Sinc2 (remember the intensity) function in both transverse directions. The width of the Sinc function (or diffraction pattern in general) is inversely proportional to the width of the aperture. For example if the rectangular aperture is oriented such that the dimension in the x-direction is wider than that of the y, then the diffraction pattern will be longer in the y direction than in the x. Propagation of the wave through a lens will bring the far field pattern to the focus of the lens.

The HeNe’s we are using have a low-quality Gaussian beam. In this week’s lab, we will perform spatial manipulations of the HeNe beam in order to obtain an approximate plane wave. We will first analyze the spatial filter, and how it works to clean up the starting beam. Then, we will collimate an expanded beam that has a low divergence angle, giving rise to a good plane wave approximation near the center of the beam. We will use this source to perform Fourier Optics experiments next week.

prelab

1. Sketch (or plot in Matlab/Python) the expected diffraction (intensity) pattern for a plane optical wave passing through each of the following apertures:



**(6 points)**

PART I LEVELING THE LASER

*Discussion* It is very useful, and sometimes necessary to level a laser beam to the surface of an optical table. The leveled beam will then define an axis, and all other optical components can be referenced to this axis.

*Procedure* If it is not already there, place the laser on top of the support at one end of the optical table, with the beam pointing towards the other end of the table. Turn the laser on. Place a small iris (in a holder) at the front of the laser. Adjust the height and the size of the aperture until the beam just passes through the center. (Be careful not to look at the reflection too long.) Place the iris at the far end of the table and adjust the jack until the beam passes through the iris. Now move the iris back to the laser and check if the jack adjustment changed the height of the beam (to within ~1 *mm*). If not, adjust the iris and repeat the procedure. When your laser is leveled, you should be able to slide the iris along the entire table and have the beam pass through it at all times.



PART II DIFFRACTION FROM A SLIT

*Discussion* We will make a slit using electrical tape and a microscope slide. You will use diffraction to determine the slit width.

*Procedure*

*1)* Using electrical tape, a microscope slide, and the exacto-knife, create a slit-like rectangular aperture.

*2)* Mount your slit in front of the laser beam and try to obtain a diffraction pattern on your white screen.

*3)* Measure the distance from the center of the diffraction pattern, and record the distance from the slit to the screen. For your writeup, calculate the width of your slit.

**(4 points)**

*4)* Try to make another slit with a different width. How does the diffraction pattern change as a function of the slit width? (i.e. does it get wider or narrower with increasing slit width?)

**(4 points)**

PART III USE OF THE SPATIAL FILTER

*Discussion* The spatial filter is used to generate an approximate point source of light which produces spherical wavefronts with no phase variations. It consists of two parts: 1) a microscope objective, 2) a pinhole. The basic idea of the spatial filter is this:

The microscope objective focuses the laser light on to a pinhole. When the beam is in focus, any spatial variations in the beam (dashed lines in figure) will not pass through the pinhole. (Note that when the objective is highly defocused, the wave fronts entering the pinhole are closer to planar than to spherical. We will use this in several sections.)

The filtered light leaving the pinhole is approximately a point source that can be collimated by use of a lens.



*Procedure* Pick up and examine the spatial filter comparing it with the pictures shown below. There are five adjustments on the device. The vertical and horizontal screws move the pinhole relative to the microscope objective. These are used to center the pinhole with respect to the microscope objective. The threaded focusing ring moves the pinhole relative to the microscope objective to focus the beam onto the pinhole. The tilt adjustments are used to align the entire spatial filter with respect to the optical axis. (NOTE: Do not loosen the screw that holds the microscope objective in place.)



In addition to the five adjustments, there is also an iris built into the spatial filter that helps align the incoming beam. Turn the focusing ring counterclockwise as from the front about ten full turns. This will badly blur the image of the laser beam on the pinhole and allow some laser light to get through the pinhole when the spatial filter is placed in the optical setup.

Place the spatial filter on a base, and put it in the path of the laser beam with the back (iris side) facing the laser. Adjust the height of the spatial filter so that the beam passes through the center of the back iris. Fully open the iris and you should notice a back-reflection originating from the surface of the microscope objective in the spatial filter (at the laser). Line up the back reflection so that it goes directly back into the laser, while keeping the incoming laser beam going exactly through the center of the iris that is integrated in the spatial filter. You should use the tilt settings to back-reflect this into the laser, not the vertical or horizontal adjustment knobs.

Now placing the screen in front of the spatial filter (such as a business card from the supplies drawer), slowly move the horizontal and vertical adjustments until some light appears on a business card beyond the pinhole. (This part takes time so be patient!) You may have to rotate the base to keep the beam passing through the center of the entrance iris. If you do this, you will have to readjust the tip/tilt. If no light appears after several trials, ask the TA for help. Each person in each group should try this.

Once there is some light through the pinhole, move the horizontal and vertical screws until a pattern of concentric rings is formed. This is the diffraction pattern of the pinhole. Show the pattern to the TA and proceed to Part IV. You will adjust the focus in Part V.

*Note: You should be very careful not to bump the laser after you have the spatial filter aligned!!!*

PART IV Far field (fraunhofer) diffraction

*Discussion* We will now use the spatial filter to study far field (Fraunhofer) diffraction from a circular aperture. In lecture, we show that this pattern is the Fourier transform of the aperture which in this case is a pinhole (a circ function).

*Procedure*

*1)* Place a screen with ruled graph paper (1-*mm* spacing) about 1 *m* from the laser and record the distance. Center the graph paper on the beam so that measurements can be easily made.

**(1 point)**

*2)* Now align the spatial filter with the microscope objective defocused until you see the earlier ring pattern that is the diffraction from the pinhole. (NOTE: Be very careful not to look at the back reflection from the pinhole for long periods of time.) This pattern should be centered about the beam. Sketch the diffraction pattern and record the distance from the center of the spot where the pattern goes to zero for the first time.

**(2 points)**

*3)* The pattern is called an Airy pattern and the first zero is given by *sin = 1.22/d,* where *d* is the diameter of the pinhole, ** is the angle from the pinhole to the first zero (half-angle, see figure below) and ** is the wavelength of light. Using this formula, calculate the pinhole diameter in the spatial filter. (=0.6328 m).

**(5 points)**



PART V COLLIMATION

*Discussion* A lens placed at exactly one focal length from the pinhole will image the pinhole at infinity. Because the light is imaged at infinity, the cross-sectional area does not change and thus the beam is collimated (i.e. forms a column of light which is approximately a plane wave.) We will use collimated light to study the concepts of Fourier Optics.

*Procedure*

*1) Carefully* continue turning the focusing ring on the spatial filter in the direction that makes the center spot larger and use the other adjustments to keep the pattern visible and centered. Eventually, the center spot becomes very large and bright and the horizontal and vertical adjustments become very sensitive. When the brightness and size of the center spot is at a maximum, the pinhole is in focus. (If the ring is turned too far, you will pass through the focus and the spot will become smaller.)

*2)* Roughly determine the focal length of the lens on the table by forming an image of an overhead light on the floor. Measure the distance from the floor to the center of the lens with a meter rule. From a previous lab exercise we know that this height is roughly its focal length. Note down the measured focal length.

*3)* Now place the lens about 1 focal length away from the spatial filter. By moving the lens, you should be able to make the size of beam near the lens the same size as the beam at the end of the table (or across the room). You can verify this by sliding the iris along the beam path. You can also use a white piece of paper taped to the wooden beam block. If it does not pass through the iris all along the beam path, check to be sure the lens is properly aligned and then use the tilt adjustments on the spatial filter to correct for the tip. After this final adjustment, you should be able to slide the iris all along the beam. Once the beam is collimated, show your results to the TA.

QUESTIONS/problems FOR WRITE-UP

*1)* When everything is exactly aligned, one may see flickering in the output of the laser. What is it caused from, and how can it be prevented?

**(3 points)**

*2)* What is the transverse spatial distribution of the collimated light given that the transverse spatial distribution of the laser light at the input of the spatial filter is Gaussian. Give reasons for your answer.

**(3 points)**

*3)* Why do you defocus the pinhole before you place the spatial filter in the setup?

**(3 points)**

*4)* (i) Explain how the spatial filter works in terms of Fourier optics.

(ii) Why is the spatial filter defocused for the Fraunhofer diffraction part of the lab?

**(4 points)**