Fourier Optics

Purpose

In this experiment we will show how the Fraunhofer diffraction pattern or spatial Fourier transform of an object can be observed within an optical system. We will construct a Fourier Optical Analyzer that can display both the real and Fourier image of any object.

Introduction

The optical system we will use is shown in Figure 4.1. In this experiment we will use commercial compound lenses instead of the simple lenses we have used so far. We will use a microscope objective to expand the laser beam and camera lenses when we need a large aperture converging optic.

The beam is first focused at point *P* by the microscope objective. Microscope objectives are labeled by their magnification, *m*, which is related to their focal length, *f*, by *f*=(160 mm)/*m*. The second lens, L2, is used to refocus the beam at the point *P*'. Since *P*' is conjugate to the initial focal point, *P*, *P*' is on a diffraction plane. A white screen placed at *P*' will show the diffraction pattern associated with the object slide, *O*. The object slide can be placed anywhere between L2 and *P*'.

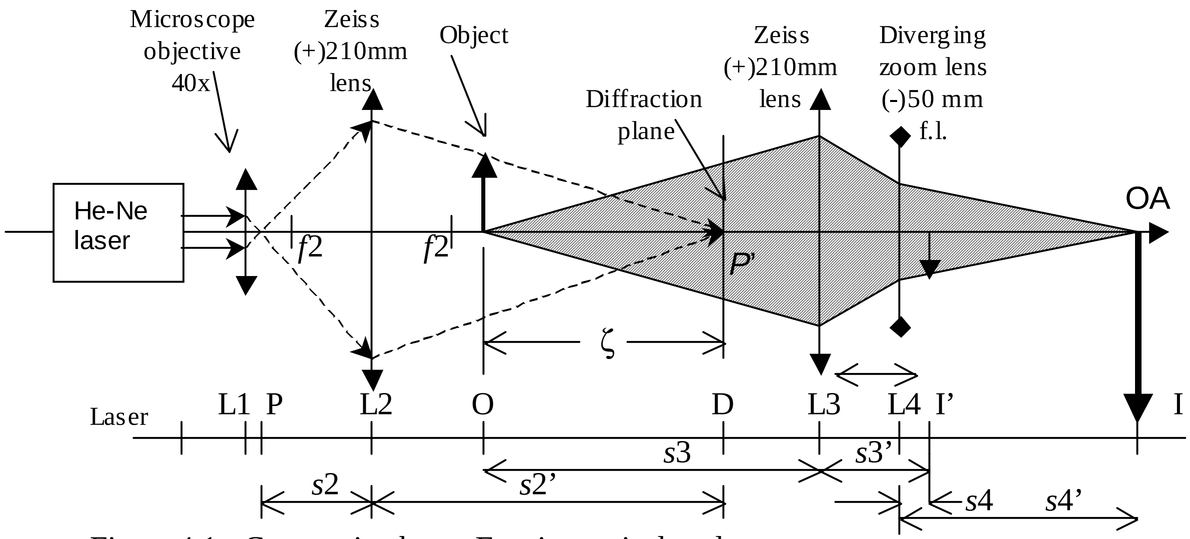

Figure 4.1. Converging beam Fourier optical analyzer.

The diffraction pattern on the screen is given by the expression:

$$I(u,v) = \frac{I_0}{(\zeta\lambda)^2}\left|\iint dxdyF(x,y)\exp\left[i\frac{2\pi}{\lambda}(ux+vy)\right]\right|^2$$

In this expression, I_0 is the intensity incident on the object, ζ is the distance measured from the object to the diffraction plane, and *u* and *v* are *x* and *y* angular coordinates in the diffraction plane, measured from the point where the object intersects the optical axis.

The final two lenses, L3 and L4, are used to create a magnified image, *I*, of the object. The combination of a converging lens, which creates an image *I'*, and a diverging lens placed to the left of *I'*, is called a zoom lens. This arrangement can provide a very large magnification. By alternately inserting and removing a screen at the diffraction plane, *D*, the direct and diffracted images can easily be compared. You can also block a portion of the diffraction pattern at *D* and see what the reconstructed image at *I* looks like with certain spatial Fourier components missing. This process is called <u>spatial filtering</u>.

Outline of the Experiment

1. Using your results from the prelab as a guide set up the Fourier Optical Analyzer. Make whatever adjustments or changes that are needed to get good direct and Fourier images.

2. <u>Examine the formation of diffraction patterns</u>.

   Try to understand in as much detail as you can the relationship between the direct and the Fourier image. Start by looking at simple shapes like round and square holes of different sizes. Then look at regular arrays of the same objects.

3. <u>Ronchi grating</u>.
   The diffraction pattern of the Ronchi grating is closely related to the Fourier transform of a square wave. Which Fourier components are visible? Recall (or derive) the fact that a square wave has only the odd harmonic components. How is this visible in the diffraction image?

4. <u>Spatial filtering</u>.
   First look at the Ronchi. How does the reconstructed image look if you a) remove the central (zeroth order) diffraction spot, b) let only the third order spots go through, c) let only the zeroth order spot pass? Next, use crossed Ronchi Gratings to create a checkerboard object. Can you find a way to filter the light at the diffraction plane so that all of the horizontal lines are removed from the reconstructed image?

5. <u>Explore</u>
   Look at some of the other objects available in the lab. What features can be removed or emphasized by spatial filtering?

Problems

These problems will give you a starting design for the Fourier Optical Analyzer. Do not be afraid to make cha

1. Refer to Figure 4.1. We will carry out our design using thin lens formulas. A 40x microscope objective has a 4 mm focal length. So the point *P* is 4 mm to the right of L1. Suppose we want the distance from *P* to *P*' to be 120 cm. A) Where should we put the 210 mm focal length camera lens L2? You will find that this problem has two solutions. Choose the one with L2 closest to L1. b) Assuming that the laser beam begins with a 1 mm diameter, what will the beam diameter be at L2?

2. Suppose now that the object, *O*, is placed 5 cm to the right of L2, and L3 is placed 8 cm to the right of *P*'. a) Where is the image point *I*'? b) Now suppose that we want the final image, I, to be 100 cm to the right of L3. Where should we put the diverging lens, L4?

3. Make a sketch of the system showing the positions of all lenses and images.

<u>Remember</u>:

Converging	→	$f>0$
Diverging	→	$f<0$
Object to left	→	$s>0$
Object to right	→	$s<0$