Spatial Filtering

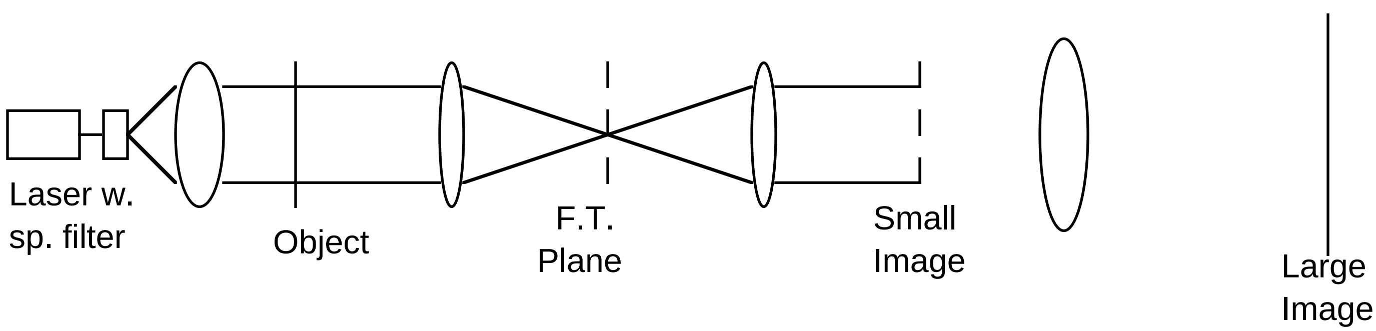
Lab Preparation

Review your work on the Fourier series lab and Fourier transforms. Reread HL Chapter 13.

Theory

According to the theory of Fraunhofer diffraction, the diffraction pattern produced at infinity by an object illuminated by a monochromatic plane wave is simply the spatial Fourier transform of the object. Since it is impractical for us to observe an object (such as an aperture) from an infinite distance, a lens is used to cause the diffraction pattern to appear in the focal plane of the lens. This diffraction pattern is thus the two-dimensional spatial Fourier transform of the object, with low spatial frequencies appearing near the center of the pattern and higher spatial frequencies appearing further out.

The Fourier transform is its own inverse, so a second lens can recreate the object from its diffraction pattern. If the diffraction pattern lies in the focal plane of the second lens, the image of the object will appear at infinity. If the diffraction pattern lies in a plane further than one focal length from the second lens, the object will appear at a finite distance. Unfortunately this object will be very small; however a third lens can be used to magnify (and invert) the object. The experimental setup is as follows:



By selectively removing various spatial frequencies from the diffraction pattern, we can alter the appearance of the final image. NASA now does this type of processing digitally on a computer. See Jenkins & White for an excellent discussion and examples. In addition, this technique is being used in the design of optical analog computers, since certain calculations (such as taking transforms) can be done literally at the speed of light.

I) The Set-Up

Adjust the microscope objective and the pinhole to produce a uniform field of illumination directed down the optical axis. Place the 1.7 diopter lens in the beam so that a plane wave is produced. (Can you devise a way to test whether the beam you have produced is a plane wave?) The object is placed in this beam, followed by a 0.9 diopter lens. The Fourier transform should be visible at a distance of one focal length beyond this lens. The last lens is placed so that the distance from it to the transform is equal to or slightly greater than its focal length f. The reconstructed image of the object should appear at some distance (> f) beyond this lens.

Since the objects are rather small, the images produced in this way will also be small. You can use an additional lens to magnify the final image to produce one which is easier to see. Put a sheet of white paper on the wall for a projection screen. (It is possible to figure out where the image of the object will appear using the lens equation from introductory physics. This equation simply tells us where the waves will superpose constructively to produce the image. The reason we don't normally see the Fourier transform is because we rarely illuminate an object with a monochromatic plane wave.)

II) The Basics

Using only ray optics, determine what should be seen at the plane where the transform appears. Examine the transform produced by a series of vertical bars. Does this agree with your predictions based on ray optics? Does what you see agree with the Fourier transform of a set of vertical bars? (Note: periodic objects can be treated by Fourier series rather than by transforms.)

III) Spatial Filtering

You will need to select an object which is reasonably simple to begin; a grid is a good choice. What does each part of the transform contribute to the reconstructed image? To find out, use different apertures to selectively block out parts of the transform. Can you remove the horizontal bars of the grid? The vertical? What happens if you remove the high frequencies? The low frequencies? (High frequencies are those far from the center of the transform, while low frequencies are those near the center.) You should understand what role these frequencies play in the formation of the final image.

Try to filter the dots out of one of the newspaper-type pictures provided in the slide set. Try to filter out the background tracks from the bubble-chamber slide. What works? Why?

IV) The Spatial Filter

The device used for producing a clean beam from the laser consists of a lens and a pinhole. How does this work? (Explain in terms of Fourier transforms.)

N.B. The error analysis for this lab is not numerical. Instead, you will be comparing images. Are the dots where they should be relative to each other? Do the intensities behave (qualitatively) as you would expect from theory? (Be explicit about what theory predicts and what you observe.)

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