Experiment 2:

Fourier Analysis and Spatial Filtering

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Abstract

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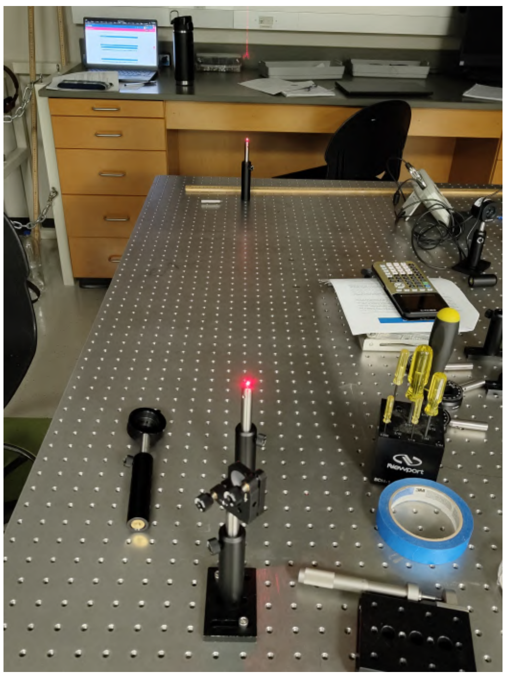
1 Experiments

1.1 Align a laser beam parallel to the optical table

Before setting up any experiment involving lasers it is very helpful to have the laser beam heading toward your setup parallel to the optical table and most of the time parallel to one of the table edges. This can be achieved by using two points far from each other, one near the laser and the other at the far end of the table. You need to make the beam at the same height between the two points. In general you need two degrees of freedom to align the beam in any given direction between two points. The two degrees of freedom can be two reflections (angular motion) by two mirrors or a translation of one mirrors and a reflection by the other. The laser itself can be used as one of the degrees of freedom if it is easily adjustable vertically or horizontally, and or it can be tip/tilted.



Task:
Set the height of two apertures or spikes to be the same. You can use the height of the laser beam as it exits the laser or set them to any desirable height by a ruler. Now mount the two apertures or spikes at the opposite ends of the optical table along one of it edges.

As the task indicates, our group calibrated the laser height using two spikes. We can see the setup in the photo.

We aligned the laser with the spikes so that it would hit accurately on the tip of both spikes, ensuring that the laser is straight (assuming that the table is).

Task:

Direct the laser beam toward the apertures by two mirrors or by one mirror with the appropriate orientation of the laser. The mirror closest to the laser is used to adjust the beam at the near aperture and the second mirror is used to adjust the beam at the far aperture. Recall that translational adjustment of the mirror holder can be very helpful. Normally use coarse adjustment by rotating the mirror post by hand and reserve the knops on the mirror mounts for fine adjustments.

We used the spike again to ensure that the laser was still parallel to the table and straight, checking both vertical and horizontal alignment of the laser beam. To do so, we used the tip and tilt knob on the laser holder itself besides the knobs on the mirror frame.

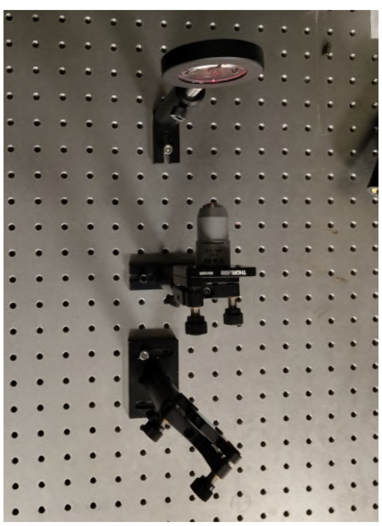
1.2 Align a lens to the beam and the construction of laser beam expander

If a lens is needed in the path of the beam then the beam must go through the center of the lens at normal incidence. This keeps the beam alignment. For the beam expander we need to have a short focal length lens in order to get a small beam waist that will diverge quickly. Recall that the beam radius at the focal plane is approximated by $\omega = 1.22\lambda f/D$, where D is the input beam diameter, f is the focal length of the lens, and λ is the wavelength.

Task:

Place an iris after the location, but very close to, where you need the place the lens. Make sure that the iris is well aligned with the beam.

A plastic iris was used to double check the alignment and to have a measurement of the laser height.



Task:

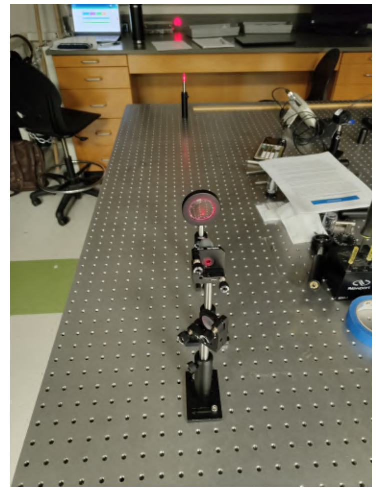
Now place the microscope objective ($40x$ or $60x$) in the path of the beam and adjust the lens horizontally and vertically until the beam is centered at the iris. You may need to adjust the iris opining to easily see the beam relative to the iris opining.

The microscope objective we used was $40x$, allowing the beam to expand. After the microscope objective, a lens of $f = 25cm$ was placed so that the beam would collimate. We checked this by moving a piece of paper from various distances to the expanded beam, and measuring the diameter of the light circle to ensure that it was constant, or mostly constant at all distances, indicating that the beam was actually collimated.

Task:

Now take a look at the reflections from the lens (you can use a paper with a hole to see the reflections or another iris placed before the lens) and make sure they are coinciding with beam before the lens. You may need to slightly rotate the post of the lens and use the tip/tilt adjustments to make the beam incident normally at the lens center. Once the reflected (from the front and back surfaces of the lens) and the transmitted beams are centered relative to the irises your lens is aligned.

Now we checked that the beam was centered by using the plastic iris that we prepared on the first task of this section. To correct the misalignment we modified the lens post alignment and obtained a centered collimated beam.



Task:

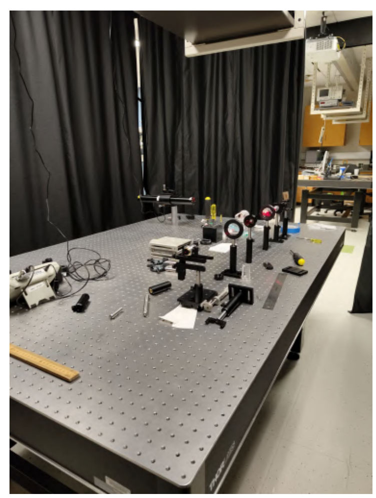
In order to construct a laser beam expander we will use the configuration of an astronomical telescope. *Use a* $40x$ *microscope objective with a* 15 *cm focal length converging lens or a* $60x$ *microscope objective with* 10 *cm focal length converging lens.*

We ended up using a $40x$ microscope objective after the lens that we call 'Fourier transform lens' of $f = 10cm$. The microscope objective was placed at the focus of the lens, ensuring that it was aligned as perfectly as possible with the beam.

Task:

Place the 10 *cm* (15 *cm*) lens after the $60x$ ($40x$) lens and adjust the separation between the lenses to obtain a collimated beam (start with a separation equal to the sum of their focal lengths). Use a ruler to measure the size of the expanded beam at different location to make sure that it is collimated. We will use this collimated beam to illuminate several objects (transparencies) and study their Fourier transforms and the effects of spatial filtering.

As we mentioned before, the setup ended up being: A laser shooting into a mirror which reflected into a microscope objective which expanded the beam. This beam was collimated by a lens so that we can illuminate transparencies. Then the collimated beam was focused by another lens into another expander, which finally projected our image into a screen made with a plywood plank and a sheet of white paper.

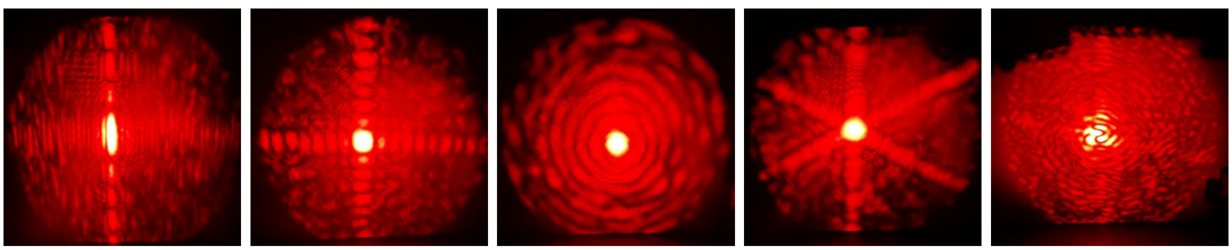


1.3 Fourier transform of simple functions

You will be given several transparencies in order to investigate the Fourier transform of the functions represented by these transparencies. Use the expanded collimated laser beam as a source of light to illuminate the transparencies.

Task:

Place the transparency that has the rectangular slit in the path of the collimated beam. The transmission of this opining resembles a 1D impulse function. Place a lens after the opining at a distance equal to the focal length of this lens (the Fourier transform lens). You may use any lens. A 20 cm or 25 cm focal length converging lens would be an excellent choice. Remember to keep the height of this lens to be the same as the height of the window (the window is centered to the lens). The image constructed at a far screen should be a square window. Now place a microscope objective at the focus of this imaging lens (the Fourier transform lens) in order to see the pattern at the focal plane. Remember that the pattern at the focal plane is the Fourier transform of the impulse function. Record your observations, take a picture of the intensity pattern, and compare them to what you expected to get.



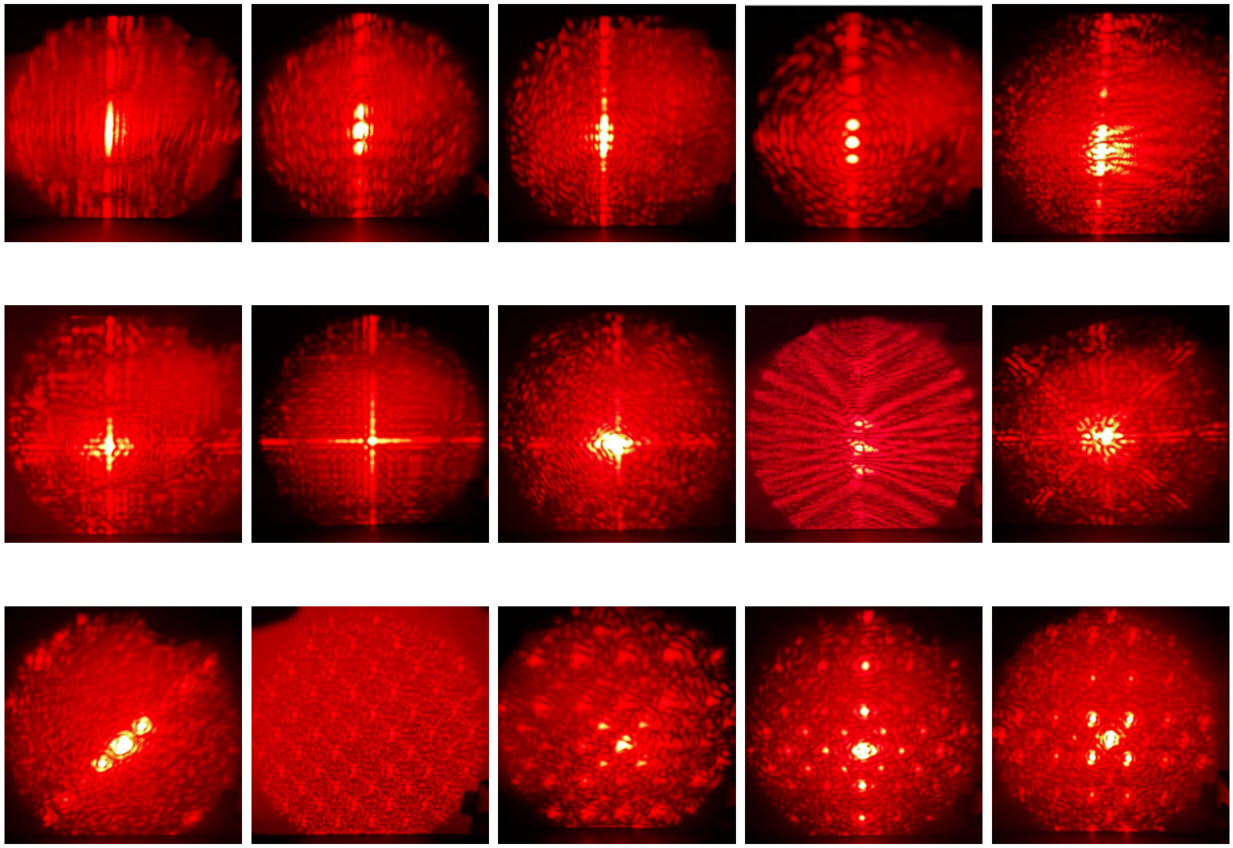
As we know, a occlusion transparency made from straight lines result in straight lines in the diffraction pattern, but with its axis flipped 90°. However, in the case of the triangle, for example, we can see that the appearance of 3 straight lines results in a sort of star, because each side of the triangle will generate a different line on the pattern.

Moreover a circular occlusion transparency will generate a diffraction pattern that reassembles a circle, because if we think of a circle as a polygonal form with infinite edges, we can think of how every edge will generate its own perpendicular diffraction pattern, forming in the end these circles that we see in the pictures.

A combination of both type of occlusions is observed on the transparency with a 5. The vertical line of the 5 is not perfectly vertical, it's slanted. That's why we can see a horizontally slanted line on the diffraction pattern. The vertical line on the pattern can be explained by the horizontal line on the number 5, and the circles can be explained by the circular part.

Task:

Repeat part 1 for these functions on the given below.

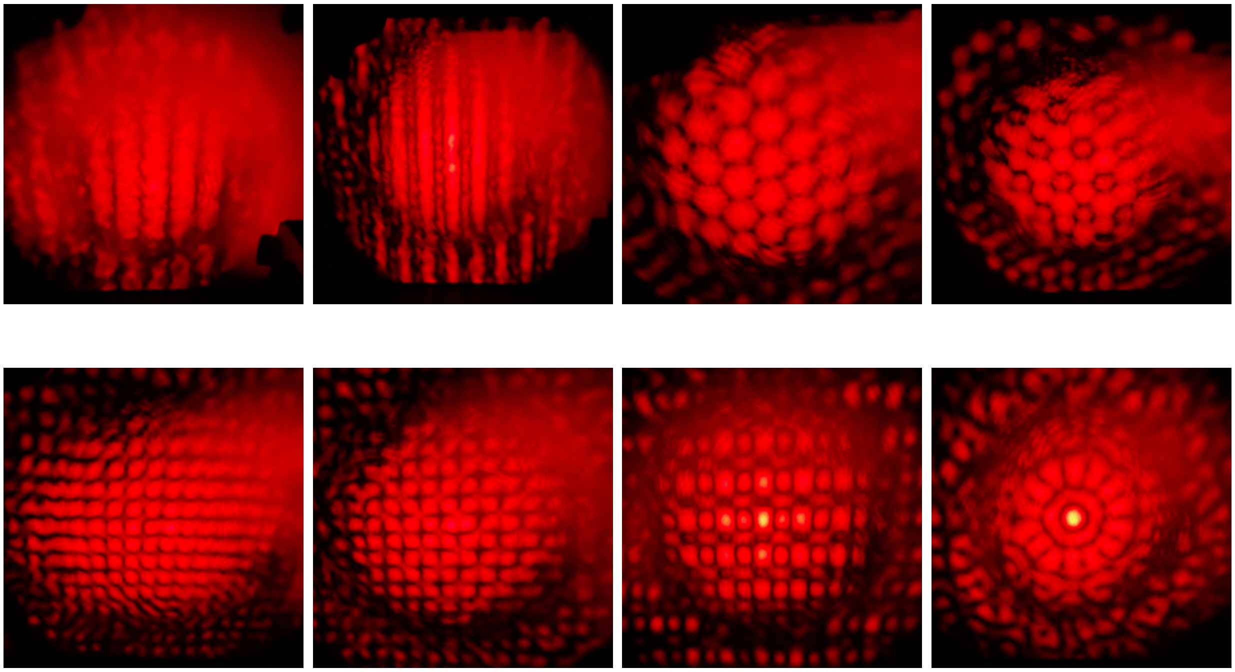


Following the same principles as before, we can see how incrementing the number of slits or their width affects to the pattern on the screen.

From these I would like to remark the last one from the second row, which is generated by a transparency equal to its own pattern. This is because each line will generate a perpendicular one, and as there are lines on all the directions all the directions end up represented in the pattern. Moreover we can see intermittent features the same way that we see them on the first three patterns of the second row.

On the third row we have meshes that make up interesting diffraction patterns. My favourite is the checkerboard, which shows sort of a bigger checkerboard pattern when you look it from far away.

Task:
Repeat part 1 for the various point sources with configurations given below.



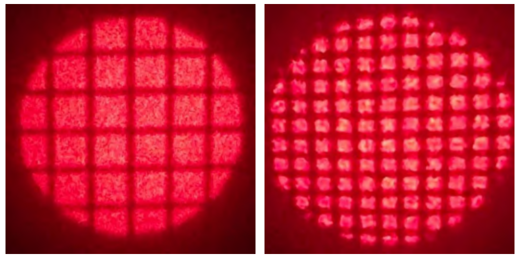
The intention of this part is to show how the appearance of a dot in the middle of a group of dots can change drastically the resulting pattern. We try to form a circle from dots increasing the number of dots each time.

On the first row the most interesting ones are the triangle and the triangle with a dot in its center. The first one makes a hexagonal pattern and by adding just a dot in the middle, we see this effect in which some hexagons are bigger than others. The same happens on the next row with the first two images, but this time with squares instead of triangles and squares instead of hexagons.

Finally, we can see a cool pattern made by an H which forms a parallelogram mesh image, and how finally a circle of dots can reassemble the previous example we discussed with a full continuous circle, although this one has more features, and noise.

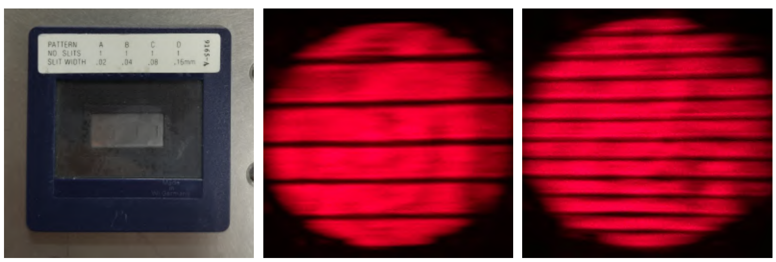
1.4 Spatial filtering and Fourier transform 1

Use the expanded collimated laser beam as a source of light for the flowing. Place a mesh in the path of the expanded beam and observe its image on a screen located about 0.5 m from the object.



Task:

Continue with what you did in task 3 part 1. Insert a vertical slit at the location of the focal plane and observe the image on the screen. You may need to use slits of different widths. Take a picture with your phone for the image and explain the results. Remember that in this case the slit is a vertical-pass filter.



We used a slit of width .04mm vertically, and we observed a horizontal pattern, as the slit is acting as a vertical-pass filter

Task:

Insert a horizontal slit at the location of the focus and observe the image on the screen. Take a picture with your phone for the image and explain the results. In this case the slit is a horizontal-pass filter.

The same way as before, we used a slit of width .04mm but this time horizontally, and we observed a vertical pattern, as the slit is acting as a horizontal-pass filter

1.5 Spatial filtering and Fourier transform 2

Use the expanded collimated laser beam as a source of light for the flowing. Replace the picture of the mesh in task 4 by the picture of the flower and observe its image on a screen located 0.5 m from the object.

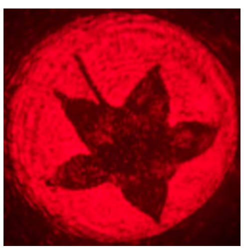
Task:

Insert a microscope objective at the location of the focus to observe the Fourier transform of the flower picture. Take a picture for the image on the screen. Record your observations.

We can see that the original image of the flower is flipped on the screen. Noise is seen inside of the flower pattern.

Task:

Now Insert an iris at the location of the focus and observe the image on the screen. Adjust the size of the iris and observe the changes in the image (take pictures). Record your observations and Explain. Recall that the iris is a low-pass filter.



The diameter of the iris determines which frequencies are filtered, a bigger aperture will filter lower frequencies, and a lower one higher frequencies. Fine tuning an aperture can help to increase the contrast of the final image.

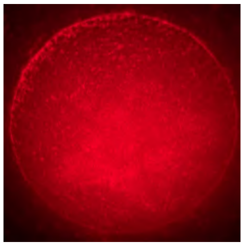
Task:

Insert a transparency with a black spot to block the center of the focused image at the location of the focus and observe the image on the screen. Observe the changes in the image (take pictures). Record your observations and Explain. Recall that the black spot on a transparent surface is a high-pass filter

The dot on our transparencies was too big, but we still can kind of see the flower. This is because a black spot is a high-pass filter, allowing high frequencies and restricting lower ones, which define the outer edges of the flower.

Task:

Insert a transparency that has a black spot at the center of a transparent ring at the location of the focus and observe the image on the screen. Explain the function of this filter.

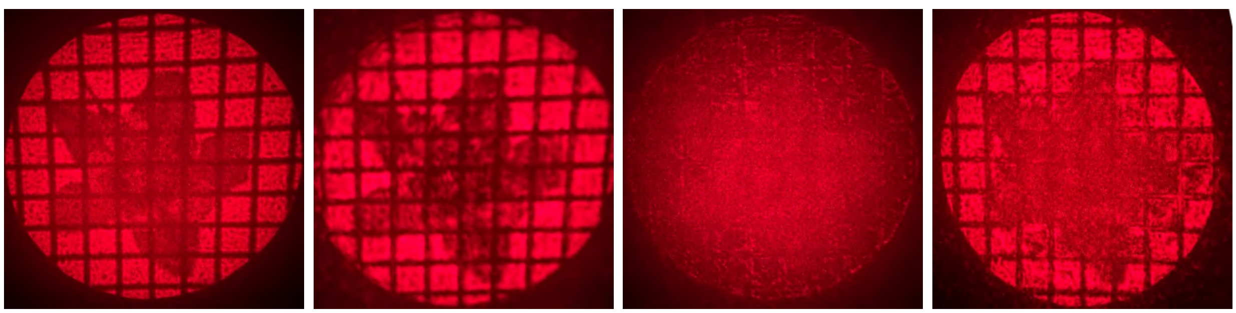


This kind of filter is a band filter, which only allows a certain range of frequencies to pass. Using this filter allowed us to see better the flower than by just using the middle dot.

1.6 Spatial filtering and Fourier transform 3

Task:

Use the expanded collimated laser beam as a source of light for the flowing. Use the various filtering methods you employed in task 4 and task 5 to study the effects on the image of a flower with a mesh.



In this section we tried to enhance the quality of the screen image of the flower using filters.
The first image is the mesh without any filter. The second one is the mesh with the iris blocking some of the light, allowing to enhance the resulting image by filtering some noise.

We tried to use a dot filter to edge-enhance, but the dot filter was too big as mentioned before. That's the third image we see on the row.

That's why we 'made' a filter with a bit of ink in a transparent layer. That's the last image we see on the row. However, the pen ink allowed some light to pass through and thus didn't work as expected.

2 Addenda

LaTeX code that generates this document

PHOTONICS-LabRep2:fourier.tex