ADVANCED OPTICS LAB -ECEN 5606

Basic Skills Lab

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The goal of this lab is to provide you with practice of some of the basic skills needed in aligning and manipulating laser beams that will help later, and using some of the most common optoelectronic measuring instrumentation. These are pretty simple, but if you have never done any of these before, it is better to struggle now rather than later.

1. **Align a laser beam through two apertures along a rail.** Often you will need a beam going from point A to point B, both of which are determined by other constraints, for instance aligning a beam centered down an optical rail is very useful for rapid assembly of an optical system. This is non trivial because your adjustments are angular and not located at point A or point B, thus not orthogonal. For this you will use either the red (633nm) or the green (532 nm light) CW laser (Coherent). For alignment you always should attenuate the output so that it is less than a few milliwatts or so.
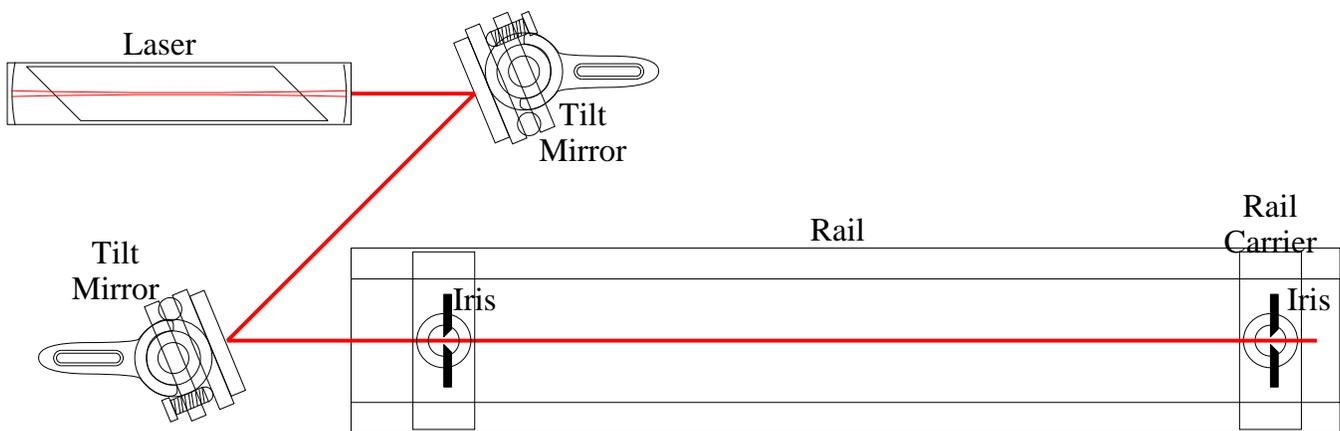

Figure 1: Z-folding a laser beam down the axis of an optical rail with two tilt mirrors.

   (a) Mount two apertures (irises) along the optical rail at the opposite ends, and set them to the same height, but at a height that is not the same as that of the laser beam. How can you make sure they are actually at the same height? Think about sliding them and exchanging their order.

   (b) You need 4 degrees of freedom (because you need to get vertical and horizontal position right at both apertures). The easiest way to do this is to bounce the beam off of two mirrors (sometimes called a Z-fold). Each bounce gives you two degrees of freedom (two knobs on the mirror mount!).

   (c) Align the beam through both apertures, so that it is centered down the length of the rail. You will have to iterate, i.e. get the beam going through the first aperture, it will miss the second. Then if you align it to the second it will miss the first. If you use the right algorithm, iterating back and forth will converge to alignment though both. Thinking about the length of the lever arms helps, and iterating first horizontally with

the two horizontal knobs, then vertically with the two vertical knobs, then iterating back to horizontal and vertical for possible fine tweaking, etc, is one good approach.

2. **Align a lens to the beam.** To get the best focusing with minimum aberrations, you should go exactly through the center of a lens and the lens should be exactly perpendicular to the beam. For a well aligned rail this is easy since the lens will be centered horizontally by the mount and rail (to within the mechanical tolerance of the rail and lens mounts), and vertical centering can use the post height adjustment. Choose a lens that will give you a waist of 25-50 μm. Remember that the spot size gets smaller for a bigger input beam size, d, smaller for a shorter focal length, f, and is proportional to wavelength, λ, and for a circular aperture goes as $w = 1.22\lambda f/d$.

   (a) Place an additional iris on the rail and align its height so that the iris is centered on the beam. Check this by opening and closing the iris and looking at the laser light on a card downstream. Tape a piece of white paper with a small hole centered on the iris. Especially useful is a set of concentric circles printed on the white card with a hole in the center.

   (b) Choose the approximate location for the lens. Place a card in the beam downstream by approximately twice the focal length of the lens. Mark/note the center of the beam by closing down the iris to it's minimum.

   (c) Place the lens in the beam and close down the iris. Adjust the horizontal and vertical positions until the beam is centered at the same place as before. This is the forward non-deviation measurement.

   (d) Look for the back reflection from the lens on the white paper taped to the back of the upstream iris. Is the reflection going back through the center of the iris? This indicates that the beam is hitting the lens normal to the lens surface. By adjusting the lens tip/tilt and x, y and looking at the 4 conditions (deviation of the transmitted beam on the card in x, y and back reflection on the iris in x, y) iterate to match all conditions simultaneously.

   (e) Note that there are reflections from the front and back surface of a singlet, even if they are anti-reflection coated. Cemented achromats have additional weak internal reflections, and multi-element lenses have many primary and a series of multiple reflections. Each reflection will produce spherical waves of different curvatures and pairs will interfere giving $N(N-1)/2$ interferometric zone-plate bulls-eye pattern that ideally should all be centered on the upstream iris, and this gives a much finer sensitivity to positioning the back reflection than the whole diverging beam. Iteratively aligning the horizontal tilt and position of a lens, followed by vertical tilt and position can help to precisely position an optical component. Short focal length, high surface curvature, lenses are more sensitive to position and mechanical centration on the rail may not be sufficiently precise, so a translation stage or transvers sliding base plate is sometimes required. Note that translation linearly affects forward nondeviation but only quadratically varies back reflection position, while tilts linearly affect back reflection but only quadratically vary forward deviation. Unfortunately, often the surfaces of multiple element lenses aren't perfectly aligned along a common axis (de-centered), and so often this interferometric bullseye is inconsistent with the requirement for forward nondeviation, so eventually you may just have to compromise.

3. **Beam profiling** Measuring the beam profile will allow you to see if you are getting a diffraction limited focus. For larger beams this can be done with a calibrated CCD camera (see part 4 below), especially one with small pixels, although systematic errors due to saturation as well as multiple reflections off CCD cover glass windows are problematic. Instead, here we will use a knife-edge beam profiler. Instead of sliding a few micron wide slit through a beam to measure a 1-D profile, a knife edge slides through the beam rapidly while the large area photodetector integrates the light passing by the knofe edge, and the time domain waveform is electronically differentiated to get a 1-D profile equivalent to that which would have been detected by a scanning slit, which is done by a spinning blade (caution! dont ever stick anything in the spinning blade!). By rotating the scanning knife edge to various angles, a number of projections can be measured in order to get a more complete picture of the shape and size of the beam.

   (a) Place the Thor Labs beam profiler in the beam near the focus and hook up its output to an oscilloscope. Find the calibration coefficient in the manual for microns per millisecond.

   (b) With the scanning knife edge moving vertically (oriented horizontally) slide it back and forth in z to find the minimum beam waist. How does the size compare to the expected diffraction limited spot size?

   (c) Now rotate the knife edge to the horizontal and 45 degree indents and measure the beam waist. Is it circular?

4. **CCD beam profiling** Power on the CCD camera, and hook it to a monitor with a 75Ohm cable, (75Ω cables are thicker than the standard 50Ω RG-58 coax) and also connect to the oscilloscope. Place the CCD in the beam near the focus, and move it towards the tightest focus.

   (a) Set up the Oscilloscope in video trigger mode, and adjust the trigger level. Using 5ms/div you should see all of the horizontal lines overlapped and an envelope of the vertical profile, although you probably have noticed that the CCD is saturated.

   (b) You need to attenuate the beam with a neutral density (ND) filter wheel, but fine adjustments can be made by using a pair of polarizers on rotation stages with the downstream polarizer vertical, and the upstream polarizer rotated at an angle θ to get an intensity transmission of $\cos^2 \theta$. Adjust the polarizer and ND-filter so that the focused peak no longer saturates.

   (c) Now switch the oscilloscope video trigger mode to line trigger, and set the time base to 5μs/div. Adjust the line number up and down until you find the line going through the focused spot. There are 244 lines per field (and 2 fields in the frame), so a spot near the center should be about line 125.

   (d) Refocus the CCD to maximize the peak height and minimize the width, and you may need to readjust the attenuation to avoid saturation. For an 8.8mm wide CCD scaled as 52.4μsec, measuring the temporal width gives the beam width. How does this measurement compare with the knife-edge beam profiler (Full-Width Half-Max or $1/e^2$).?

5. **Spatial Filtering.** In most of the ECE experiments, it is necessary to remove fluctuations in the intensity profile of the laser that are acquired when the beam scatters off of dust particles in the air or small defects on the surfaces of various optical components of the system. In
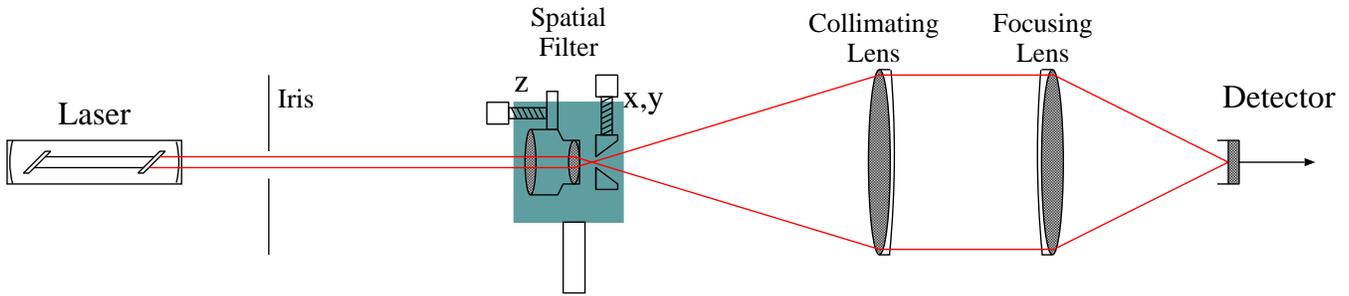
Figure 2: Experimental setup for spatial filtering experiment. Part II. Spatially filtering a beam from a HeNe laser.

k-space these random fluctuations result in higher spatial frequency components added to the system. These components can be filtered out by using a low pass filter (i.e. a small circular aperture) in the focal plane. We will now use either of the two standard spatial filter assemblies commonly found in the ECE lab.

In the following experiment, the beam from a HeNe will be spatially filtered and then the output power of the spatial filter will be measured. The setup for the experiment is illustrated in Fig 2

(a) Use the power meter to measure the total laser power. For a calibrated optical power reading that compensates for the detector sensitivity you must check that the meter is set to the appropriate wavelength.

(b) For the 5-Axis spatial filter insert the objective and pinhole into the assembly. Note: For the 3-Axis spatial filter start at step e.

(c) Hold the assembly up to a low power white light source and look through the objective. Adjust the X-Y position of the pinhole so that the white light source (room lighting) is visible and centered in the objective.

(d) Using the knurled ring, adjust the ring until the light is in focus.

(e) Insert the spatial filter assembly with the pinhole removed after the HeNe and monitor the reflection off of the objective lens back onto an iris centered on the beam or onto the laser head to make sure that the beam is normally incident on the objective. retroreflect onto the laser at the laser aperture. Observe the centration of the transmitted beam on an iris centered on the beam axis and adjust the spatial filter position to obtain a forward nondeviated beam. Adjust the spatial filter x-y tilt to obtain a centered back reflection. Iterate until both forward nondeviation and centered back reflection are obtained. Insert the spatial filter and observe the back reflected scatter speckle on a centered iris or the laser face to ascertain the approxomately correct z-position when the speckle size is maximized.

(f) Place a white card after the spatial filter and adjust the X-Y position of the pinhole until a faint spot is incident on the card. If you don't initially see a spot on the card, you can try the next step or raster through the x and y positions, or do a z search. As soon as you see any light on the card, use it as your feedback method.

(g) Turn the room lights off and look at the front of the pinhole (OBLIQUELY NEVER PUT YOUR HEAD AT TABLE LEVEL). You should see a dim red gleam from the pinhole. Adjust the pinhole position to maximize the intensity.

(h) Rotate the knurled nut to bring the pinhole closer to the objective and adjust the X-Y position of the pinhole to maximize the intensity on the white card.

(i) Repeat the previous step until the maximum throughput is obtained. This is indicated by a bright "circular blob" of light surrounded by a symmetric pattern at the output. A slight movement of the X-Y position of the pinhole should result in the complete disappearance of the diffraction pattern as well. An example is illustrated in the figure below. The asymmetry of the spot can give you clues as to whether to adjust x or y, and a good strategy is to adjust one until the comet tail (asymetry of the far field) is aligned along the other axis. So say the comet tail is along say a 30° angle from x, then adjust the y pinhole translation knob until the comet tail is purely along x, then switch to x and adjust to move the spot towards the center, then move z to maximize the sensitivity of the $x-y$ adjustments, and continue with this strategy of adjustment until the pinhole is aligned. Notice as you get closer to the correct z-position the sensitivity of the x and y adjustments increases, so you goal is to increase this sensitivity until x or y adjustment just makes the spot blink off uniformly rather then smearing and translating.

When the pinhole is beyond the focus the sense of motion of the transmitted beam is the same as the pinhole, but as you adjust the z-position of the pinhole to be upstream (toward the laser) from the position of the focus this reverses so that the motion of the transmitted beam is opposite to that of the pinhole motion. The motion of the pinhole is determined by its right handed threaded adjusters, but this can be hard to keep track of in the dark as you adjust the z-position of the pinhole. The z knob sticks on some of the older spatial filters, and moves quite slowly in order to give you precision near the focus, but when you are far from focused on the pinhole this slow motion can be frustrating. Alternatively, minimally loosening the objective and sliding it back and forth while observing the back scatter from the brushed aluminum pinhole can get you quite close. This is also useful to observe as you screw the removable pinhole into the mount and tighten it, which can give you a hint as to the direction the pinhole has to move by deciding if it moved through the focus plane as it was screwed in or not.

(j) Measure the transmitted power. You may need to collimate and then focus the spatially filtered beam onto the detector and measure the throughput. For the correct objective and pinhole size (unlike above), the power passing through the spatial filter could approach the theoretical limit of 99.3% of the power incident on the spatial filter. Typically, mismatches of pinhole size from the optimum, and spatial noise in the laser beam, make the best transmission efficiency more like 80%.

(k) Collimate the beam to 1 or 2 inches in diameter by placing an appropriate achromat (F/#5 is usually a good choice that has good aberration performance when well alignesd) in the expanding beam separated by the focal length. Use two identical 1cm diameter downstream irises separated by 1-2m to help determine the proper z position of the lens for collimation. When the transmitted beam cut off by a 1cm iris, is still 1cm on the second iris 1-2m away it is very close to perfectly collimated. Switch the irises to make sure they are both set to 1cm. Again adjust the forward non deviation and the back reflections to optimize the lens positioning.

(l) Interferometric collimation testing using a wedged collimation tester is very helpful for perfecting the alignment. Place the collimation tester in the beam, and observe the fringes on the screen. Adjust z of the lens, and watch the fringes. When they rotate by
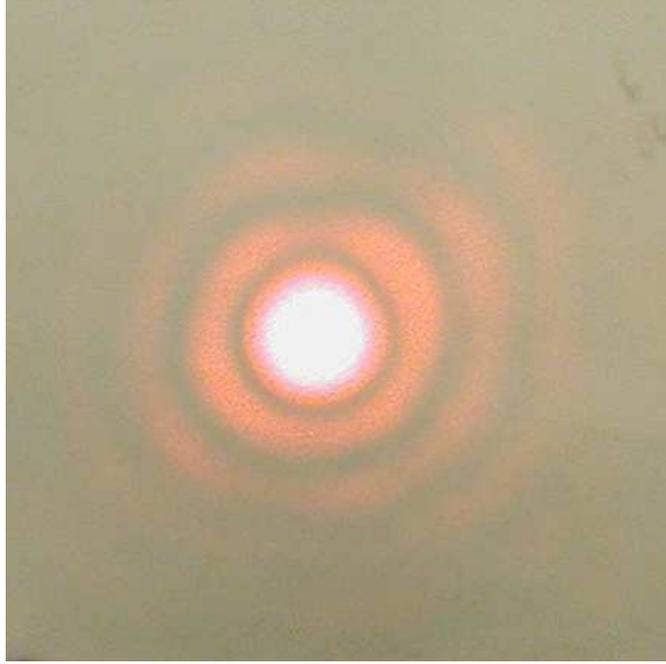
Figure 3: Output of the spatially filtered HeNe laser beam. The spatial filter was 10 μm and the magnification of the objective was 20X (f = 9mm, NA=0.4). The diffraction limited spot size after the objective was 13.89 μm, so the output power in the central lobe was 22.8% of the input power. The pinhole in this photo was chosen to be somewhat small to show the diffraction rings. A properly filtered beam is a smooth, nearly Gaussian profile with no visible features. Rings like those shown can occur with a properly-size pinhole when the pinhole is not at the focus of the objective.

90 degrees so that there is approximately 5 fringes across the face (due to the wedge) aligned parallel to the black line the beam is collimated. If there are curved fringes then there are aberrations in the lens that can be minimized by optimizing the transverse positioning and tilting while still paying attention to the forward non deviation and back reflection. If you cant get an aberration free collimated beam, try flipping the lens around and realigning. The rule of thumb is *the curved side goes towards the plane wave* in order to split up the refractive power more equally between the surfaces in order to minimize the aberrations.

6. **Retroreflecting.** It is common to need to align a beam back on itself (especially when aligning a standing-wave resonant cavity or laser).

   (a) Insert a beam splitter before the spatial filter, this will allow you to monitor the retrore-flected power transmitted back through the pinhole. Note that the forward deviated beam appears on one side, and backwards deviated beam on the other side, and some multiple reflection artifacts can be seen on both sides.

   (b) Insert a plane mirror a distance F behind the collimating lens (any distance works) that reflects the beam back on itself. Adjust the tip and tilt of the mirror to maximize the power going backwards through the pinhole by monitoring the power being reflected by the beamsplitter. A useful trick for rough alignment is to punch a hole in a card and then have the beam go through the hole and look for the retroreflected spot on the card.