PHGN 480 Laser Physics
Lab 3: Interferometry

Turn in your write-up in lab on Monday, 16 Oct.

For this lab, you will be performing several experiments to help you understand interference.

The goals of this lab are to:

1. Build a Michelson interferometer
2. Measure the angle between two output beams.
3. Test the phase delay introduced by tilting a window in one arm of the interferometer.
4. Interfere two diverging beams by focusing into the interferometer. Calculate the difference in arm length from the fringe pattern.
5. With the interferometer set near zero path difference, obtain interference fringes using a broadband source like LED, obtain interference fringe and compare the measured coherence length to an estimate based on the bandwidth of the source.

1. Michelson interferometer setup

a. For these experiments, you can either use the HeNe laser that you have built, or one of the other HeNe lasers (any wavelength). The beam from the laser you use must be level and straight to the table, as well as collimated to a beam diameter of approximately 3-4mm (to have a beam that fits on the camera).

b. Lay out the optics for a Michelson interferometer. The arm lengths should *each* be approximately 4" from the beamsplitter. In a later part of this lab, you will be directing a different light source into the interferometer. One of the mirrors should be mounted on a translation stage, and one of the mirrors should be mounted in one of the nice Polaris (brushed aluminum finish) mirror mounts. Place one of your irises near the entrance of the interferometer, and the second about 12" behind it (toward the laser).

c. Align the output beams to be overlapped and collinear. Making one of your input irises small, and retro reflecting the beam from each arm back to the input iris should get you very close. You can then follow the beams out some distance from the beam splitter. Place a screen at the exit and look for interference fringes. Then put the CCD camera on the output beam with appropriate neutral density filters to avoid saturation. **Make a schematic of your optical setup, and describe your coarse alignment procedure.**

d. When you first see fringes, there is a good chance they will be rotated rather than either vertical or horizontal. **Make a note of how the fringes change with adjustments on one of the mirrors.**

e. **Calculate the intensity of a sum of two plane waves,**

$$E(x,y) = E_0 \exp\left[i\left(k_0 \sin\theta_x x + k_0 \sin\theta_y y\right)\right] + E_0 \exp\left[-i\left(k_0 \sin\theta_x x + k_0 \sin\theta_y y\right)\right] ,$$

to get an expression for the fringe pattern that can be plotted (using DensityPlot). Calculate the fringe spacing in terms of the beam angles, and explain the significance of the fringe rotation angle.

2. **<u>Tilted beam angle measurement.</u>** Here we want to align the beams so that we can both measure the fringe spacing to determine the crossing angle and also measure the relative beam angle directly.
   a. Set the relative beam tilt so that both beams lie in the horizontal plane. Looking on the CCD camera, set the beam angle so that there are a dozen or so fringes across the beam. Removing the camera, you should see the two beams separate after propagating some distance.
   b. Measure the beam separation at a known distance to obtain the relative beam angle. Then compare that to angle you calculate from the measured beam separation from the intensity fringe pattern you calculated in part 1. You will need the camera pixel size, which you can obtain from your measurement in an earlier lab or by looking up the specifications of the camera. Compare the two measurements of the beam angle.

3. **<u>Tilted window phase shift</u>**
   a. Place a window in a mirror mount, and position the window in one of the interferometer arms at an angle near 45 degrees so that the reflected beams are at 90 degrees to the beam. The exact angle doesn't matter, but you need to know what the angle is. Check the alignment to produce a few vertical fringes across the output beam. Put a screen or an iris to mark the position of one of the beams reflected from the window.
   b. Tilting the window will cause a slight phase shift, and is an easier way to introduce a wavelength-scale optical path difference than to manually adjust the translation stage. Adjust the window angle to make a countable number of fringes move across a given point at the output. Look at the displacement of the reflected beam and use this to measure the actual angular change of the mirror.
   c. The transmitted phase of a tilted window follows $\phi = (\omega / c) n \cos(\theta_{refr}) L$, where n is the material refractive index at this wavelength, θ_{refr} is the angle of the internal refracted ray, relative to the surface normal, and L is the window thickness. Compare this theoretical calculation of the phase shift to what you measure experimentally, and use it to obtain a value for the refractive index.

4. **<u>Interference between diverging beams</u>**
   In this experiment, we will be able to directly observe the effects of the curved wavefront of a diverging beam.
   a. Align the interferometer for "null fringe", in other words, make the two output beams as parallel as possible.
   b. Choose a positive lens that has a short focal length, but not so short that the beam cannot make it through the interferometer without clipping on the beam splitter or mirrors. Ensure the lens is well-centered, and look on an output screen for fringes. You should see some curvature to the fringes – when the lens is well-centered, the fringes will be circular. **Describe how to achieve centered circular fringes, and about what effect changes to the arm length and relative beam angle has on the fringe pattern. Illustrate with pictures from the camera.**

c. The beamsplitter makes a copy of the input beam, but each path will be of different length unless they are specifically aligned to be the same. A diverging beam will emerge from the focal point and the radius of curvature is approximately equal to the distance to the focus. So when the path lengths are different, we are interfering two beams that have wavefronts of different curvature. The relative phase shift will depend on the distance from the central axis, so we see circular fringes. The interferogram can be constructed by combining the two paraxial diverging fields: $E_{tot}(r) = E_{0a}\exp\left[-ikr^2/2z_a\right] + E_{0b}\exp\left[-ikr^2/2z_b\right]$. **Make a plot of the intensity of the interferogram in Mathematica.**

d. **Use the CCD camera to record a picture of the interferogram. Using the calibration of pixels to distance, do a rough fit to your calculated interferogram to estimate the path difference between the interferometer arms.**

e. Use the translation stage to try to adjust the path difference to zero. At this position, you should be at a null fringe. **Compare the distance moved to your estimate from part d.**

f. Adjust the angle of one of the mirrors at this zero path difference position and note the shape of the fringe pattern. **Explain why the fringes look this way, in the context of the two virtual sources that are interfering.**

g. Return the alignment to the best null position you can make, as it will make the final experiment easier. Remove the input lens and detune the relative beam angle slightly to get easily visible output fringes.

5. <u>**Broadband interference.**</u>

a. Interference is "easy" when the source is monochromatic. But it is possible to obtain interference fringes with broadband light. What is required is that the interferometer path difference must be small. The "coherence length" is defined as $L_{coh} = c/\Delta\nu$, where $\Delta\nu$ is the source bandwidth in Hertz. **Measure the spectral width and central wavelength of your LED source with a spectrometer, calculate $\Delta\nu$ and L_{coh}.** The value of the coherence length gives an idea of how close the two path lengths must be to observe the fringes.

b. Use a short focal length lens to collimate the light from the LED and direct this beam into the interferometer. Using the camera with a lens at the output, make an image of the end mirror of the Michelson onto the camera. This will make it possible to see interference fringes even though the source is spatially incoherent. Try to align the interferometer to obtain fringes. **Take a picture of the interference fringes.**

c. Adjust the path length with the translation stage, and see how far you can move it without losing the fringes. **Compare this distance to your estimate of the coherence length.**

d. Set the output to a null fringe, then place the optical fiber to measure the output spectrum of the combined beam for several relative delays. Record the spectrum and explain the pattern that you see.

6. Sagnac interferometer for creating spatial shear (extra credit)

A Sagnac interferometer is made with a beam splitter and two mirrors arranged in a triangle, so that one path travels in the clockwise direction and the other counter-clockwise. Just as with the Michelson, one mirror should be on a translation stage. If all the beams are in a plane, the path length is same for both paths, but the translation stage adjusts the transverse shear (which is the sideways offset between the beams).

a. Align the interferometer so that both beams are collinear. Then detune the position of one of the mirrors to introduce a spatial shear. Describe your alignment procedure.
b. Use this interferometer to measure the divergence of a beam – if you start with a collimated beam, you can insert a known lens so that you know what divergence to expect.

7. Passive Fabry-Perot alignment and operation:

We have two passive Fabry-Perot interferometers – these are flat mirrors with an air gap. The angles of one of the two mirrors can be adjusted.

a. To align the FP, direct the beam into the fixed mirror, and adjust the pointing so that the reflected beam returns close to the output of the laser. With the transmitted beam directed onto a screen or right onto the CCD camera, you should be able to adjust the second mirror to see a series of spots. To see them distinctly, you may need to use an iris to make the beam smaller. Try to make the spots move in a horizontal line, and record a picture of them with the CCD camera. Make a lineout so you can determine the round-trip loss of the mirrors.
b. Now adjust the second FP mirror to bring all the spots on top of each other, so that you see them interfere. Then use a short focal length lens and focus the beam into the FP. You should see a symmetric circular pattern of fringes. Try to get the fringe pattern directly onto the CCD camera rather than imaging the screen. This should give you the maximum resolution. Something to try is to put the focal length of the lens beyond the FP to make the ring pattern small enough for the sensor. Describe your procedure for alignment, showing a schematic of your setup.
c. Record the ring pattern you see, and compare to the applet at the website http://www.physics.uq.edu.au/people/mcintyre/applets/fabry/fabry.html . Estimate the finesse of the Fabry-Perot and compare with what you expect based on the measured reflectivity of the mirrors.

8, Fizeau wedge interferometer

The Fizeau wedge, as described in class, is a way to measure the absolute wavelength of a narrow-bandwidth laser. With a telescope for your laser beam, collimate the beam to about 20mm diameter. Take two windows, and place a thin spacer at one edge to make an angle between the beams. The spacer could be a piece of foil, tape or shimstock from the machine shop. Tape the two windows along the edges to keep the two windows together. Reflect the beam off the wedged interface, and record the fringe pattern by imaging the intensity seen on a screen. Since you can measure the spacer thickness, you know the wedge angle, and you can count fringes to measure the wavelength. Estimate the accuracy of the measurement. Extra points for a more accurate measurement.