PHGN 480 Laser Physics
Lab 3: Interferometry

Turn in your write-up in class on Wednesday, 10 Oct.

For this lab, you will be perfoming 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. <u>Michelson interferometer setup</u>

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.

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. The output beams must be overlapped and collinear. Making one of your input irises small, and retro reflecting each arm back the iris should get you very close. Place a screen at the exit and look for interference fringes. **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. By writing a sum of two plane waves,** $E_{\pm}(x,y,z) = E_{0\pm}\exp\left[\pm i\left(k_0 \sin\theta_x x + k_0 \sin\theta_y y\right)\right]$ **, calculate an expression for the fringe pattern, and explain the significance of the 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 and the relative beam angle directly.

a. The direct angular measurement will involve letting the beams propagate a known distance and measuring their separation. The angle must be large enough to measure in this way and small enough to be able to resolve the fringes. **Use the**

expression for the interferogram to calculate the fringe separation and the beam separation.

b. Based on your results, decide how to view the fringes with the CCD camera. One option among several is to make an image of the screen to the CCD camera, preferably with the camera behind the screen to avoid distortion that comes from viewing the pattern at an angle. Another option could be to place the camera at the output of the interferometer with a neutral density filter instead of the camera lens. Calibrate the pixel spacing in terms of real distance units. **Describe your rationale for your experiment design, the method for the pixel calibration, and show a representative image used for this purpose.**

c. Set the relative beam tilt so that both beams lie in the horizontal plane. Adjust the relative angle to produce fringes and verify that you will be able to measure the beam angle directly. Take an image of the fringes and measure the fringe separation. Then measure the relative beam angle. Compare the two measurements and make sure they are consistent before moving to the next experiment.

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. 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 reflected beams.

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 the theoretical to the experimental, 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 light with wavefronts that have 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: $E_{tot}(r) = E_{0a}\exp\left[-i\,k\,r^2/2z_a\right] + E_{0b}\exp\left[-i\,k\,r^2/2z_b\right]$. **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 at the output, 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.**