## PHGN 480 Laser Physics

## Lab 6: resonator and mode-matching

Do this by the end of the day Monday, 7 November. Turn in your write-up in class on Tuesday, 8 November.

In this lab, you will align a folded confocal resonator, that is a plano and a concave mirror separated by the curved mirror focal length. A passive resonator is instructive because we can see the spatial mode structure of a resonator and get a feel for the level of precision that is required in the alignment of a resonator. From a research an applications point of view, such a resonator is a stable Fabry-Perot interferometer, and is used to get an enhancement of the laser field inside the cavity. This enhanced field makes the system sensitive for detecting compounds that might be in the cavity, or for inducing a nonlinear effect in a material. With a pulsed laser input, a passive cavity is used for so-called ringdown spectroscopy, where small amounts of absorption can be measured by looking at the decay of a pulse that circulates in the cavity.

The goals of this lab are to:

1. Calculate the desired beam size to approximately match the mode size of the resonator; set up the laser beam to focus to that size.
2. Align the mirrors of the resonator using this input beam. Use the CCD camera to observe the mode structure of the cavity along the way.

## 1. Setting the laser beam size and divergence ( $w$ and $R$ ):

The beam waist of a confocal resonator is given by:
$w_{c 0}=\sqrt{\frac{R \lambda}{2 \pi}}$ (adapted Svelto 5.5.11, which is for a resonator with two curved mirrors)
where R is the radius of curvature of the curved mirror ( 250 mm for this mirror). The wavelength for the yellow HeNe laser is 594.1 nm . Calculate the spot size of the resonator mode.

What you will be doing is to focus the laser beam to this size, then pass the beam through the flat mirror into the resonator. If we were setting this resonator up for research purposes, we would do an ABCD beam propagation to determine how to manipulate the Gaussian beam so that it has the exact spot size and radius of curvature.

For the purposes of this lab, we will take an approximate approach that will get close.

- Choose a focusing lens of around 750 mm or 1 m , then determine what the beam size needs to be at this lens to get the desired spot size: $w_{0}=\frac{2}{\pi} \lambda \frac{f}{2 w_{i n}}$. Remember that this assumes that the Rayleigh range of the input Gaussian beam is much longer than the lens focal length.
- Check to make sure that the laser beam is level to the table and straight along one of the rows of holes. It will make your life much easier if the beam is directly
above the line of holes and stays that way as you add the lenses. The aperture of the resonator mirrors is not large.
- Design and build a two-lens to collimate the beam at the desired size. Use the knife edge method to measure the beam size just after the second fold mirror and choose a pair of lenses to use for your down-collimator. Admire how easy this is to do when you use a translation stage that has a built-in micrometer. Measure the output beam size from your collimator.
- Place your focusing lens after the collimator, find the approximate position of the beam waist (the confocal parameter $b=2 z_{R}$ will be quite long), and measure the size of the focused spot. Does it match the prediction? If not, why not?


## 2. Aligning the resonator

The resonator mirrors are mounted already; the flat mirror is mounted on a post and base, the curved mirror $(\mathrm{R}=250 \mathrm{~mm})$ is mounted on a post and a translation stage.

- place the flat mirror at the approximate position of the beam waist, either centering it on the beam, or tweaking the beam pointing to center the beam on the mirror.
- Align the back-reflection from the mirror so that it returns back through the iris.
- Place the curved mirror 125 mm from the flat mirror. Make sure that the mirror is centered on the beam. Look for the beam reflected from the curved mirror, and align it so that it returns along the input. You should see some light transmitted through the curved mirror. As the alignment gets close, you should see two or perhaps multiple beams emerging from the curved mirror. The resonator is close to aligned when these lie on top of each other.
- Install a fold mirror to direct the output light to the open CCD sensor (no camera lens). You will need to attenuate the beam with an ND filter. Look at the structure of the beam: you will likely see multi-mode structure. Make observations of what this looks like as you make adjustments to the resonator mirrors - the resonator alignment is best when the pattern is the most symmetric. Since the pattern is interferometrically sensitive, you must take your hands off the adjusters after making changes to let the vibrations settle.
- The intensity if the output depends sensitively on the mirror spacing. Try moving the translation stage to go to a maximum or minimum transmission. If we had a piezoelectric transducer, we could dial through the longitudinal modes of the resonator.
- You probably have noticed the consequences of feedback to the laser - laser

output hops to a different lasing line, most likely to the 604 nm line. (I didn't expect this as I was setting this up.) Since your camera needs filtering anyway, you can try putting an ND filter before the resonator; this should limit the feedback. If you had set the resonator at a minimum of transmission, see if the change in wavelength changes the transmission.

