Investigating Longitudinal Laser Modes using a Scanning Fabry-Perot Interferometer

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Version 2; May 27, 2014

The Fabry-Perot (FP) interferometer is an optical instrument which uses multiple-beam interference. In its simplest configuration, the Fabry-Perot cavity consists of two plane, parallel, highly reflecting surfaces separated by some distance d. We will instead use a confocal FP interferometer (Figure 1) which has spherical mirrors separated by roughly their radius of curvature. In this experiment we will learn to characterize the FP interferometer and use it to diagnose the longitudinal modes of a HeNe laser.

Essential pre-lab reading: "*Introduction to Optics*" by F. L. Pedrotti, L. S. Pedrotti and L. M. Pedrotti, Pearson Education, 2008; (Section 8.4 to 8.9).

Scanning Fabry-Perot Interferometer SA200-5B Manual, Thorlabs, "http://www.thorlabs.com/thorcat/194 5B-Manual.pdf"

FP Interferometer Controller SA201 Manual, Throlabs, "http://www.thorlabs.com/thorcat/6600/SA201-Manual.pdf"

HeNe Laser HRR020 Manual, Throlabs,"http://www.thorlabs.com/thorcat/12100/HRR020-Manual.pdf"; (Page 7 to 9)

1 Test Your Understanding

For spectral analysis, the length of FP cavity is varied by a small amount and the transmitted intensity is monitored. Consider a parallel mirror FP interferometer which is to be used to resolve the mode structure (allowable wavelengths in a laser cavity) of a green laser operating at 532 nm. The frequency separation between the modes i.e., the minimum spectral line width to be resolved ($\Delta\nu_{1/2}$), is 200 MHz. The plates are separated by an air gap and have a reflectance R of 0.999.

1. (a) What is the finesse of the interferometer, (b) the coefficient of finesse?
2. What is the corresponding wavelength spacing to be resolved ($\Delta\lambda_{1/2}$)?
3. What is the resolving power of the interferometer?
4. What is the free spectral range (FSR) in Hz and in nm?

5. What plate spacing is required to achieve this?

6. If we increase the plate spacing, how will this affect $\Delta\nu_{1/2}$, $\Delta\lambda_{1/2}$, finesse, FSR, and the resolving power?

The transmission of a FP cavity is an Airy function. Use the simulation named *CavityTransmission* to further investigate its properties. Make plots of the transmission for some choice of finesse or reflectance and paste them in your notebook.

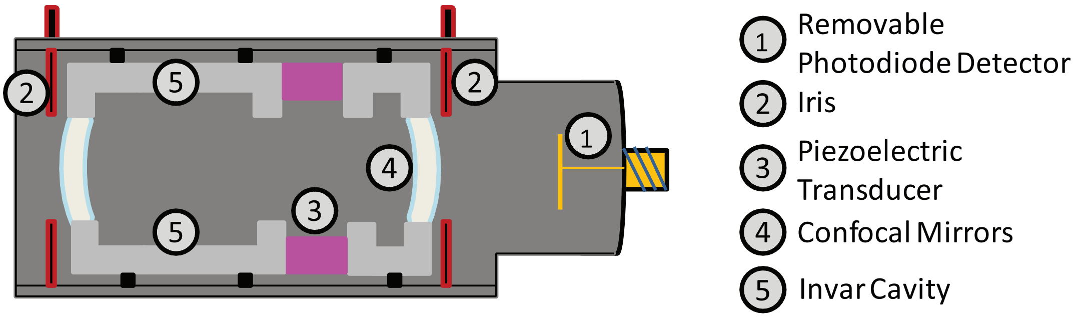

Figure 1: Fabry-Perot interferometer. (This figure is seen best in color.)

2 The Experiment

Mount the FP interferometer in its kinetic mount on the optical bread board. Set the apparatus and make the connections as shown in the Figure 3 in the SA200-5B Manual. Turn on the HeNe Laser, control box of the interferometer and the oscilloscope. Align the laser and the interferometer by following steps

- Remove the photodiode detector mounted at the back of the FP interferometer.
- Close the input iris so that it becomes a pinhole.
- Watch for the laser beam falling back into the laser cavity as that can disturb the cavity modes and may also stop the lasing action.
- Place a screen or a laser detector card in front of the FP's output iris.
- Align the laser beam such that two red spots appear on the screen.
- Now fine tune the FP interferometer using all three screws of the kinetic mount. You should be able to overlap the red spots perfectly. Once the spots are congruent, this means that the assembly has been adequately aligned.
- Carefully put the photodiode detector back without disturbing the alignment.

The oscilloscope will now show you the trace of different modes of the HeNe laser (Figure 2). These longitudinal modes lying within the Doppler-broadened gain curve of the laser are shown in Figure 3.

Note how the modes move. This is because the optical cavity of the laser is warming up and is expanding thermally. When the laser is warmed up and the cavity length is stable, the modes will also be stable. This is the reason one must allow the laser to warm up before doing work which depends on a stable frequency output of the laser. Use the Sec/Div control on the timebase of the oscilloscope to make the signal appear wider and Volts/Div control to make the signal taller. The controls provided on FP cavity controller can also be utilized. Print out the oscilloscope trace wherever needed for each question below.

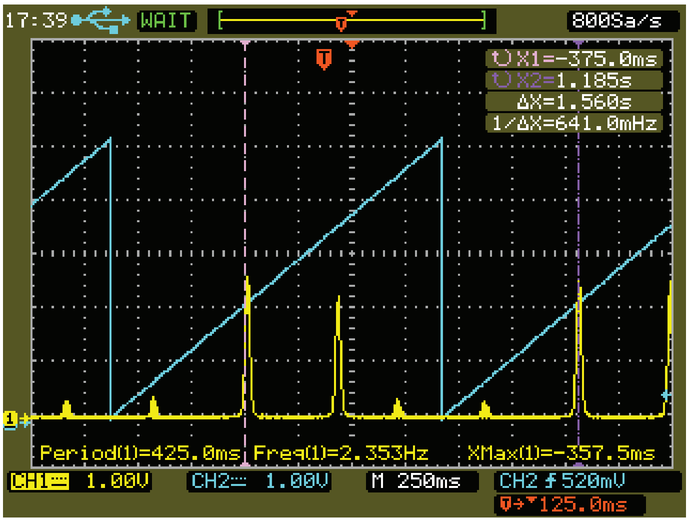

Figure 2: Longitudinal modes of the HeNe laser as seen on the digital oscilloscope.

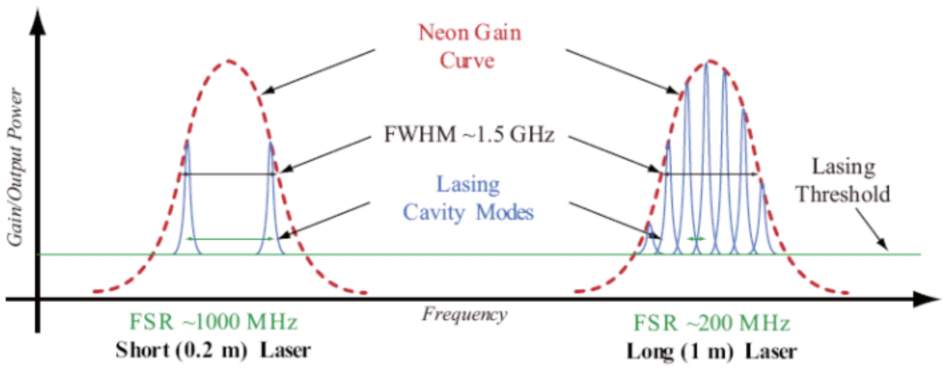

Figure 3: HeNe laser gain curves with longitudinal modes for short and long cavities (HRR020 Manual figure 2).

Q 1. Describe the sawtooth curve seen on the oscilloscope screen?

Q 2. Calculate the Free Spectral Range (FSR) and based on it determine the calibration factor for the oscilloscope signal? The units will be *time/frequency*.

Q 3. Determine the finesse of the interferometer? Verify that it lies in the range stated in the SA200-5B manual?

Q 4. Find the reflectivity of the FP's cavity mirrors?

The laser itself is an FP cavity. The transmission of this cavity also follows an Airy function. The separation between consecutive peaks of the Airy function is given by

$$\Delta\nu = \frac{c}{2d}, \tag{1}$$

where d is the length of the laser cavity and c is the speed of light inside the laser cavity. This cavity is filled with a mixture of helium and neon which produces a Doppler broadened emission spectrum of approximate linewidth 1.5 GHz. From this spectrum, only those wavelengths are emitted which are above the lasing threshold and satisfy the relationship 1.

Q 5. Determine the longitudinal mode spacing of the helium-neon laser and the number of longitudinal modes which are within the gain curve and above the lasing threshold. Furthermore, estimate the length of the laser cavity.

Q 6. As the sawtooth wave is swept to 20 V, estimate the maximum change in the length of the FB cavity. Use the scope to determine what spectral range is swept in this sawtooth ramp?

Q 7. What adjustments are required in order to obtain the laser beam with a single longitudinal mode? Print out the oscilloscope trace once you obtain a single longitudinal mode.

Q 8. Place a linear polarizer, mounted in a rotation mount in front of the HeNe laser and determine the polarization state of the different laser modes?

Q 9. How can you produce different modes at (a) different intensities and (b) the same intensity?