Intro:

In the first part of the experiment, a scanning Fabry-Perot Interferometer (F.P.I.) with two flat mirrors is demonstrated by modification of the Michelson interferometer apparatus. The spacing of the F.P.I. is scanned in the identical manner to the Michelson interferometer. Transmission of the F.P.I. is measured by a photodiode, and the intensity as a function of scan motor steps is recorded and plotted using a computer. The transmission \( T \) of a lossless Fabry-Perot is:

\[
\frac{I_{\text{trans}}}{I_{\text{input}}} = T = \frac{1}{1 + g \sin^2(\Delta/2)}
\]

\[
g = \frac{4R}{(1 - R)^2} \quad \Delta/2 = \frac{2\pi D n}{\lambda} \quad n = 0, 1, 2, 3, \ldots
\]

\( R \) = reflectivity of one mirror (intensity); assume both mirrors are the same.
\( D \) = spacing between two mirrors

For the case of constructive interference:

\( \Delta/2 = 0, \pi, 2\pi, \ldots, m\pi \) or \( D = 0, \frac{\lambda}{2n}, \frac{2\lambda}{2n}, \ldots, \frac{m\lambda}{2n} \)

For the case of destructive interference:

\( \Delta/2 = \frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2}, \ldots, (m+1/2)\pi \) or \( D = \frac{\lambda}{4n}, \frac{3\lambda}{4n}, \frac{5\lambda}{4n}, \ldots, \frac{(2m+1)\lambda}{4n} \)

The finesse \( F \) is the ratio of the separation of the fringes to the FWHM of the resonance power transmission.

\[
F = \frac{\pi}{2\sqrt{g}}
\]

In the second part of the experiment, a Spectra-Physics scanning F.P.I. is used to resolve the longitudinal (axial) modes of 5 different kinds of HeNe laser. These modes correspond to the resonance of the laser cavity, and their spacing is

\[
\Delta f = \frac{c}{2L}
\]

\( L \) = cavity length
The Spectra-Physic F.P.I. is made out of two spherical mirrors in a concentric arrangement. Resonance frequency for a concentric resonator is given by:

\[ f_{mnq} = \left[ q + \frac{m + n + 1}{2} \right] \frac{c}{2nL} \]

Where \( q \) corresponds to the axial modes, and \( m \) & \( n \) corresponds to transverse modes (Fig. 1). If the input laser beam is not perfectly colinear with the cavity axis, some transverse modes will also be excited along with the fundamental axial mode.

Prelab Theory:
1. Give a physical interpretation of Free Spectral range.

2. If this lab is your final write-up, derive the equations for \( T \), \( g \), and \( F \) of a flat-flat F.P.I. with loss \( A \) in each mirror. Note that two arrangements are possible (Fig. 3). Do both cases.

Experiment:
1. Measure the scanned spectrum of the F.P.I. using a red HeNe at 632.8 nm. Do a 1000-step scan. From the data, compute the free spectral range and finesse of the F.P.I. To obtain values that are close to theoretical calculation, the two mirrors must be as parallel as possible, and the laser beam must be very close to normal to the input mirror surface.

2. Repeat the measurement with a F.P.I. spacing that is about 1.3 times the spacing used in part 1.

3. Measure the output mode spacing of the different HeNe lasers with the Spectra-Physics scanning F.P.I. Note that the laser output frequency shifts across the free spectral range of the F.P.I. during the warm up period. This effect is due to the thermal expansion of the laser cavity. As the laser tube reaches thermal equilibrium, the rate of the shift should reduce.

4. The orange HeNe has two independent transition lines. How do you distinguish them from the laser cavity modes of a single transition?
5. Use the Envelope mode of the storage scope to acquire the output spectral profile of the laser. Explain what you observed.

6. Turn the F.P.I. slightly off axis and observe the transverse (off-axis) modes. How many off-axis modes can you see.

Helpful Information:

1. The Spectral Physics scanning F.P.I. has a free spectral range of 2 GHz, and a Finesse of 200. This translates to a bandwidth of 10 MHz. The mirrors are coated to reflect in the range of 530 nm to 670 nm (Fig. 2).

2. Dispersion calibration of the Spectra-Physics F.P.I.
- Direct the output of a red HeNe laser into the small aperture of the F.P.I. Make sure that the retro-reflection from the F.P.I. goes directly back to the laser.
- Set DISPERSION control at max. and the DISPERSION SWITCH at x1. Adjust the timing of the scope to 1ms/div so that only one scan is shown across the screen. Approximately two free spectral range are displayed.
- Observe the spectral patterns on the scope. There should be two sets of identical patterns across the scan (Fig. 4.1). Adjust the VARIABLE DISPERSION and CENTERING controls to expand the patterns so that only a little more than one free spectral range is shown (Fig. 4.2). Stop the movement of the modes by using the SAVE function of the storage scope.
- Measure the time between two identical mode peaks of the neighboring free spectral range with cursor. The scope is now calibrated to show one free spectral range (2 GHz) over the time period. Compute the time-frequency conversion factor.
- Once the conversion factor is computed, VARIABLE DISPERSION control MUST NOT be adjusted again. Change the dispersion only with the DISPERSION SWITCH (x1, x2, x5, x10, x20, x50).
- The desired mode may now be moved to the center of the screen with the CENTERING control.

3. Wavelength of the HeNe lasers:
   Red = 632.8 nm  Orange = 612 nm
   Yellow = 594 nm  Green = 543 nm
Fig. 1

$\Delta f_{m,n,q}$

$\Delta f_{m,n,q}$

$\Delta f_{m,n,q}$

TRANVERSE MODE RESONANCES

INCOMING LIGHT

MIRROR SEPARATION, d

SPHERICAL MIRRORS, RADII d.

Spherical Mirror Fabry-Perot Interferometer

Fig. 2

Finesse

300

200

100

0

400 450 500 550 600 650

Wavelength (nm)

Model 450
EE172L

FABRY-PEROT INTERFEROMETER: Experimental Procedure

1. Turn on the oscilloscope, spectrum analyzer, plotter, and spectra-physics interferometer driver. Set up the oscilloscope triggering as follows: edge-triggered, source = “ext”, ref. = “center”, level = 0 V, holdoff = 80 ns, and triggering on the downward edge of the pulse. Set the timebase to 2 ms/div, the delay to zero, the ref. = “left”. When in doubt, press “preset” and start over. Turn channel 2 off. Set channel 1 to 2 V/div, offset = 8 V, with the input DC-coupled, with an impedance of 1 MΩ.

2. A. Insert a He-Ne laser into the set-up (start with “Red #3”). You can have the professor or the TA do this and align things. Go to the “waveform save” menu and make sure the “display” entry under the “waveform save” menu is off. Set the display to “norm” and observe the moving “spikes” on the screen. Each “spike” represents a Fabry-Perot laser mode.

B. Adjust the continuously-variable gain knob on the interferometer driver so that the “spikes” are not clipped by the top of the screen. Next, set the display to “env”, and wait for things to stabilize. Press the “waveform save” button and then press “store”. Set the “display” option under the “waveform save” menu to “on”. This maps out the intensity envelope of all the possible Fabry-Perot modes. Use the ΔV and ΔT markers to find the time interval associated with the FWHM (Full-Width, Half-Max) of this oscillation “envelope”.

C. Set the display to “norm”. When you can see a few modes under the envelope curve, press the “run-stop” button to freeze the display. Measure the separation between adjacent Fabry-Perot modes with the ΔT markers.

D. Plot your result. (Later, make copies for everyone in your group. Turn in the plots with your lab report.)

E. Measure the physical length of the laser to get an upper bound on the mirror spacing.

3. Turn on the photodiode module, and connect the output to the spectrum analyzer. Go to the “marker” menu on the front panel of the spectrum analyzer, and press “peak search”: what is the frequency of the left-most peak (excluding the “peak” at 0 Hz)? How many peeks do you observe? How many Fabry-Perot modes, on average, do you think are running in the laser? Calibrate the time interval on the oscilloscope by realizing that the optical frequency interval between adjacent Fabry-Perot modes on your oscilloscope plot must be the same as the first frequency peak that you measured on the spectrum analyzer. What is the calibration factor, in “Mhz per msec”? What is the (c/2L) mode spacing for this laser, in Mhz? The oscillation “envelope” FWHM? What is the mirror spacing in cm? (Assume the index of refraction is equal to unity.)

4. Repeat part 2 with “Red He-Ne #2”. What is the (c/2L) mode spacing? The “envelope” FWHM? The mirror spacing in cm?

5. Repeat part 2 with “Red He-Ne #1”. What is the (c/2L) mode spacing? The “envelope” FWHM? The mirror spacing in cm?

6. Repeat part 2 with the green He-Ne. What is the (c/2L) mode spacing? The “envelope” FWHM? The mirror spacing in cm? Also measure the frequency separation between the peaks of the two “humps” in the oscillation “envelope”. This envelope is related to the laser gain curve, less the pro-rated cavity losses.

7. Repeat part 6 for the orange He-Ne.
8. A. Ask the TA or the professor to help you measure the -3dB oscillation bandwidth of a single Fabry-Perot Mode for the orange He-Ne by observing the peak on spectrum analyzer “close in”. Actually, this is probably more of an upper bound for the oscillation bandwidth of an individual longitudinal mode. If the average free-space wavelength is 612 nm, what is the fractional -3 dB bandwidth (FWHM) of the (c/2L) mode?

9. Additional questions to be addressed in your lab report:
   A. Why do the (c/2L) modes “move” across the screen on the scope (and appear and disappear?)
   B. Why did the peak signal value appear to grow and then decline in amplitude on the spectrum analyzer?
   C. Why was the FWHM of the oscillation “envelope” different for the three red He-Ne’s?
   D. Why were there two humps in the gain curve for the green and orange He-Ne’s?

A.A.W.

8. B. Measure the Free Spectral Range of the Fabry-Perot Etalon by measuring the time interval between the repetition of the envelope of the oscillator modes. Convert to MHz.