Mini-Lab on Confocal Fabry-Perot Spectrum Analyzers and Emission Spectrum of the He-Ne Laser

Questions

1. Give definitions of *free spectral range*, and *finesse* of a Fabry-Perot Interferometer.
2. What are these for the interferometer you are using? How would these change if we were using a "flat-flat" interferometer? Why are we using the confocal configuration?
3. Indicate the spatial location of the centers of curvature and foci of the two spherical mirrors comprising the Fabry-Perot interferometer.
4. What is the finesse of our interferometer? Based on your finesse measurement, estimate the reflectivity of the mirrors we are using.
5. We scan the Fabry-Perot interferometer by moving one of the mirrors (by applying voltage to a piezo-ceramic transducer on which the mirror is mounted). Calculate the amount of displacement.
6. Take the cover off the (unplugged!!!!) He-Ne laser. Measure separation between mirrors. Assuming that the resonator is of near flat-flat configuration, calculate the frequency separation between adjacent modes. What is the frequency interval between adjacent modes?
7. Sketch the gain curve for the He-Ne laser (i.e. gain vs. frequency) and the laser cavity longitudinal modes. Make predictions for the structure of the laser output spectrum. Do these predictions agree with your observations?
8. Analyze your photographs of the oscilloscope output. Explain why we use the horizontal (time) coordinate as the frequency axis.
9. Calibrate the horizontal axis using the known radius of curvature of the Fabry-Perot mirrors: R=2.50 cm. Note the effect of piezo-ceramic element nonlinearity. Devise a method of taking that into account. (Hint: you can linearize the scale by fitting your data with a function: $\delta\nu=at^2+bt+c$).
10. Why is the laser frequency "drifting"? Why is the laser sometimes lasing single-mode, and sometimes multimode? From your observations, determine whether the laser is likely to lase on adjacent cavity modes.

Additional Questions (for Inquiring Minds)

1. Place a film polarizer in front of the spectrum analyzer. Rotate the polarizer and observe the change of the interferometer fringe signal on the oscilloscope. What can you conclude about polarization of the adjacent He-Ne laser modes?
2. Can you explain these observations?

Questions Relevant to the Holography Lab

1. How is the laser coherence length related to the spectral width of the emission?
2. What is the coherence length of the laser you will be using in this experiment? Does this length fluctuate in time? The answer should be based on your experimental observations.

Introduction to Fabry-Perot Spectrum Analyzers

These notes can be used in conjunction with both the **Nonlinear laser Spectroscopy and Magneto-Optics** and the **Holography** labs.

- If you take a mirror with high reflectivity (say, R=0.90) and shine a laser beam on it, very little light is transmitted. If you put two such mirrors facing each other, even less light will normally be transmitted. That is unless the mirrors are aligned with respect to each other and the resonance condition that

$$\mathrm{RT} = 2\pi\cdot\lambda\cdot n$$

is satisfied. Here RT is the round trip distance between the mirrors, λ is the wavelength of light, and n is an integer. On resonance, all multiply reflected waves interfere constructively inside this Fabry-Perot interferometer, a large light field amplitude is built-up inside, and in an idealized case, the transmission of such optical system is about 100%.

- The transmitted intensity for the Fabry-Perot interferometer as a function of the incident light frequency is given by the **Airy function**:

$$I_T = I_0 \frac{1}{1+F\sin^2(\varphi/2)},$$

where I_0 is the input intensity, $F = 4R/(1-R)^2$ and φ=2π·RT/λ=2π·RT·ν/c. (The Airy function for R=0.90 is shown in Fig. 1.) Transmission maxima occur when the sine turns to zero, or when the light frequency ν satisfies ν=(c/RT)·n. The frequency interval Δν=c/RT between two adjacent transmission peaks is an important characteristic of an interferometer, it is called **free spectral range** (**FSR**). Another parameter characterizing the sharpness of the resonances is **finesse** F^* which is the ratio of the full width at half maximum (**FWHM**) of a transmission peak to FSR. Under the conditions where the finesse is determined by finite mirror reflectivity (see e.g. Ref. 1), we have:

$$F^* = \frac{\pi\sqrt{R}}{1-R}.$$

- The two most commonly used types of Fabry-Perot interferometers are **plano-plano** and **confocal**. In the former type, nominally flat mirrors are used, while in the latter type, spherical mirrors are used and the focal points of the two mirrors (which are located at half the curvature radius from the mirror's surface) coincide. For a plano-plano interferometer, RT=2·L, where L is the separation between the mirrors, while for a confocal interferometer, RT=4·L. We use confocal interferometers because they are much easier to construct, align and use. For example, a confocal interferometer is remarkably insensitive to angular alignment of the mirrors. A detailed discussion of why this is so can be found e.g. in Ref. 1.

- If the distance between the mirrors varies, the transmission pattern shown in Fig. 1 translates or "runs" in the horizontal direction. It is easy to show (do it!) that if the separation of mirrors in a confocal interferometer changes by $\lambda/4$, the transmission pattern shifts by one FSR. This suggests the use of this device as a **laser spectrum analyzer**: if we observe the transmitted light intensity as the Fabry-Perot interferometer is scanned, we will see a peak whenever a transmission peak of the interferometer will be passing through the emission frequency of the laser. If the laser emission spectrum consists of more than one line, a corresponding picture will be seen at the output of the analyzer.

- A mechanical drawing of the confocal spectrum analyzer used in the Holography lab is shown in Fig. 2. The drawings and descriptions of the analyzer used in the Nonlinear Magneto-Optics experiment are given in Refs. 2,3. The body of the Holography lab analyzer is constructed out of two stainless steel tubes that are screwed one into the other. The fine threads allow precise adjustments of the separation between the mirrors, which is essential for achieving the confocal condition. One of the mirrors is mounted on a piezo-ceramic tube. When voltage is applied between the metal-coated sides of the tube, its length changes leading to translation of the mirror. For the particular piezo-ceramic tubes used, scanning the applied voltage in the range 0-100 V results in a frequency sweep corresponding to approximately seven FSR. Please note that the piezo-element is polarity sensitive and **can be damaged** if voltage of wrong polarity, or excessive voltage (>200 V) is applied. Note also that the spectrum analyzer is, after all, a **delicate optical instrument that is unlikely to survive a fall**. The transmitted light intensity can be measured with a photodiode detector, the description of which can be found in Ref. 3.

- Why do we analyze the spectrum of the laser in the Holography experiment? From elementary wave optics (see e.g. Ref. 4), we know that the **coherence length** (the parameter relevant to holography telling us how well we have to equalize the path lengths for the signal and the reference beam, etc.) and the **coherence time** are related by

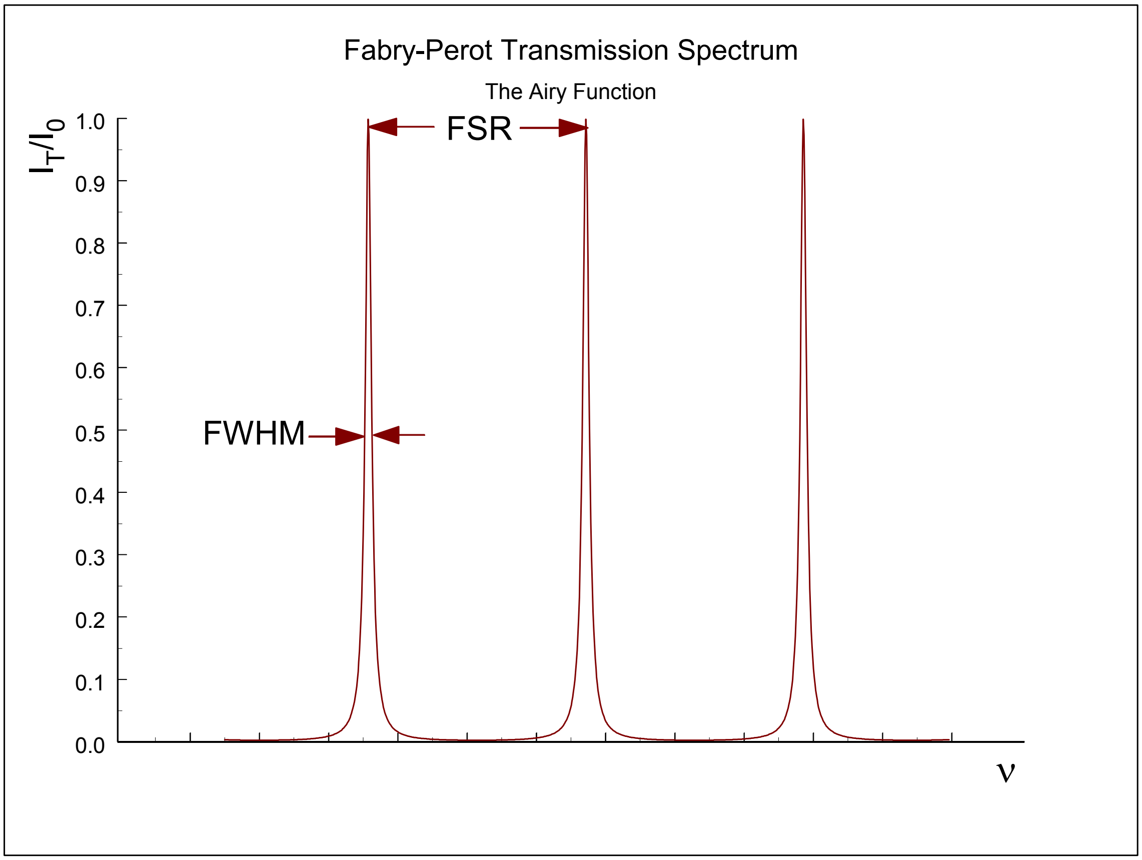
  $$L_c=(\Delta t)_c \cdot c\ .$$

  In turn, the coherence time is given by the inverse of the spectral spread of the light:

  $$(\Delta t)_c \approx 1/\Delta\nu\ .$$

  Thus, knowing the spectrum of the laser, we can estimate the path length difference requirements for the Holography experiment.

Fig.1.


Fabry-Perot Transmission Spectrum
The Airy Function
I_T/I_0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
FSR
FWHM
ν

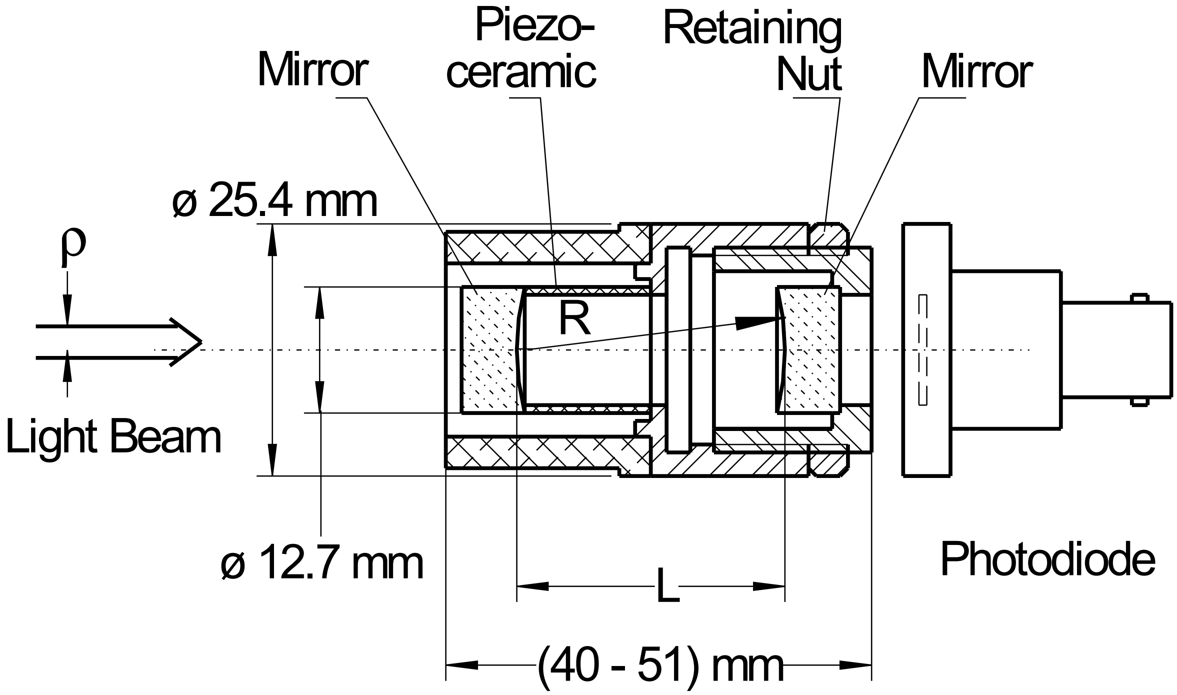


Fig. 2

- Literature

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[1] W. Demtröder. *Laser Spectroscopy*. 2-nd edition, Springer, 1996.
[2] Dmitry Budker, D. J. Orlando, and V. Yashchuk, Nonlinear Laser Spectroscopy and Magneto-Optics; Am. J. Phys. **67**(7), 584 (1999).
[3] Nonlinear Laser Spectroscopy and Magneto-Optics (MNO). Physics 111 Advanced Laboratory Manual (available online at http://socrates.berkeley.edu/~phylabs/adv/).
[4] E. Hecht. *Optics*. Addison-Wesley, 1998, Chapter 7.