Revision 11/05/2009

OPTICS 380A
Lab 11: LASER

The purposes of this experiment are many-fold:

Learn to align a HeNe laser.
Learn to use an electrical spectrum analyzer.
Discover beats in the photocurrent spectrum produced by two modes.
Explore spatial and temporal modes of an adjustable HeNe laser.

PART A: LASER ALIGNMENT:

HeNe lasers are relatively difficult lasers to align because they have very low gain (typically 3% to 10% per pass), and a very narrow bore gain tube, (to ensure that only the lowest order modes oscillate). The gain tube we will use is specially designed to have a large bore (about 2 mm) in order to permit oscillation of some higher order modes which we want to study. Since HeNe laser gain is inversely proportional to bore diameter, our gain will be usually low (about 3% per pass). Compensating for this gain handicap we will work with tubes which have one mirror (the flat) already aligned.

Typical reasons why HeNe lasers sometimes won't oscillate include:

1. Unstable resonator configuration (for concave mirror of radius r versus flat separated by a distance L, make sure $L \leq r$);

2. Gain too low (gas contamination or a problem with power supply)

3. Losses too high (mirrors or Brewster window dirty);

4. Reflectivity two low;

5. Misalignment

There are two main methods used for alignment of lasers: Using a laser to align the other laser, and using an autocollimating alignment telescope. The latter is a very good tool to know about, since it gives you a chance to inspect the clear aperture over the entire region between the mirrors, including the mirrors themselves. Unfortunately, it is hard to use this technique with very narrow bore lasers, such as HeNe. It works better with fat lasers, such as CO_2 and other IR lasers: Therefore, we will use only the former method.

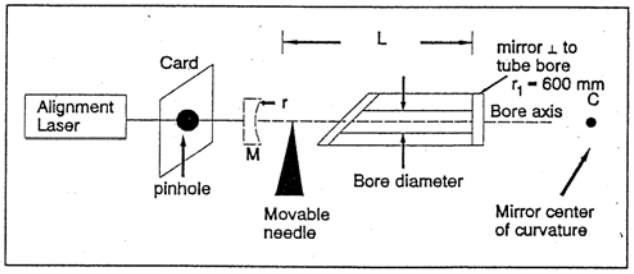

Figure 1. Laser Resonator Alignment

Figure 1 shows a schematic for the laser cavity and mirror (M) to align. The cavity length is about 500 mm. Your task is to adjust curved mirror M so that its center of curvature C lies on the bore axis.

First make electrical connections to the anode (close to anode resistor) and cathode (large aluminum cylinder). Then, with the concave mirror removed, set up an alignment laser adjusted so that its beam reflects back on itself without scattering much off the gain tube walls. To achieve this, turn off the room lights and use a card with a small hole as shown above. Next, introduce concave mirror M and center the reflections off front and back surfaces of mirror M. Plug in the high voltage, power supply (be careful), and stand back! Adjust the mirror until the laser starts to lase, then optimize the output.

> (A) Why is the laser gas tube slanted at an angle as shown in Figure 1? Can you guess the angle assuming index of glass is 1.5? (Hint: Brewster angle.) Characterize the polarization of the laser output using a polarizer. What is the polarization?

EXPLORING HIGHER ORDER TRANSVERSE MODES

Laser cavity theory tells us that all eigenfrequencies of an optical cavity are solution of the following equation.

$$\nu_{mnq} = \frac{c}{2L}\left[q + \frac{(1+m+n)}{\pi}\cos^{-1}\sqrt{g_1 g_2} \right]$$

$$\text{where } g_1 = 1 - \frac{L}{r_1} \quad ; \quad g_2 = 1 - \frac{L}{r_2} \qquad (11\text{-}1)$$

m,n,q = integers that label the eigen modes

c = speed of light

The output intensity distributions look like the square of Hermite-Gaussian functions. Here m and q label the transverse modes and q labels the longitudinal mode. $r_{1,2}$ are the curvatures of the mirrors. (11-1) is valid for $r_{1,2} >> L$. Theory predicts that the m, n off-axis modes of order q looks as follows:

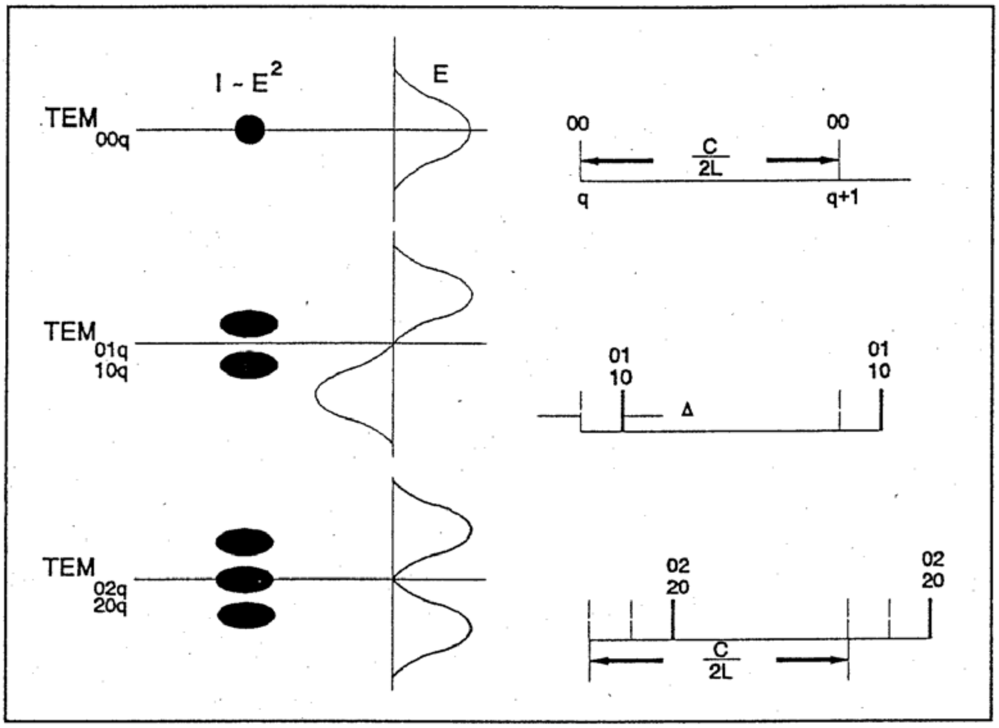

Figure 2. Laser Modes

When one mirror is flat; the intermode spacing ($\Delta q = 0$, $\Delta(m+n) = 1$),

$$\Delta = \frac{c}{2L}\left(\frac{\cos^{-1}\sqrt{1\text{-}L/r}}{\pi}\right) \tag{11-2}$$

You can select the lasing mode by putting a fiber inside the cavity, so that some modes become too lossy to lase. One strategy is to excite simultaneously two adjacent on-axis (TEM_{00q}) laser modes and at least one off-axis (TEM_{mmq}) mode. The spectral pattern and beats would look respectively like this:

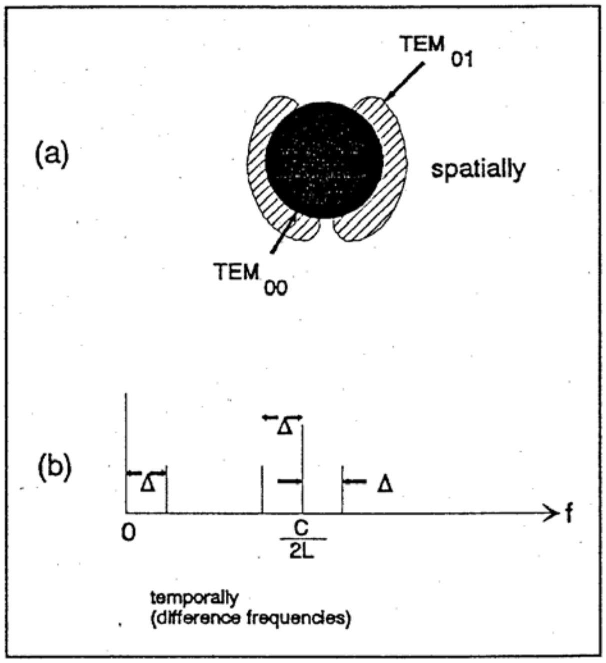

Figure 3. Two modes simultaneously with the corresponding frequency distribution expected.

(B) Try to excite the TEM00q and TEM01q by adjusting the position of the fiber. Add a second mounted fiber, perpendicular to the first. Try to achieve lasing in high-order modes. Modes at least as high order as TEM55q have been observed with this setup. Record your observations.

PART B: ELECTRICAL SPECTRUM ANALYZER (ESA)

The function of the electrical spectrum analyzer (ESA) is to Fourier analyze an electrical current, i(t), to obtain a panoramic view of i(f) versus frequency (f). To get started, use a test signal from an rf oscillator, such as HP 608E or internal calibration source, and get comfortable with control of the central frequency, scale factor (MHz/div) and resolution (which in turn depends on the sweep rate), as shown in Figure 1. See electrical spectrum analyzer instruction manual.

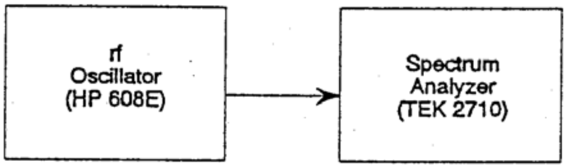

Figure 4. Spectrum Analyzer Tests

WHY LIGHT OF TWO OPTICAL FREQUENCIES INCIDENT ON A PHOTODETECTOR CAN RESULT IN DIFFERENCE FREQUENCY (BEATS) IN THE PHOTOCURRENT

If a multi-mode laser beam is detected by photodetector, a low RF frequency is often measured. The reason why the photocurrent [i(f)] contains these RF frequencies (beats) is when the laser oscillates in two or more model it is lasing at several frequencies.

The photodetector yields a signal current, i, proportional to optical power, P,

$$i \sim P \sim (\text{net optical field})^2$$

Assuming there are only two optical frequencies fields, E_l' and E_2', and that their polarization and wavefronts are identical,

$$i \sim (E_1' + E_2')^2$$

Let us call

$$E_1' = E_1 \cos \omega_1 t \text{ , and } E_2' = E_2 \cos \omega_2 t \text{ .}$$

Then

$$\begin{aligned} i &\sim (E_1 \cos \omega_1 t + E_2 \cos \omega_2 t)^2 \\ &\sim E_1^2 \cos^2 \omega_1 t + E_2^2 \cos^2 \omega_2 t + 2\, E_1\, E_2 \cos \omega_1 t \cos \omega_2 t \text{ .} \end{aligned}$$

But since the photodetector isn't fast enough to follow optical frequencies ω, it averages $\cos^2 \omega t$ to 1/2, yielding two dc terms. In addition, we can express the third term

$$2E_1\, E_2 \cos \omega_1 t \cos \omega_2 t = E_1\, E_2 [\cos (\omega_1 + \omega_2)t + \cos (\omega_1 - \omega_2)t] \text{ .}$$

The first term averages to zero, but the second term, $E_1\, E_2 \cos (\omega_1 - \omega_2)t$, is an ac signal ("beat") at the difference frequency of f_l and f_2, which a fast detector can generally follow temporarily.

Setup the following lab equipment:

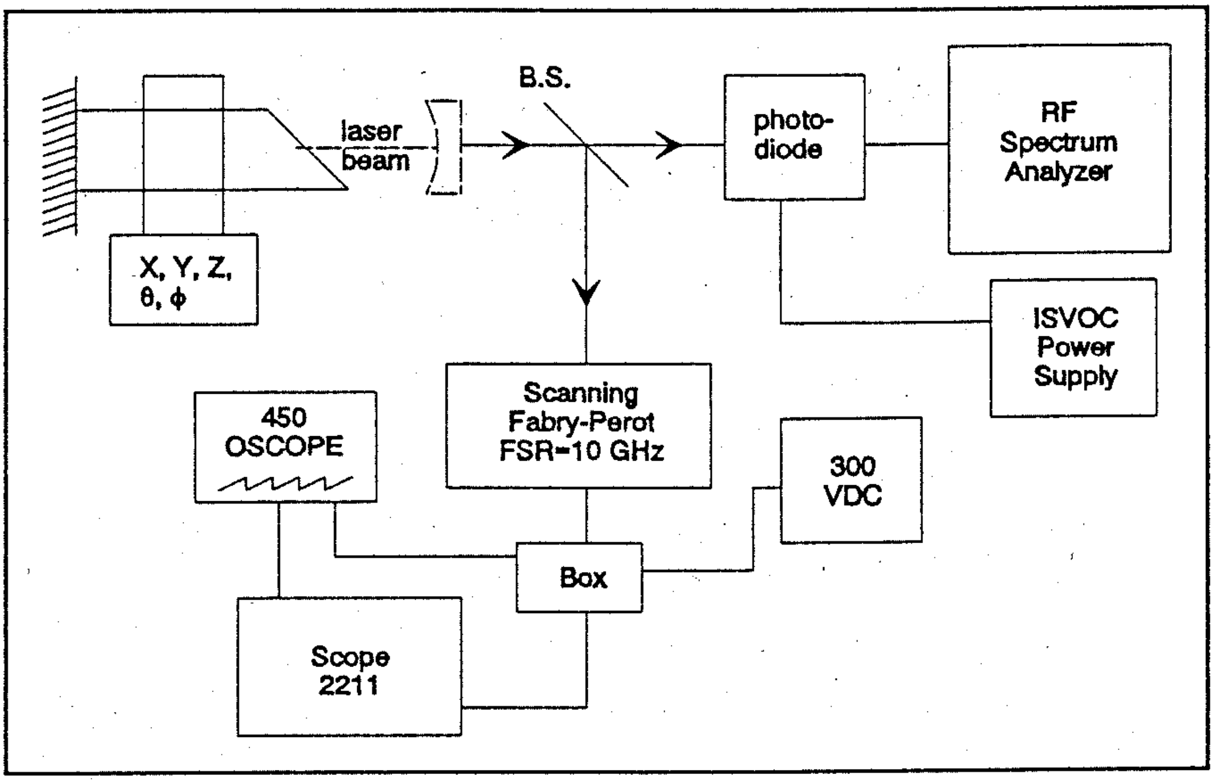

Figure 5. Frequency analysis of multimode laser.

(C) Draw and label the different modes that you see from the setup using the RF spectrum analyzer. Measure L and estimate the longitudinal mode spacing.

(D) Using the electrical spectrum analyzer (ESA), look for beats between longitudinal TEM_{00q} modes of the laser. Do these occur at f=c/2L?

In this part of the lab, you will measure the longitudinal spacing of the output of a HeNe laser using another technique.

(E)Describe how the scanning Fabry Perot can be used to measure the spectrum of light.

(F)Look at the output of the scanning Fabry Perot on the scope. Do you see the longitudinal modes? Since you know the free spectral range of the Fabry Perot, which is either 10GHz or 20GHz, you can estimate the longitudinal spacing. What is it? Does the spacing agree with part (C)? Estimate the cavity length L.

(G)Characterize the polarization of the laser output using a polarizer. How is this compare to the laser in Part A?

PART C: BEAM PROFILER

In the third setup of this lab, you will use a commercial beam profiler to measure the divergence angle of the output of a HeNe laser. The output should be close to a Gaussian beam. You will use the beam profiler to measure the beam waist, w_0, the divergent angle and the NA of the output. A schematic of the beam profile is shown in Figure 6. You can estimate the angle by measuring the beam size at two different locations.

(G) What is the beam waist, divergence angle, Θ, and NA (sin Θ/2) of the output of the HeNe laser?

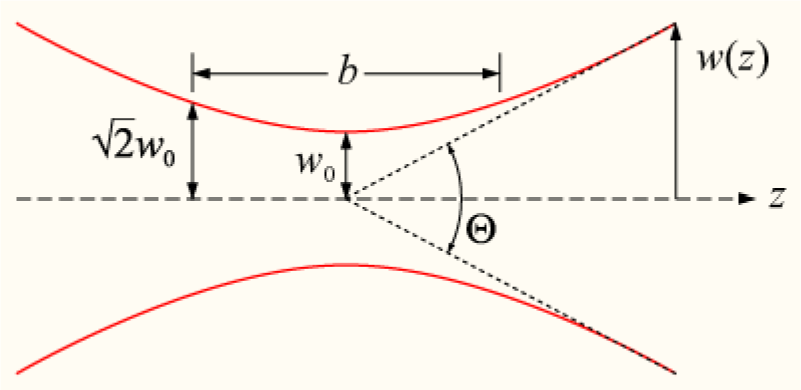

Figure 6: Schematic cross section of a Gaussian beam.