Speed of light notes/Additional comments

This lab contains concepts such as direct as a simple time of flight style (distance over time) measurement of the speed of light, but also contains some insight into the deeper behavior of lasers. We need to ask "what is it exactly that we are following moving some distance in some time"? What was moving?

The HeNe Laser we use is considered a continuous wave (CW) Laser. If I sat and watched a perfectly smooth stream of water and took a video, I would have no way to measure the speed. I would need to see a ripple, or a grain of sand travel with the stream of water, or I would need to see it break up into drops to measure the speed of a given drop. At the very least I would need to see ripples of some kind moving.

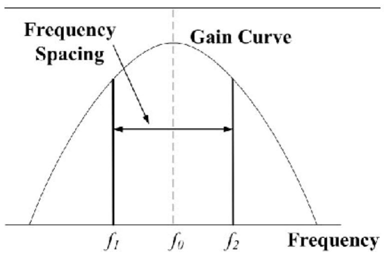
In order to measure the speed of light, I must observe a transient effect (change in intensity of the photon stream). Even though the HeNe appears CW to our eyes—there are transient effects on a nano-second scale. The reason for these transient effects is that the laser is "Lasing" on several modes at once. What does Lasing mean? What are modes?

LASER=Light Amplification by Stimulated Emission of Radiation

If I somehow give a medium (here HeNe gas) energy to excite atoms/molecules, and then insert light at just the right wavelength---all the energy will follow the "seed photons" and dump there energy in synchronicity with the seed photons. In a HeNe the energy is input as an electrical discharge. The seeding is accomplished using a Laser Cavity. This consists of two very well aligned mirrors to help reinforce some of the light emitted from de excitation following the discharge. The energy comes out differently than it went in. Energy is "stimulated" to emit by that seeding process---and comes out on one specific wavelength. The nature of the HeNe gas and the intrinsic energy levels select a rough wavelength of operation of the laser, but the cavity as some wiggle room to tweak this.

The reinforcement of light at one specific color is accomplished by a laser cavity with mirrors separated by a distance L. The frequency of a supported mode might be $f=n*(c/2L)$- where n is an integer (often quite large depending on L)--which is exactly like standing waves on a string. However, some geometry effects and some energy level bandwidth actually allows for several different modes to generate stimulated emission---modes n, and maybe n+1, and n+2, and we could count downward also. For the longer tubes we use in our HeNe's it is possible to get something like 5 or 6 modes to all "Lase" at one time. Each mode with different n may be slightly more or less favored depending on the geometry of the laser cavity, details of the discharge, changes in index of refraction of the gas, thermal cycling, and other unstable issues. This is a subtle effect.

A Gain Curve is the name given to the "envelope" that determines which modes is most favored or centered (best for lasing). If the medium and laser cavity allow for gain (one photon in, more follow it coming out)—then lasing occurs on that mode. I've included a picture below—but again for our system—there are probably 5 or 6 modes all achieving lasing threshold (gain above 1).



The spacing between modes is c/2L. These are the standing wave—or longitudinal modes of the laser cavity. Now, there are minor transverse mode effects that change the simple formula from c/2L—but we'll ignore those effects for now. What you need to know is that when two frequencies are mixed like n c/2L and (n+1) c/2L are mixed—the two frequencies form a beat---at the difference. When there are 5 or 6 modes all lasing, then modes 1,2 and 2,3, and 3,4, and so on—all differ by c/2L. There are other frequencies too---those that correspond to modes 1,3 or 2,4 or 3,5 and so on. These have frequency spacing of 2*c/2L –or simply doubled. So we get beats that contain both c/2L and also 2(c/2L) and also 3(c/2L) and so on.

If we had a really nice fast, 100k$ instrument called a spectrum analyzer with really good specifications –then we could observe these separated frequencies by simply Fourier analyzing the signal we obtain on our scope (sort of---remember we need averaging too). We don't have that instrument.

Even though our laser is unstable, and the gain curve tends to drift around right and left a bit as it warms or cools, or as power supply voltage changes---we always have that fundamental mode spacing beating. It is the biggest part of our signal. So we are able to see pulses come out of our CW laser because the long tube length means we have enough modes beating together that c/2L is always the biggest Fourier component of the signal—and those peaks are pretty well formed always (after averaging 512 shots).

It is typical for speed of light labs to use a diode laser and some carefully constructed electronics to make very fast pulses. The electronics can be tricky (sub nanosecond), and the amount of light (weak) can be a problem. The Diode lasers are unstable also, but usually only lase on one mode (n c/2L)---but for diodes L is very small---the modes are far apart, and instability leads to mode hops rather than beats. Anyway—Diode lasers work fine for speed of light if you want to construct your own (you thought I was gonna say light saber) pulser to rapidly turn on /off the diode. Such experiments usually settle for microsecond pulses, send light down a long fiber optic (1000 ft or so) and just barely measure a 50% number on the speed of light. There are other ways to modulate the light to give a fast transient.

Another method is to use an external laser cavity to change the mode structure, examine the mode structure and obtain the speed of light—but again, this typically requires expensive equipment.

Be impressed. We are able to observe speed of light by taking advantage of a natural process in the laser. I observed this by looking for another speed of light method ~20 years ago. Oops---I found this method by mistake. The only two requirements here are a long enough laser tube to have many closely spaced longitudinal modes under the gain curve, and a sufficiently fast oscilloscope.