Physics 80 Lab Manual

February 23, 2019

Chapter 1

The Speed of Light

1.1 Pre-lab Calculations

1) What is the definition of the meter ? What is the exact value of the speed of light in vacuum?

2) How long does it take a light to travel a length of 1m? Using the time you just calculated and assuming that the uncertainty in the length measurement is 0.01m, calculate the uncertainty in the speed of light you would obtain if you were to use this measurement. Using again the time you just calculated and assuming that the uncertainty in time measurement is 1ns, calculate the uncertainty in the speed of light you would obtain if you were to use this measurement. Which uncertainty is larger?

3) Light is slowed down in transparent media such as air, water and glass. The ratio by which it is slowed is called the refractive index of the medium. Calculate this speed of light in air if the index of refraction is 1.0003. Calculate (in %) how far off is speed of light in the air from the speed of light in vacuum? Assuming that in our setup we are aiming at few % accuracy is this correction relevant for us?

1.2 Introduction

In this lab, you will measure the speed of light in the air by measuring the time between sending and receiving a flash of light over a known distance, evaluate statistical and systematic uncertainties and compare it to the known value. In the process, you will also learn how to use your scope to make time measurement.

1.3 Collimated pulsed laser diode and photodiode

The flash of red light is created by a pulsed laser diode, a device very similar to a laser pointer, except this laser is switched on and off (pulsed) at a very high rate: 1 million times per second (1 MHz). The laser diode is housed in green plastic box (see Fig. 1.1) and powered by a fixed +5VDC from your bench-top DC power supply (see simplified circuit diagram in Fig. 1.2). Whenever laser diode is pulsed a "trigger" pulse is sent to the oscilloscope via BNC cable. The pulsed beam of red light is collimated by a small lens (housed inside the green box), bounced off of a mirror and detected by a fast photodiode detector. The photodiode is housed in green plastic box and powered by one of the two variable outputs of the same power supply. The photodiode needs +(15-18)VDC (see simplified circuit diagram in Fig. 1.3). **Do not set the voltage for photo diode higher than 18VDC as you might damage the circuit.** After amplification a "signal" pulse is also sent to the oscilloscope via a BNC cable. Both BNC cables might need ferite chokes installed close to the boxes to suppress the high frequency noise in the setup. The time difference between the two pulses Δt can be measured as a function of the path length of light L between the laser diode and photodiode.

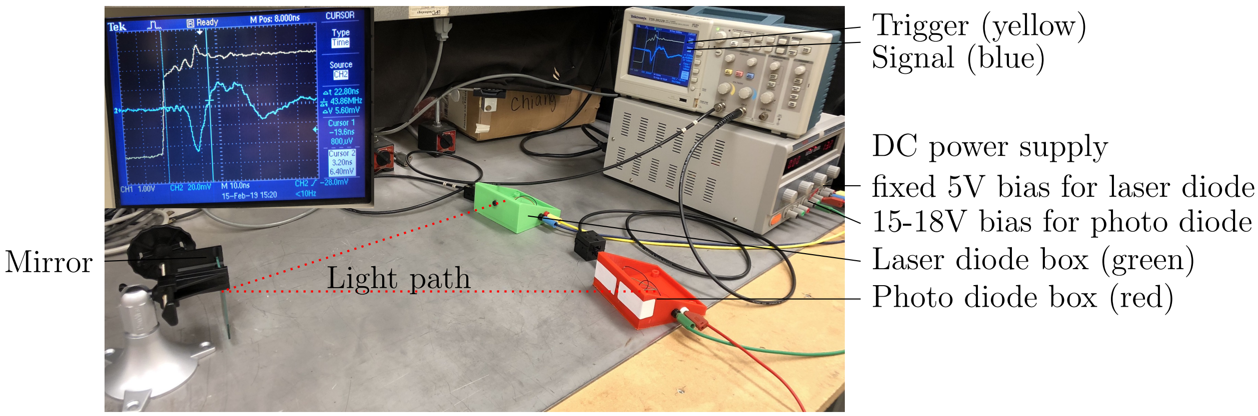

Figure 1.1: The speed of light experiment assembly. Insert shows an example of the trigger and signal traces.

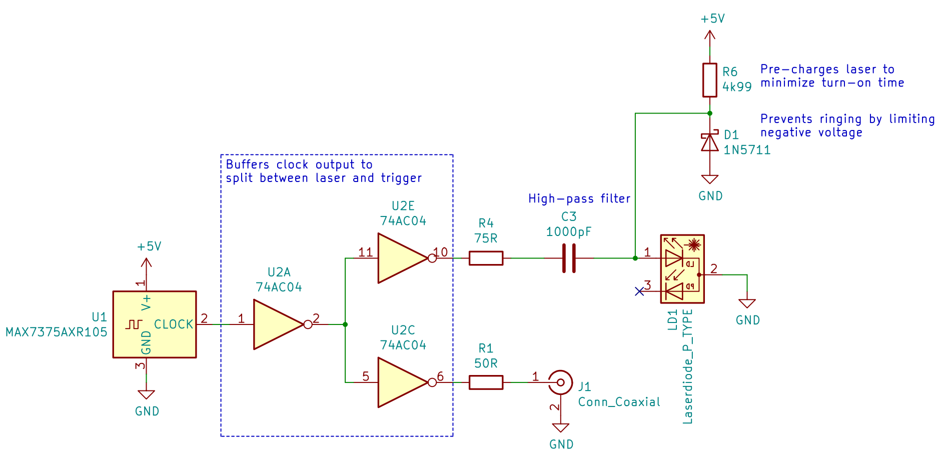

Figure 1.2: Simplified circuit diagram for pulsed laser diode.

1.4 Data taking

Arrange the setup similar to what is shown in Fig. 1.1. Place the laser diode and photodiode box nearby each other and power them. Connect their outputs to the oscilloscope. Trigger the scope using trigger channel. Adjust time/division settings on your scope. Set the scope in AC coupling

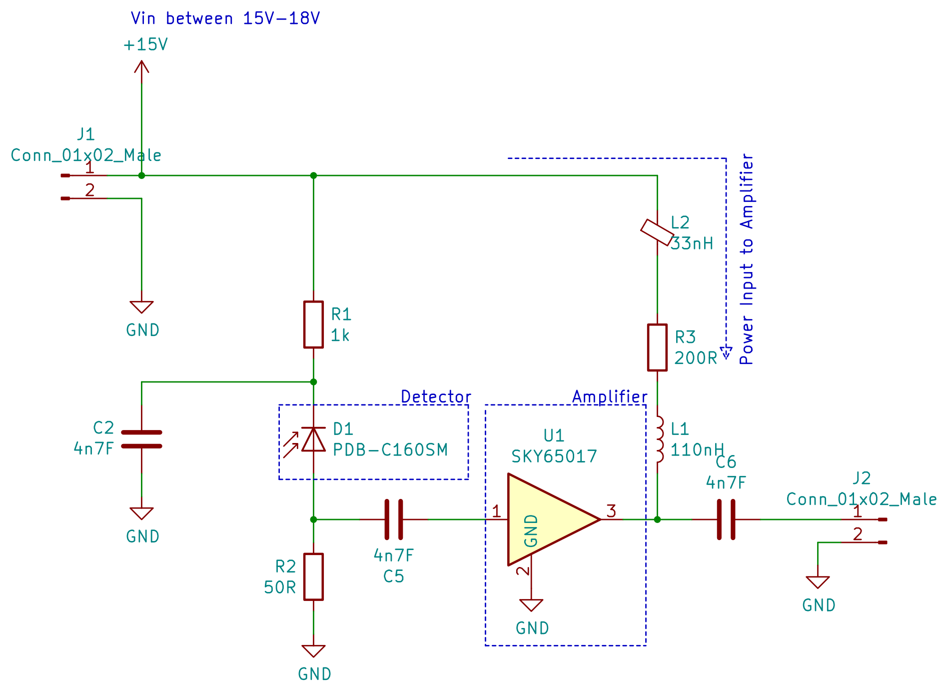

Figure 1.3: Simplified circuit diagram for photodiode.

mode and no filtering. You should see a trigger trace and empty signal trace with some noise. Set a mirror at some arbitrary distance away from the laser diode and photo diode. For ease of alignment keep the distance above 10cm and below 70cm. Try not to touch the surface of the mirror as you might degrade the quality of your signal. Adjust the laser, mirror and detector so that the beam goes from the laser to the mirror and then back to the detector. The laser light is intentionally kept at low power and is not visible in the full daylight. Even so, **do not look straight at laser diode.**

To align the system try a following technique: place a piece of paper in front of the laser diode box; locate the beam and track it to the mirror; the laser beam spot should be fairly focused and if not the lens needs to be adjusted (call the TA); adjust the position of the mirror to have the laser beam spot far away from the edges; with the piece of paper track the path of the light after it is reflected; adjust/rotate the mirror stand to point the laser beam at the photodiode; you might want to first adjust the beam to be at the correct height and then guide it into the opening of the photodiode box; use the white paper glued to the front face of the photodiode box for tracking the beam when it is close to the opening; look at the traces on the scope and optimize the laser/mirror/photodiode alignment and scope controls to give the strongest, clearest signal. If you aligned the system reasonably well you should see signal traces starting with the negative peak (amplified photocurrent from the photodiode), slow recovery due to capacitor at the output of the photodiode circuit and some overshooting and signal reflection due to not finely tuned circuit when dealing with very fast pulses (see Fig. 1.1).

Use the scope cursors to measure the time difference between the laser's trigger trace and the photodiode's output. The pulses that you see on the scope will have many wiggles. **You will need to adopt a consistent method for picking the "same" points on the different pulses that you will use to estimate the time difference.** For example, you can measure time difference from the point where trigger trace crosses zero and where the signal trace crosses zero. You can also pick some other points but choose the parts on the traces where you see the fast change. You will also need to estimate the reproducibility in these measurements and obtain an uncertainty for them. Perform the measurement at least twice i.e. one lab partner should perform the measurement in one time/division settings of the scope and the other in slightly changed time/division settings. You might observe that sometimes there is no signal trace for a given trigger even when the system is aligned. You can either select good pulses in a single trigger mode when triggering on the trigger trace or you can trigger the scope using the signal trace and use a normal trigger mode (or even persistence mode). Measure (with a rope and tape measure) and record the distance L traveled by the beam from the laser to the mirror to the photodiode. Perform length measurement at least twice (once per partner) and record these numbers in your log book.

Measurement 1: In your log book: 1) sketch the trigger and signal traces and indicate your chosen points you used to measure the time difference, 2) record time difference measurements and settings of the scope, 3) length measurements, 4) calculate average time difference and estimate its uncertainty, 5) calculate average distance and estimate its uncertainty, and 6) calculate the speed of light from your single point measurement together with uncertainty. How does your measured value compare to the known value for the speed of light? What is percent error (the difference between a measured and known value, divided by the known value, multiplied by 100%)? Do not be alarmed if it is quite far away. This is because we did not calibrate the apparatus. The propagation of the signals down the cables and through the rest of the electronics actually does take a significant time. You can confirm this by measuring the trigger and signal pulses when the laser and detector are pointed right at each other with almost no distance between them. So one wants to either calibrate the apparatus or design a experiment and data analysis so that this part of the total time difference can be extracted from the results. This effect should be a constant since it depends on the cables and electronics, and not on the distance that the light travels. So, what happens if we take several data points and fit the trend? **This is a first sign-off point for the lab.** Discuss with the TA your measurement 1.

1.5 More data taking

Repeat the process to obtain in total five different values of distance and time difference together with the uncertainty in each quantity. **Measurement 2:** Record those measurements in the log book. Which measurement length or time difference has a larger percent uncertainty?

Plot 1: Plot the data with the x-values populated by the quantity with smaller uncertainty and y-values populated by the quantity with the larger uncertainty. Include x and y-uncertainties in the plot. Perform a straight line fit using `curve_fit` function. Include y-uncertainties in the fit. From the fit values calculate the speed of light together with its uncertainty. **This is a second sign-off point for the lab.** How does your measured value (from the fit) compare to the known value for the speed of light? How many "sigmas" is away? What is percent error (the difference between a measured and known value, divided by the known value, multiplied by 100%)? Discuss with the TA your measurement.

Measurement 3: What is the meaning of the intercept value different than zero? Use this intercept value to correct your speed of light estimate from Measurement 1 i.e. perform a calibration of the apparatus. Record it in the log book and compare it to the speed of light value you obtained from the fit.