Speed of Light — c

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I. Introduction

This lab will be an introduction to measuring high speed signals by measuring the speed of light c, and how to work with measurements made with offset data. The known value of the speed of light is $c \equiv 299792457$ m/s, we will attempt to replicate this quantity with essentially a ruler and a stop watch.

II. Layout and Equipment

To conduct this experiment, we will be using a solid state laser which is a Power Technology model LDCU5/5894. The output of this laser is held at a wavelength of $\lambda = 639$ nm. The laser output is pulsed and controlled with the Global Specialties model 4001 electronic pulse generator. This is because we need to trigger a fast oscilloscope (Tektronix TDS 2024B) with the output of the pulse generator to measure the time it takes for the laser to travel any distance. However, this causes a problem due to the fast signal propagating down a coaxial cable, it will reflect off the high impedance of the scope or the laser. To fix this, we must terminate the cable with a 50 Ω terminator. The specific apparatus we will be using is seen below.

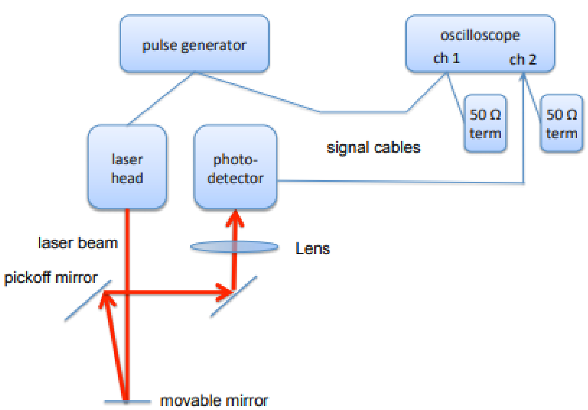

Fig. 1: The optical and electronic arrangement of our experiment. Credit: Dr. George R. Welch.

As seen in the apparatus, we will be reflecting the laser output by a movable mirror towards a pickoff mirror that will then bound the laser towards another pickoff mirror and then into a lens that will focus the laser onto a photo-detector (Thor Labs DET-10A), the output of which will be shown on the oscilloscope with our pulse generator.

III. Procedure

After setting up our experiment to the same apparatus of Figure 1, we must start by turning on the pulse generator to make a rectangular waveform with a frequency in the 1-100 kHz range with a *very high* duty cycle. We must also turn on the oscilloscope and photo-detector.

Next, we must use a key to activate the laser, this will shoot out a signal through the laser head that we will be able to visualize where it is by placing a sheet of paper in front of it. Doing out best to align the laser, we must then adjust the movable mirror, pickoff mirrors, and lens, so that our laser follows the path described in our apparatus towards the photo-detector.

If this is done correctly, we will receive a signal similar to what is shown below on the oscilloscope.

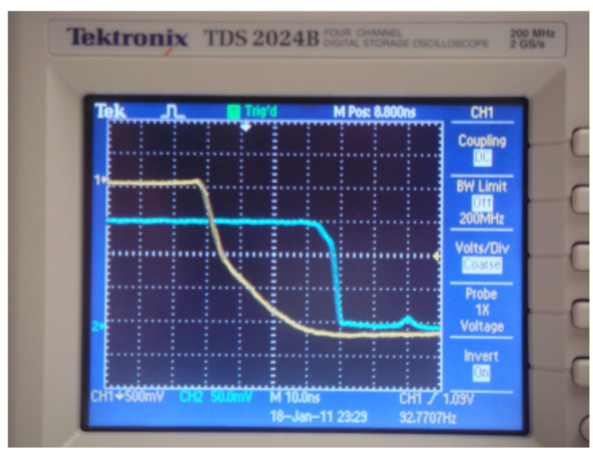

Fig. 2: Oscilloscope display when the experiment is working (measured 1.5 meters from the laser). Credit: Dr. George R. Welch.

The delay between the yellow and blue curves means there is a delay between when the laser is shut off, and when the light stops falling on the detector. If we measure from the center of the trace with the "cursor" function on the oscilloscope, we should see a delay of about 3 divisions, or 30 ns since the scope is set for 10 ns/division.

Once the signal is similar to that of Figure 2, we can begin taking measurements. We will do this by adjusting the movable mirror backwards and measuring the distance between the laser and the mirror. We can then measure the time delay on the oscilloscope by defining a ‘set position’ of our blue curve (the input from our detector) by using the “cursor" function on the oscilloscope, and writing down what that delay is.

We will continue this by setting the movable mirror back by another measured distance ensuring to measure from the same location on the laser to the same location on the mirror as we did for our firs data point for more accurate results. Then we will adjust the cursor on the oscilloscope to where our defined ‘set position’ moved to, writing down what the delay is.

We will then repeat this process until we have 8-10 data points ranging roughly 0.5m - 2.0m. To where we will then plot the delay time versus the position of the mirror. The slope of this line will be $2/c$, this is due to the laser having to travel roughly the same distance back to the detector, in a sense, doubling the length of travel time.

IV. Data/Analysis

When we were conducing the experiment, we defined our ‘set position’ to be the point after where the blue curve drops suddenly, resulting in a gain of roughly 0 - 2 mV. As seen in the image below, it is the rightmost line, highlighted as “Cursor 2" on the oscilloscope.

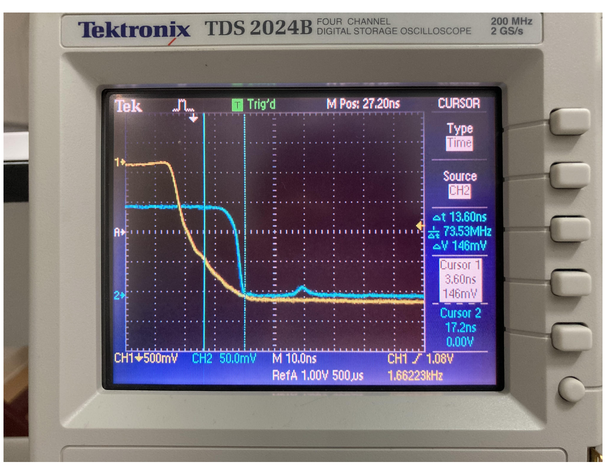

Fig. 3: Oscilloscope display showing where we defined our ‘set position’ (measured 1 m from the laser).

We took a total of 10 measurements held at different positions, our data along with the best fit line could be found in figure 4.

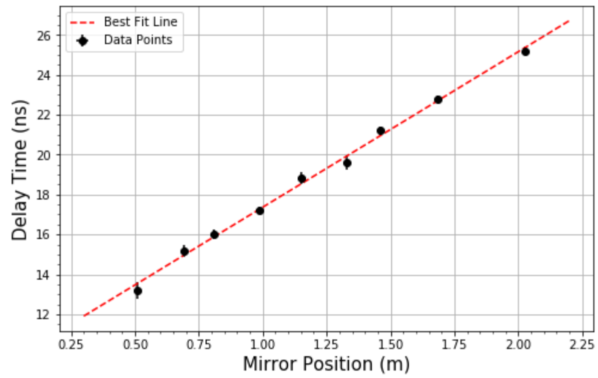

Fig. 4: Our data plotted as Delay Time vs. Mirror Position, alongside our best fit line.

When we were finding the slope of our best fit line, we also found the residuals of our data. These can be seen below in figure 5.

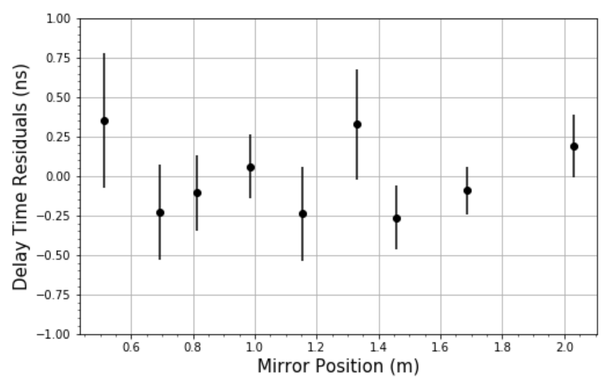

Fig. 5: The residuals of our data.

We found the slope of our best fit line to be 7.7988 ns/m, we can then let this value equal to $2/c$, where we would get the value of:

$$c = 256446909.805 \text{ m/s} \tag{1}$$

This measurement is 14.459% less than the known quantity of the speed of light (c = 299792458 m/s), which lies outside the uncertainty of our measurements.

V. Conclusion

We measured the speed of light to be $c = 256446909.805$ m/s, which lies outside the uncertainty of our measurements. We believe this could be caused by a multitude of factors. For one, we believe the slope of our best fit line is not exactly $2/c$.

As seen by our apparatus in figure 1, the laser travels slightly further than just twice the distance from the laser head to the movable mirror giving us a possibly more accurate numerator ranging from 2 - 2.5. If we replace the numerator in our slope = $2/c$ equation to 2.3, we would receive a measured value of c = 294913946.276 m/s, which would be only 1.627% less than the known quantity of the speed of light, well within our uncertainty.

Knowing this we could improve this experiment by further measuring the distance the laser travels after bouncing off the first pickoff mirror, until it hits the photo-detector, and including this measurement when deciding our numerator in our $2/c$ ratio.

Furthermore, when addressing the uncertainty we encountered in taking our measurements, we found that human error could be another factor. We had to adjust the cursor onto our 'set position' on our oscilloscope by hand every time we adjusted the movable mirror. This led us to having to use the gain measurement as our only frame of reference in ensuring we are over the correct 'set position'. We could remove this uncertainty by more accurately measuring the same 'set position' on our oscilloscope.