Modern Physics Lab

Speed of Light

Purpose of the experiment

- Familiarize you with advanced experimental techniques and equipment.
- Determine the speed of light through an optical fiber.
- Extrapolate data to determine the speed of light in a vacuum.

Background Info

The speed of light is a fundamental constant that has far reaching implications throughout physics. Electromagnetic waves have a velocity of 3 x 10^8 m/s in a vacuum. The speed is independent of the frequency and amplitude of the wave. However, the speed of light can change depending on the material. The speed of light is slower than 3 x 10^8 m/s for any media other than vacuum.

Dane Ole Christensen Römer performed the first measurement of the speed of light in 1676. He calculated the orbit of Io around Jupiter and, using Io eclipse observations, he determined the speed of light to be 2.3 x 10^8 m/s. Not bad for a first try! Later, in 1849, Armand Hippolyte Louis Fizeau constructed a rotating toothed wheel to measure the speed of light. A pulse of light was sent through the wheel to a distant mirror. By adjusting the rotation of the wheel, the returning pulse could be blocked by a tooth or allowed to pass. His experiment arrived at a value of 3.15 x 10^8 m/s. During this same period James Clerk Maxwell brilliantly summarized the world of electricity and magnetism into a series of equations. Using his work, he theoretically derived the speed of light as

$$c = 1/\sqrt{\varepsilon_o \mu_o}$$

showing that the speed of light depended on two fundamental electromagnetic constants. Now experimentalists had something to compare their results with.

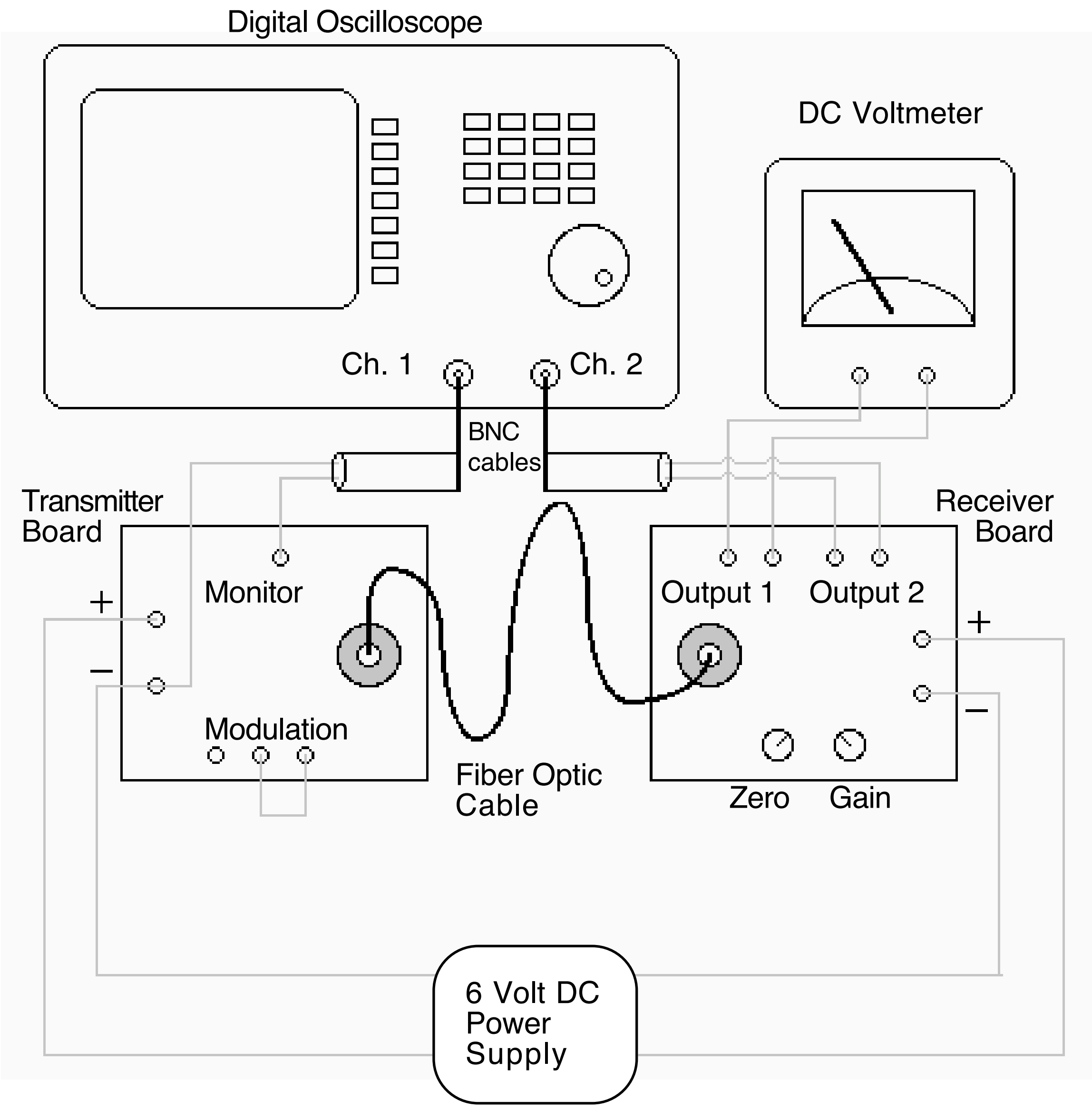
The Equipment

This experiment measures the speed of light in a plastic optical fiber (index of refraction n = 1.49). A reference pulse is fed into a light emitting diode (wavelength = 630 nm) at a rate of 300 kHz. This causes the light to rapidly blink on and off. These pulses travel through an optical fiber and are detected. The time delay between the reference (Channel 1) and the detected (Channel 2) signals gives a measure of the speed of light over a known path length.

The experiment is complicated by the very short times involved and delays which occur in the electronics. As a result, we need to compare the difference in delay times between two lengths of optical fiber to remove the electronics effects.

You are provided with three lengths of optical fiber:

0.275 meters (+/ - 1 mm)
5.142 meters (+/ - 1 mm)
20.00 meters (+/ - 3 mm)


Digital Oscilloscope
DC Voltmeter
Ch. 1
Ch. 2
BNC
cables
Transmitter
Board
Receiver
Board
Monitor
Output 1
Output 2
+
–
+
–
Modulation
Fiber Optic
Cable
Zero
Gain
6 Volt DC
Power
Supply

Prelab

- What is "index of refraction"? Give both a mathematical definition and a description.

- A pulse of light is sent down 50 m of dense flint (n = 1.66) fiber optic cable. It is discovered that the pulse is received at the other end at a time of 1.10 μs (some of this time is due to delays in processing the pulse through a circuit and some is due to travel time down the cable). Another pulse of light is sent down a similar cable of length 1 m and is received at a time of 0.83 μs. Show that the speed of light in vacuum is given by:

$$c = \frac{n(L_2 - L_1)}{t_2 - t_1}$$

What is the speed of light in vacuum calculated to be from these data?

- Find an expression for the uncertainty in the speed of light for this experiment.

The Lab

The goal: To measure the speed of light through a fiber optic cable. Use this information to extrapolate the speed of light in a vacuum.

Remember to include the uncertainty in your measurement and label all units clearly

Data Collection

- Connect all cables as show in the equipment diagram. Turn on the oscilloscope and meter to allow them to warm up and stabilize.

- The oscilloscope is a crucial part of this experiment. You will likely need to to work with it for a while if you are not familiar with it. If you are using the HP 54502A digitizing oscilloscope, you will mainly be working with the gray colored keys. The vertical row of keys just to the right of the display is used to select various options on menus which will appear on the display. You will also need to use the "TIME BASE", "CHAN", "TRIG" and "ΔT ΔV" buttons under the MENU section of buttons. The large dial on the lower right is used for changing the value of selected options and moving the cursors. The other button that might be useful is the white RUN/STOP button in the top row. You can use this to freeze the screen while making a time delay measurement.

- To set up the oscilloscope, start with the CHAN button. Make sure that both Channel 1 and Channel two are ON. They should both be set to DC with no offset. The 1 MΩ inputs seem to work better. Channel 1 should be set to 1 V/div. and Channel 2 should be 2 V/div. Next use the TIME BASE button and set the time base to 0.5 μs/div (500 ns/div). You may need to go even lower later in the lab to make a more accurate measurement. This may be noisy until the equipment warms up. Set the TRIG so that the scope triggers off of Channel 1. I found that an EDGE trigger worked pretty well. It does not really matter if it is on the leading or trailing edge. You may have to adjust the level of the trigger until the oscilloscope actually starts to trigger.

- Check that the transmitter LED is lit.

- Connect the longest fiber piece between the transmitter and the receiver. Make a note of the reading on the DMM. This value is a measure of the signal strength can be adjusted by moving the fiber up and down within the optical connectors. The speed of light should not depend on this intensity - but some of the electronics rise times do depend on it. As a result you will need to try to have the same reading on the voltage meter for each of the fiber pieces.

- Check the beam shape between the two pulses. Are there any changes in pulse length? If so, it may be better to use the leading edge of the pulse rather than the trailing edge.

- Use the cursors and the ΔV Δt button on the digital oscilloscope to measure the delay of the received signal compared to the reference signal.

- Change the fiber to the shortest piece. The use of the small piece is to determine the delay due to the electronics.

- Adjust the position of the fiber to achieve the same reading on the DMM. This will assure that the only change in the signal will result from the length of the fiber.

- You may also wish to do the intermediate length to have additional data to work with.

- I would recommend repeating the measurements at each length several times in order to improve your accuracy.

- Determine the travel time of light trough the optical fiber. This is found by measuring the time difference between the received signal of the small piece and the 20-meter length.

- Use the definition of velocity to determine the speed of light in the fiber. Calculate the speed of light in vacuum from this and compare this to the accepted value of 2.998×10^8 m/s.

- Use any and all error analysis to explain any discrepancies.