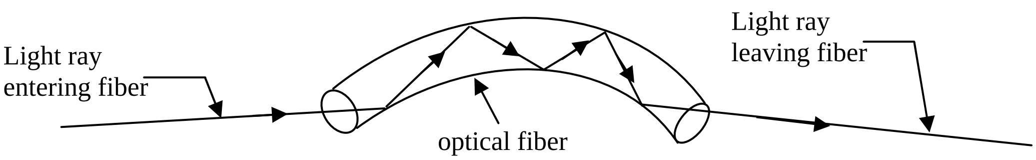
Optical Fibers and the Speed of Light

Purpose:
1. To observe the propagation of light through an optical fiber
2. To get experience measuring a very short time interval with an oscilloscope
3. To calculate the speed of light in a optical fiber.

Equipment: dual channel oscilloscope with two oscilloscope probes, pulse generating circuit board with AC adapter, 20 m optical fiber, 15 cm optical fiber

Introduction: To measure the speed of anything you need two things: a distance and a time. If something is traveling very fast (like light) you are either going to be measuring a very short interval of time or a very long distance. One of the very early (1676) experiments to measure the speed of light involved using the distance between the earth and Jupiter. Doing the experiment on the earth just wasn't practical then since there was no way to measure time over intervals as short as a few millionths of a second. The only problem with the Jupiter experiment was that at that time no one knew the distance to Jupiter very well! Today we have the luxury of being able to time extremely short intervals of time electronically and thus it is possible to measure the speed of light using a distance that is short enough to fit into a standard size laboratory room.



The other thing that we need to consider is that light will travel through a thin fiber of glass or plastic even when the fiber is not straight. This is because as the light travels down the optical fiber it is repeatedly reflected off of the walls of the fiber as shown in the above diagram. This is referred to as total internal reflection (see your text). We will send our light through such a fiber so that it won't spread out and become too weak to detect by the time it arrives at its destination. We will use 20 m of fiber wound loosely in a coil so that it will fit nicely on your desktop. In order to determine the speed of light as it travels down the fiber we need to know how long it takes for the light to travel the 20 m length. Since this is a very short amount of time, we will do the timing electronically with the use of an oscilloscope. An oscilloscope is useful whenever we want to look at an electrical signal (voltage) that is repetitive and changes rapidly with time. The basic idea behind the measurement is that we use a light emitting diode (LED) to produce and send a series of very short light pulses (light on, light off, light on, light off, ...) into the fiber and observe when they arrive at the other end of the fiber. Since the oscilloscope produces a graph of voltage vs time it is a simple matter of reading the graph to determine the time delay between when the light pulse enters the fiber at one end and when it leaves at the other end.

Procedure:

1. Just to get an idea of what sort of time we are trying to measure, calculate the time that it takes light to travel 20 m through empty space (vacuum). You can look up the speed of light in vacuum in your text. (Of course, in our experiment, the time interval will be a little longer because the light is slowed down when it travels through the plastic material that makes up the fiber.) Show your calculations here:

2. Your instructor will help you make the initial settings and connections between the circuit board that produces the light pulses and the oscilloscope**. Please treat this equipment with respect. It is expensive!**

3. The first thing that you need to see on the oscilloscope is the reference pulse that is produced by the LED on the circuit board. In order to do this, connect the Channel One probe to the blue test point marked "**Reference**" on the

circuit board. Connect the ground alligator clip on the probe to the ground just below the Reference test point. Similarly, connect the Channel Two probe from the oscilloscope to the blue "**Delay**" test point and its alligator clip to the ground just below this test point. See Figure 1.

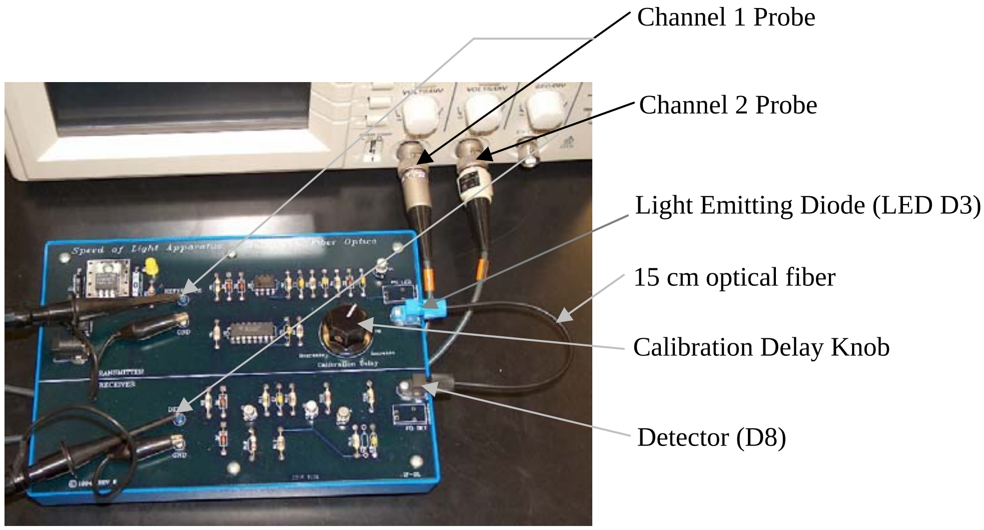


Figure 1—The circuit board with oscilloscope probes attached

4. Plug in the power adaptor into the wall (110 volts AC) and connect its output to the left side of the circuit board thus providing the DC power that runs the circuit board. At this point you should be able to see the red light produced by the LED by looking into the right side of the circuit board at the point marked "**D3**". Loosen the nuts on LED D3 and detector D8 (marked on the circuit board) and gently slide each end of the short 15 cm length of optical fiber completely into those locations. Hand tighten the nuts to secure the fiber. You will use this very short path as a way to calibrate your equipment. The time for light to travel through 15 cm is so short that we will treat it as zero and thus use this as a means of comparison when we send the light through the longer 20 m fiber. With the help of your instructor, observe the pulse when it leaves the LED (on Channel 1 of the oscilloscope) and simultaneously observe the pulse when it arrives at the detector (on Channel 2 of the oscilloscope). Adjust the volts per division for each channel and the seconds/div setting on the oscilloscope until the screen displays something like what is shown in Figure 2a. Remember that this figure shows a graph of light intensity versus time. Can you tell looking at the graph in Figure 2a which pulse happens earlier in time?

5. Turn the "Calibration Delay" knob on the circuit board until the peak of the arriving pulse occurs at the same time as the departing pulse. See Figure 2b. This calibrates your apparatus so that the two pulses appear to happen at the same time. This is very closely true since it takes very little time for the light pulse to travel through the 15 cm of optical fiber.

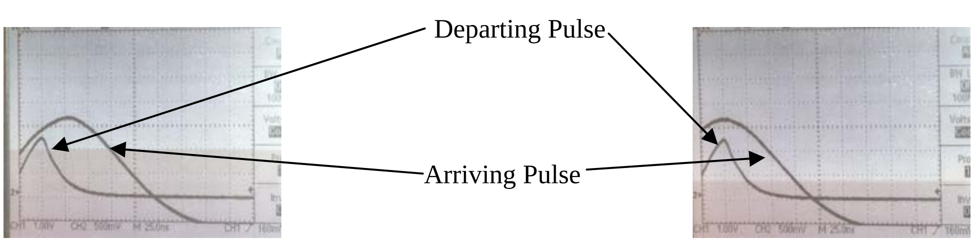


Figure 2a—Uncalibrated Pulses

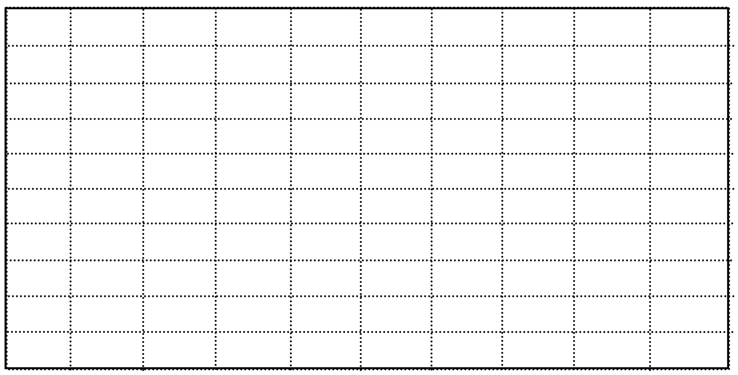
Figure 2b—Calibrated Pulses

6. Adjust the seconds/div knob on the oscilloscope so that the display has a scale of 25 ns/div. Carefully explain what a ns is. Give an explanation using words and also one using numbers:

7. Now that your apparatus is calibrated, it time to do the real measurement. Carefully remove the 15 cm optical fiber from its connections on the circuit board and return it to the plastic pouch. Put the 20 m long fiber in its place and gently tighten the nuts on the fiber as you previously did with the short fiber. Now you will measure the travel time of the light pulse as it travels through 20 m of the optical fiber. You should see the two pulses on the oscilloscope screen, but now they should be distinctly separated in time.

Make a sketch of the appearance of your two pulses here. Be sure to put a scale on each axis of the graph.

Voltage (Volts)



Time (ns)

Using the time (horizontal) scale determine the time between the peaks of the departing pulse and the arriving pulse in nanoseconds. Record that time in the space provided. Be sure to include the units.

Time Interval between peaks = [ ]

Now it is time to calculate the speed of light from the equation for speed. Fill in the numbers and do the calculation with units:

$$\textbf{Speed} = \frac{\textbf{distance}}{\textbf{time}} = \underline{\hspace{4cm}} = \boxed{}$$

Speed of Light in the fiber

8. Wrap up questions (Write your answers on the back of this page.):

   1. Comment on the accuracy of your method for determining the speed of light in an optical fiber. What were sources of error in your experiment?

   2. Can you deduce the speed of light in vacuum from the number that you have found? Do a little background research and see if you can come with a good answer for this. Hint: Treat the fiber as being made of glass (silicon dioxide).