PHYS 1301

Speed of Light in a Cable

Introduction

Although it may not appear to be so, the speed of light is not infinitely fast but a measurable quantity. It is an amazing fact that, under suitable conditions, every one in the Universe would measure the same value for the speed of light $c = 3 \times 10^8$ m/s in empty space (vacuum). That this is so has profound implications and you will see some of these implications when you learn about special relativity in lecture. For now, we will perform a simple measurement of the speed of light in an electrical cable. When we speak of the ”speed of light”, it is important to understand that what we mean by *light* encompasses much more than what call “light” when we look at, say, a light bulb. Light is a so-called *electromagnetic* wave that means, first of all, that it is wave-like in nature and secondly, that it is composed of oscillating electricity *and* magnetism. It turns out that these two waves oscillate at right angles to one another as they travel through space. It is also the case that both waves are synchronized in the sense that the crests of the electric wave occur at the same time as the crests of the magnetic wave and similarly for the troughs. The distance between successive crests of either the electric wave or the magnetic wave is the *wavelength* of the light wave. The speed of light is simply the distance equal to a wavelength divided by the amount of time it takes for the crests of the light wave to travel that distance.

We will measure the speed of light using a very low frequency (vibration rate) radio wave. We will launch this wave down two cables that are identical except for their length. The radio wave will travel down the length of the shorter cable in a shorter period of time than it takes to traverse the longer cable. By measuring the transit time difference for the two cables and knowing the cable length difference, we will be able to measure the speed of light in a cable. It will turn out, for reasons that are not important here, that this speed is somewhat smaller than the speed of light in vacuum.

Equipment

Oscilloscope, waveform generator, coaxial cables, tee and barrel connectors, meter stick.

Procedure

1. Verify that the oscilloscope is turned on. Several small green lights on the oscilloscope panel should be illuminated. If it is not already done, connect one end of the short cable to the *waveform* generator via a tee barrel. The instructor will show you how. Connect the other end of the same cable to the input of oscilloscope channel #1. Again, the instructor will assist you.

2. If it is not already done, connect one end of the long cable to the waveform generator via the same tee barrel. Connect the other end of the cable to input channel #2 of the oscilloscope. The instructor will assist you. (The instructor will set the waveform generator so that it is oscillating at a frequency 50 kHz (50,000 vibrations per second) and producing either a `square' or `triangular' wave.)

3. Adjust the "time sweep" on the oscilloscope so that each centimeter on the screen's horizontal axis equals 10 μs. (1 μs = 10^{-6} sec = 1 millionth of a second.) The instructor will assist you. Look at channel #1. Pay attention to the height and width of the trace features in units of squares. **Question 1.** On graph paper, sketch what you see on the oscilloscope for channel #1. Label the horizontal scale on your sketch so the reader knows how long in time the features are that she is looking at.

4. Adjust the time sweep on the oscilloscope until each centimeter equals 5 μs. **Question 2.** Now sketch again on graph paper what you see and again indicate the duration of key features. How does the oscilloscope display for channel #1 compare to the one for the previous sweep setting?

5. Adjust the time sweep on the oscilloscope so that each square is worth 2 μs, then depress the small "x10" button found beneath the knob labeled HOLDOFF (located along the top row of knobs). Each square is now worth 2/10 μsec or 200nsec. (1ns = 10^{-9} sec = 1 billionth of a second.) Measure the time difference between two similar points or features on the waveforms for channel #1 and channel #2. The top row of knobs allow you to move the waveforms up/down independently and left/right together; this will make comparison easier. **Question 3.** Sketch what you see from channels #1 and #2 on the same graph and label the time difference. **Question 4.** What is the <u>difference</u> in cable lengths for the two cables? Take any measurements necessary.

6. Now connect a second long cable (borrow from another lab pair if necessary) to yours to make a very long cable connected to channel #2. The following questions should be answered by each group using their own oscilloscope/generator. **Question 5.** Sketch what you see now on the oscilloscope. Indicate the duration of key features. **Question 6.** Again, measure the time difference between similar features for the two waveforms. What is this time difference? **Question 7.** What is the very long cable length? Take any measurements necessary.

7. **Question 8.** Using the difference in cable lengths for part 5, calculate the speed of light in the particular kind of cable we used. **Question 9.** Repeat this calculation for the very long cable used in part 6. **Question 10.** Average these two values and write down your estimate for the speed of light in a cable of the type we used today. Express your answer in scientific notation and include an uncertainty.

Conclusions