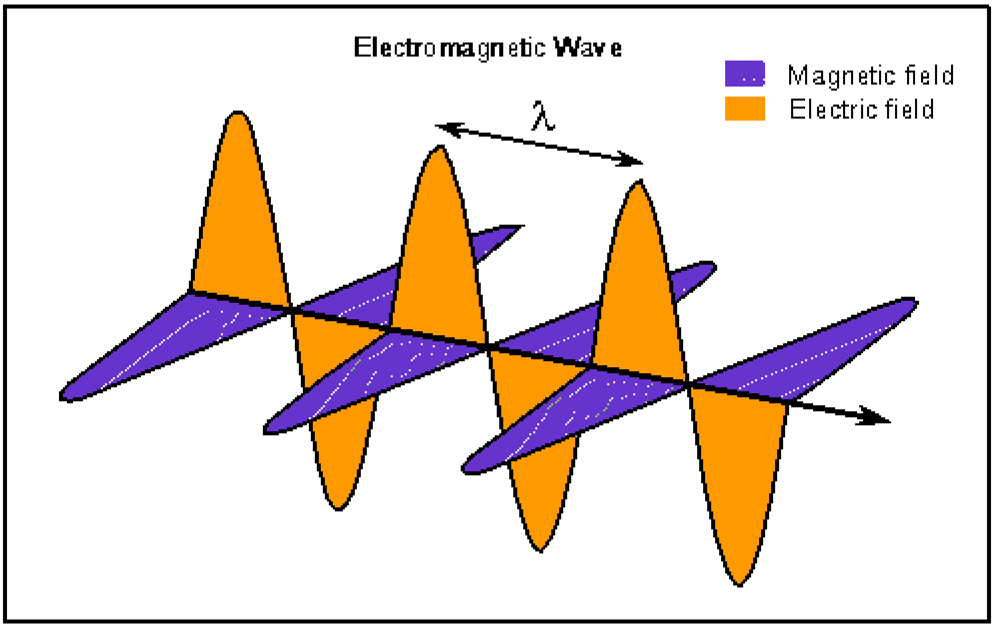
PHYS 1301

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 simple measurements to obtain 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 we call “light” when we look at, say, a light bulb. Light is a so-called *electromagnetic* wave. This 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 but 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, denoted λ. The speed of light is simply the distance λ divided by the amount of time it takes for the crests of the light wave to travel that distance.



We will calculate 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 calculate 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.

The right hand picture shows an oscilloscope (right), waveform generator (left), connected by a short cable. The generator is sending a triangular “saw-tooth” electromagnetic wave through the cable to the oscilloscope which displays the wave shape in time.

Procedure & Questions

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.

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.)

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.

> **Question 1.** On graph paper, sketch what you see on the oscilloscope for channel #1 only. Label the horizontal scale on your sketch so the reader knows how long in time the features are that she is looking at. (The vertical scale is not important in this experiment).

Adjust the time sweep on the oscilloscope until each centimeter equals 5 μs.

> **Question 2.** Now sketch again on graph paper what you see for channel #1 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?

Adjust the time sweep on the oscilloscope so that each square now worth 2/10 μsec or 200nsec. (1ns = 10^{-9} sec = 1 billionth of a second.) Compare 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.

Look for a sharp feature that is common to both channels and use these points to measure the time delay of one channel relative to the other.

> **Question 3.** Sketch what you see from channels #1 and #2 on the same graph and label the time delay.

> **Question 4.** Estimate the <u>difference</u> in cable lengths for the two cables. Take any measurements necessary using a meter ruler.

Now connect a second long cable (borrow from another lab pair if necessary) to the first one 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 delay between similar features for the two waveforms (short cable channel #1 and very long cable channel #2).

> **Question 7.** Estimate the very long cable length. Take any measurements necessary.

> **Question 8.** Using the difference in cable lengths from Question 4, calculate the speed of light in meters/sec in the particular kind of cable we used.

> **Question 9.** Repeat this calculation for the speed of light using the difference in cable lengths from Question 6.

> **Question 10.** Why do you expect the two values for the speed of light to be similar? Average these two values and write your estimate for the speed of light in scientific notation on the blackboard.

> **Question 11** Estimate the uncertainty on your final value for the speed of light in the cables, and quote a final answer (Average Value ± Uncertainty) m/s. Remember, the Uncertainty should be written to only 1 significant figure and the Average written to the same number of decimal places as the Uncertainty.

<u>Conclusions</u>

Write a paragraph explaining the key things you *learnt from your data*, quoting data to support your reasoning. Do not be vague. Do not describe procedure or what you learnt about or learnt how to do.

(Look at the example lab report on the website if you are unsure what kind of thing to write here).