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SPEED OF LIGHT

Advanced Laboratory, Physics 407,

University of Wisconsin

Madison, Wisconsin 53706

Abstract

The purpose of this experiment is to measure the velocity of light. Pulses from a light emitting diode are sent over both a long and a short path and detected in a photomultiplier. The velocity of light can then be determined by knowledge of the light path lengths and the frequency of the light pulses.

Method

A light emitting diode (LED) is placed at the focus of a telescope and is pulsed at a constant frequency f. The light is sent by two paths to a second telescope and focussed onto a red sensitive photomultiplier. The path length L can be directly measured.

An oscillosocope is used to inspect the two pulses produced by the photomultiplier for each LED pulse. The frequency of the LED pulse is increased until the light pulse following the short path arrives at the photomultiplier at the same time as the previous light pulse following the long path.

The frequency f is measured by counting the pulses in a precision frequency counter. The period T then corresponds to the time required for a pulse to travel the difference in length L between the long and short paths and the speed of the light pulse is given by:

$$c = \frac{L}{T} = Lf \quad .$$

The statistical fluctuations in the number of photons detected per pulse causes the pulse shapes to vary. This limits the accuracy with which the pulse positions can be mathced. The apparatus uses the brightest LED which is available since the ratio

$$\frac{\text{signal}}{\text{fluctuations}} \propto \frac{1}{\sqrt{\text{signal}}} \quad .$$

For the same reason, it is important to align the apparatus to maximize the light reaching the photomultiplier.

A reference describing a similar method is J. Vanderkooy & M.J. Beccario, American Journal of Physics, Vol. 41, page 272, February 1973.

Apparatus

Pulse Generator—(General Radio 1340). This is used to generate positive pulses of up to 8 volts to 3 devices:

(a) the scope external trigger,

(b) the counter inputs, and

(c) the LED driving circuit (this has an internal termination).

Counter. The counter is a Hewlett-Packard Model 5314A Universal Counter. It has a frequency range of 10 Hz to 10 MHz with a resolution of 1 Hz.

LED Driver and LED. The red light emitting diode is an HP 5082-4486. It has maximum emission at wavelength of 655 nm. The driving circuit is intended to deliver a triangular current pulse to the LED with a maximum of 1 Amp and a full width at half-max of 10 nsec. The pulse height is about 4 volts.

The first stage is capacitively coupled to the second stage. The e^{-1} decay time of the coupling is intended to be about 100 nsec so that the LED and output transistors are protected against accidental long pulses. The resistive loading of the capacitor is due mostly to the base currents of the output transistors. The output is non-symmetric push-pull intended to match the non-linear LED resistive loading and also the LED capacitance of up to 500 pF.

The pull-up transistor has the greatest load and runs hot but can handle 7 watts if necessary. The leads carrying the suddent LED current are kept very short. This includes the transistors and bypass capacitor.

The LED output may be red or yellow. The red LED can be used with a red filter but has a lower light output than the yellow. The yellow LED cannot take advantage of a yellow filter because the flourescent lighting background is largely yellow.

Telescope—(Edmunds 3 inch diameter mirror, $f = 700$ mm). The first telescope has the LED mounted in the eyepiece position. The second telescope has an RCA photomultiplier mounted in a similar position. Both telescopes can be adjusted for angle vertically and horizontally by adjustments at the mirror end of their mounts. The photomultiplier can be unscrewed and replaced by the regular eyepiece.

Photomultiplier. The photomultiplier is a Hamamatsu Type R928. This is a 9 stage photomultiplier with a multialkali (Na-K-Sb-Cs) photocathode which is more red sensitive than most photomultipliers. The quantum efficiency of the photomultiplier is about 8% (100 photons cause an average of 8 photo electrons) at $\lambda = 650$ nm. A red filter is placed in front of the photocathode to reduce the sensitivity to room and corridor lighting.

The R928 PM has a transmit time of about 22 nsec at -1000 volts and a risetime of 2.2 nsec. The photomultiplier is expensive, so treat it gently. The absolute maximum voltage is -1250 volts.

The photomultiplier base is wired to deliver negative pulses directly into a coaxial cable. The 50 ohm cable should be terminated with 50 ohms at the oscilloscope.

High Voltage Supply. This delivers a regulated negative high voltage through the white coaxial cable and high voltage BNC connectors. It can supply up to 2.5 mA at 2.5 kV.

Large Mirrors. These may be adjusted with finger screws. The alrge mirrors and telescopes are mounted on antivibration platforms which, in turn, are mounted on very heavy steel mobile tables.

Small Mirros. These are mounted on adjustable bases so that they may be easily aligned and then misaligned so that the reference pulse is the same height as the long distance pulse.

Low Voltage Supply—Heathkit IP-28. This provides +10 volts for the LED driver. Take care to use only the 10 volt scale (not 30 volt!).

Procedure

Place a large black piece of cardboard behind the two mirros to reduce the background due to the lightly painted wall.

Aligning the Optics. The idea is to adjust the telescopes and mirrors 1, 2, and 3 so that each telescope is viewing the other. First unscrew the photomultiplier from telescope 2 and insert the eyepiece.

The alignment may be carried out by first obtaining an image of mirror 3 centered in the field of view of telescope 2, then removing the mirror cover and adjusting mirror 3 to get a centered image of mirror 2, then uncovering and adjusting mirror 2 to get a centered image of mirror 1, and finally getting an image of telescope 1, centered in the field of view of telescope 2.

Now insert the LED in place of the eyepiece in telescope 1 (it will probably be already mounted), and use the brightest conditions for the pulsing; Frequency = 5 MHz, Pulse length = 100 nsec, Pulse voltage = +10 voltes and tunr on the +10 volt supply for the LED Driving Circuit. by gently adjusting the direction of telescope 1 with the LED, obtain the best image of the red light in the eyepiece of telescope 2.

Now cover one of the mirrors, syay mirror 2, and locate the two small reference beam mirros so that a smear of red light is seen in telescope 2.

The photomultiplier may now be mounted instead of the eyepiece in telescope 2. Connect the scope and don't forget to terminate the 50 ohm cable. Trigger the scope externally from the pulse generator.

Make sure the photomultiplier supply is set to less than −1250 volts. and then turn it on. You should be able to see negative pulses of about 20 mV arriving at the scope.

For best measuring, shorten the pulses to a pulse width of about 10–15 nsec. At this stage you may try refocusing and making very slight adjustments of the telescope directions to increase the height of the negative pulse from the photomultiplier to about 20 mV when the high voltage is −1000 volts.

Measurements

1. Adjust the small reference beam mirrors so that the reference and delayed light pulses are about the same size on the oscilloscope. Vary the repetition rate of the LED to obtain overlap of the delayed light pulses with the reference light pulses. If you are using the yellow LED, turn off the corridor lights for the few minutes necessary for the best measurement. After the overlap condition is achieved, use the frequency counter to determine the time between pulses. Each student should repeat this measurement about 10 times so as to get an estimate of the random error involved. Now you msut determine the appropriate distances for the reference and delayed light pulses in order to determine the speed of light.

2. Analyze the random errors involved in your measurements and discuss how the random errors may be reduced. Describe any sources of systematic errors.

3. Use your frequencymeasurement to check the calibration of the timebase of the Tektronix 454 scope.

4. (Challenge!) Measure the variation in the pulse heights seen by the scope and so estimate the number of photoelectrons released in each pulse from the photocathode of the PM. Assume the quantum efficiency to be 8% and calculate the number of photons/steradian leaving the photodiode.

5. Check that you understand all of the devices and can answer questions on their method of operation.