Speed of Light

Physics 3600 – Advanced Physics Lab-1 – Summer 2010

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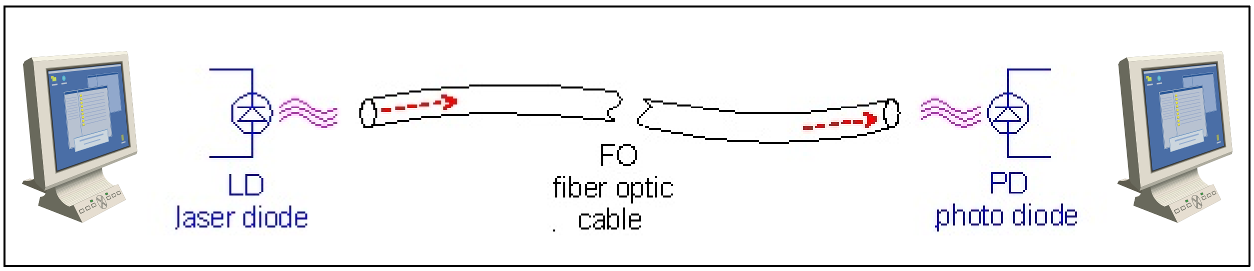
This experiment introduces you to high-speed laser diodes and detectors, which are key elements in optical communications. Short light pulses of a few nsec duration (1 m long) are sent through various media (air, water, glass) in order to determine the velocity of light (v) and index of refraction (*n*=c/v) in each medium.

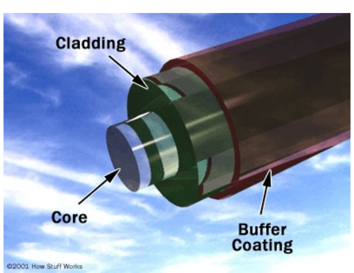
I. Introduction

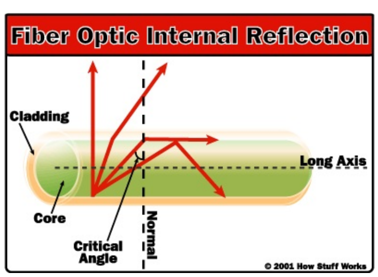
Fiberoptic (FO) systems are routinely used for long distance telephone and internet communications - and they are presently being implemented for shorter distances. The FO communication system illustrated below contains: (*i*) a laser diode (LD) which is electrically modulated (on/off) with the digital input information; (*ii*) a FO cable for transmitting the light pulses; and (*iii*) a photodiode to convert the light pulses back into electrical pulses.

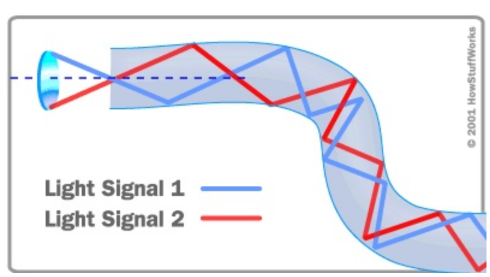


Most long-haul FO systems use light pulses generated by a GaInAsP semiconductor laser diode operating at 1.55μm wavelength where the optical absorption in the glass FO is minimum. In a 10GHz system the pulses are only a few cm in length. These pulses are transmitted through single-mode fibers of optical glass (SiO_2=silica=quartz) having a core diameter of about 6-8 μm. At the receiving end of the optical fiber the pulses are detected by a high-speed Si or InGaAs photodiode which converts the encoded light pulsed back into electrical pulses.

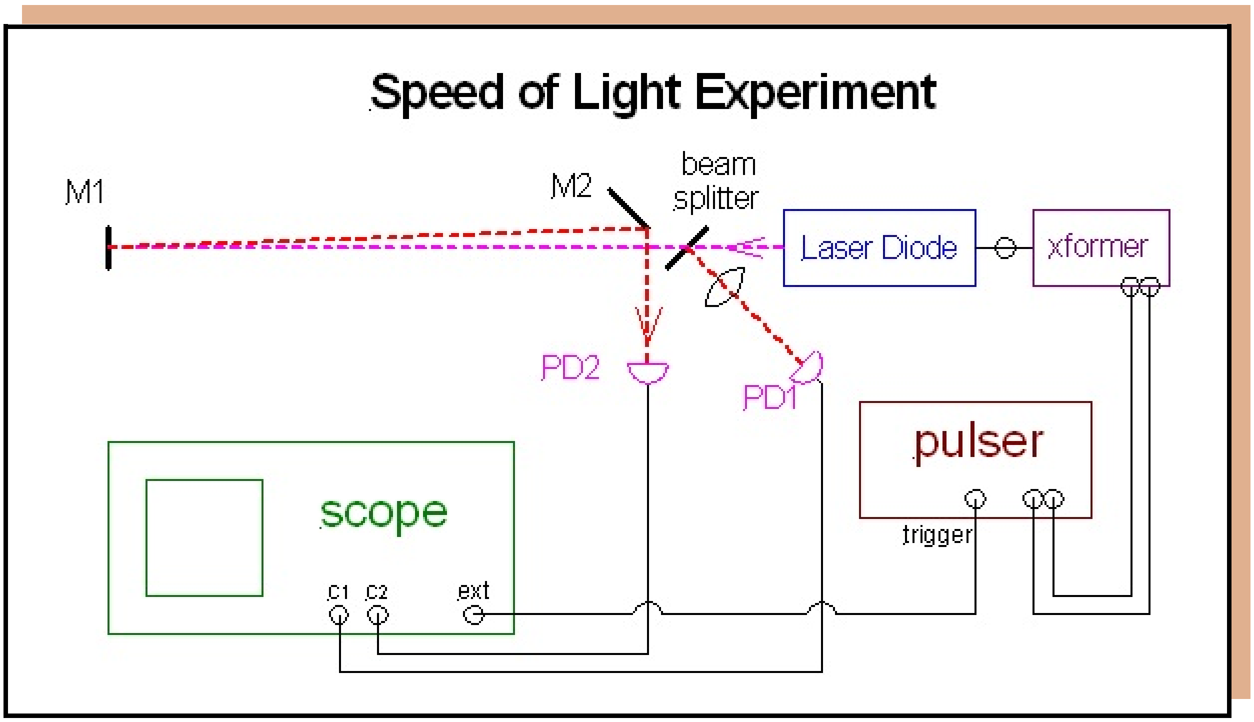
The illustrations below show: (left) construction of a FO cable where the light passes through the glass core region; (center) internal reflection inside the glass fiber; and (right) transmission of light inside the FO core. Light is confined inside the core by total internal reflection for angles greater than about 70 degrees from the normal. For light to exhibit total internal reflection, the cladding layer must have a smaller refractive index than the core region.







II. Apparatus (be sure to write down manufacturer and model numbers in your report)
optical breadboard, beamsplitter, 2 mirrors (M1, M2), lens
visible laser diode, high-speed nanosecond pulser
2 amplified, high-speed silicon photodiodes (PD1, PD2)
high-speed (500 MHz) oscilloscope
water-filled optical cell
optical fiber (SiO_2 quartz glass) with large core (~0.6 mm), FO mounts



III. Procedure

A. Test Pulser and Scope

Confirm that the pulser is turned **OFF**.
Disconnect laser diode from transformer box (AVO-2-T).
Set the PRF (pulse repetition frequency) to midrange and set the range to 20 kHz. Turn **ON**.
Trigger the scope externally with the TRIGGER output of the pulser.
Use a BNC Tee to also put the trigger output into the scope chnl-1 (expect ~5V and width ~100ns).
Transfer data from the scope using the 3.5" floppy disc.
☐ What is the approximate trigger amplitude, frequency, pulse width, and risetime (10% to 90%)?

Turn **OFF** pulser. Connect transformer (ATO-2-T) output to scope.
Set PW (pulse width) to about 3 and turn amplitude to minimum (full CCW).
Turn **ON** pulser and turn amplitude to maximum to observe transformer output on scope
(expect ~1V and width ~10ns).

B. Initial Laser Setup

Turn **OFF** pulser. Connect laser diode to the transformer.
Set PW (pulse width) to about 3 and turn amplitude to minimum (full CCW).
Turn **ON** pulser and turn amplitude to maximum while looking for laser output as a red stripe on a white card. Configure the optical components roughly as shown in the diagram.
Place the small focusing lens between the beam splitter and PD-1 to reduce the spot size.
Adjust both beams to hit the centers of the photodiodes.
Look for the photodiode signals on scope chnl-1 and chnl-2 (>20 mV).

☐ Copy the two photodiode pulses from the scope onto a single plot for your report.
☐ What is the pulse width (full-width at half-maximum) of one of the laser pulses?

Temporarily add another length of coax cable to one of the Pds.

☐ Copy the photodiode pulses, with and without the extra cable, onto a single plot.
☐ Measure the added delay time and compute the velocity of the electrical pulse in the cable.
☐ How could the cable length affect your other measurements?

C. Speed of Light

Return to equal length cables.

☐ **For your report, always compare the two photodiode pulses in a single plot.**

Air

☐ Measure the time lag between the two PD pulses on the scope.
Find the time difference precisely to an uncertainly much less than the linewidth.
☐ Measure the path difference of the two beams.
☐ Compute the velocity of light in **air**, including the uncertainty.

Glass

Next, measure the velocity and refractive index of glass.
For one of the PDs, accurately record where the pulse is on the scope timebase.
Remove that PD and replace it with one end of the fiber optic cable in a holder.
Place the other end of the FO in a mount which screws into the PD that was replaced.

☐ Record the time shift produced by the added FO cable.
Measure the time difference precisely to an uncertainly much less than the linewidth.
☐ Compute the refractive index (n=c/v) in **glass**, including the uncertainty.

Water

Measure the velocity and refractive index of water.
Configure the path of the laser so that the returning beam, which is reflected from the mirror M1, hits the second mirror M2 about 5 mm from the original laser beam path.
Place the tube containing water in the beam in a double-pass configuration. Note that the water cell will deviate the beam slightly, so make sure the beam travels through the center of the cell.

☐ Compute the refractive index n in **water**, including the uncertainty.
(Note that the time lag from the water *replaces* the time lag in the air.)

Conclusion

- ☐ <u>In a TABLE, compare the measured values with the accepted values (look them up).</u>
- ☐ <u>Discuss the wavelength dependence of the refractive indices, $n(\lambda)$.</u>
- ☐ <u>How could you improve the accuracy of the results?</u>