12. Measuring the Speed of Light

INTRODUCTION

Measure the speed of light using an optical fiber.

THEORY

I. The refraction of the light

The index of refraction of an optical material, denoted by n, plays a central role in geometric optics. It is the ratio of the speed of light c in vacuum to the speed υ in the material.

$$n = \frac{c}{\upsilon}, \tag{1}$$

where $c = 3 \times 10^8 m/s$.

If light passed through a material whose length is l and index of light is n, we could obtain the next equation.

$$c = n\upsilon = \frac{nl}{t}. \tag{2}$$

II. Snell's law and total internal reflection

The incident, reflected rays, and the normal all lie on the same plane, as shown in *Fig. 1*. The ratio of the *sines* of angles θ_1 and θ_2, where both angles are measured from the normal to the surface, is equal to the inverse ratio of the two indexes of refraction.

$$n_1 \sin\theta_1 = n_2 \sin\theta_2. \tag{3}$$

This experimental result is called the law of refraction or Snell's law.

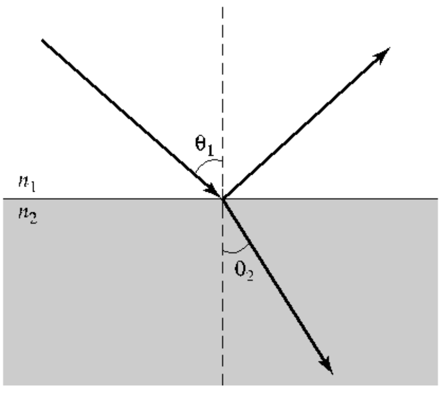

Fig. 1. Reflection and refraction in the case where $n_1 < n_2$.

Under certain circumstances, all of the light can be reflected back from the interface, with none of it being transmitted, even though the second material is transparent. *Fig. 2* shows how this can occur. Beyond the critical angle, the ray cannot pass into the upper material. This situation called total internal reflection. We can find the critical angle for two given materials by setting $\theta_2 = 90^\circ$ in Snell's law. We then have

$$n_1 \sin\theta_c = n_2 \sin 90^\circ \quad \rightarrow \quad \theta_c = \sin^{-1}(n_2 / n_1)\,. \tag{4}$$

The angle of incidence for which the refracted ray emerges tangent to the surface is called the critical angle, denoted by θ_c.

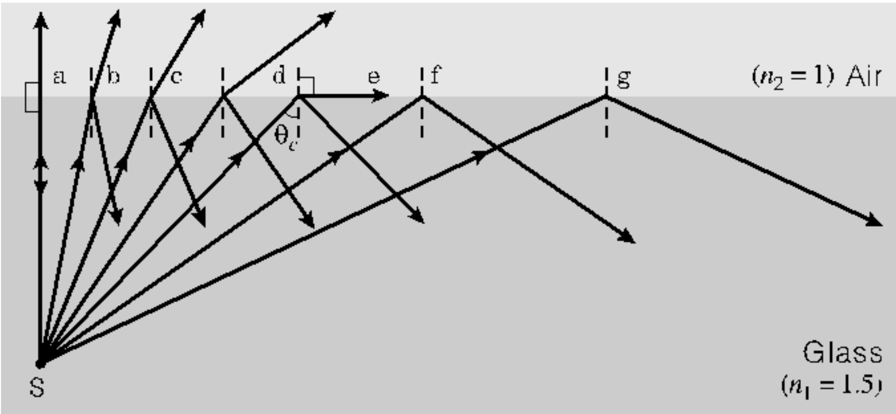

Fig. 2. Light passes at the boundary between two different media (air and glass).

III. Optical fiber

An optical fiber is a thin glass fiber which transmits light. Fiber-optic devices are widely used in medical applications as illuminators and in communications technology. *Fig. 3* shows the structure of optical fiber.

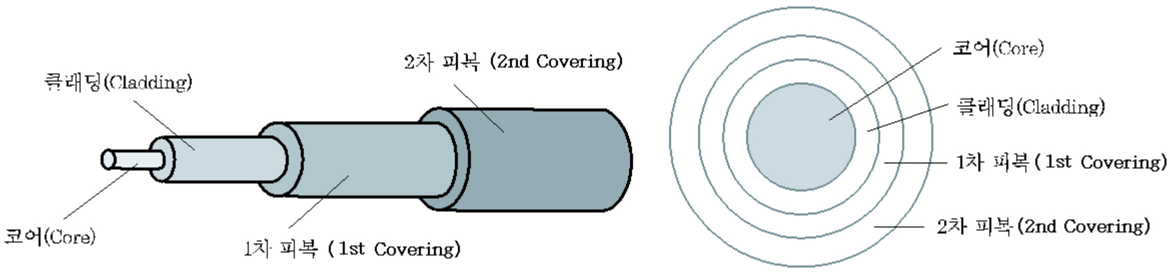

Fig. 3. The structure of optical fiber.

Different output signals appear according to the radius of the core and the cladding even though the same signals are input. We can categorize optical fiber as multimode or single-mode by the radius of the core and the cladding.

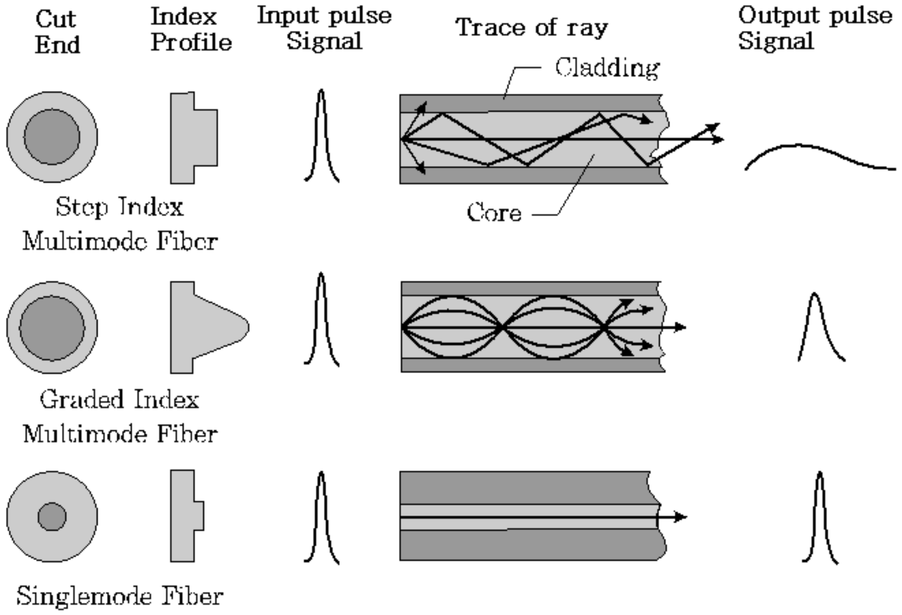

Fig. 4. Types of optical fiber.

EXPERIMENTAL SYSTEM

1. Speed of light measurement device (transmitter and receiver)
2. AD converter or oscilloscope and connector
3. Optical fiber

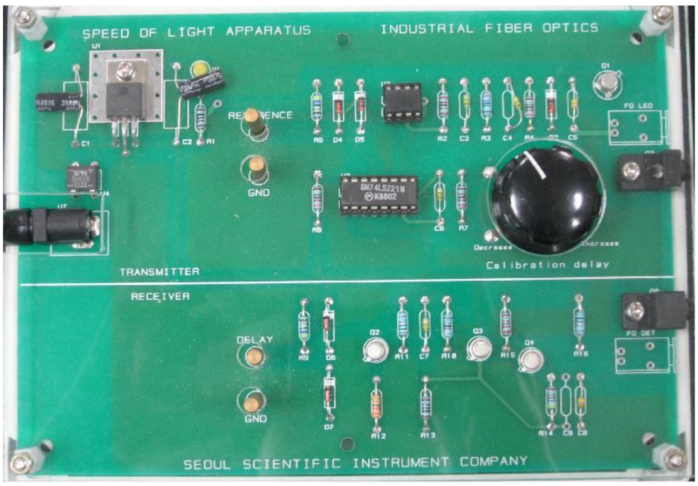

Fig. 5. Speed of light measurement device (TRANSMITTER and RECEIVER).

Fig. 6.　AD converter or oscilloscope and connector.

Fig. 7.　Optical fiber.

PROCEDURE

1. Set up the equipment as in *Fig. 8*. Turn on the power of the AD converter and connect a computer. The AD converter is composed of two channels (A, B).

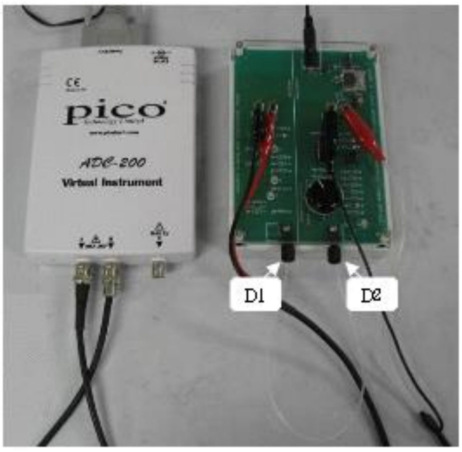

Fig. 8.　Experimental setup.

2. Connect the power supply to the TRANSMITTER part of the speed of light measurement device and check the signals at D1. Using the BNC cable, connect channel A of the AD converter to GND and the Reference terminal of the TRANSMITTER part. Check the Reference pulse shape through a monitor.

3. Using the BNC cable, connect channel B of the AD converter to the GND and Delay terminal of RECEIVER part. Using a short optical fiber(longer than 15cm), link D1 and D2 and observe the Reference and Delay pulse shape.

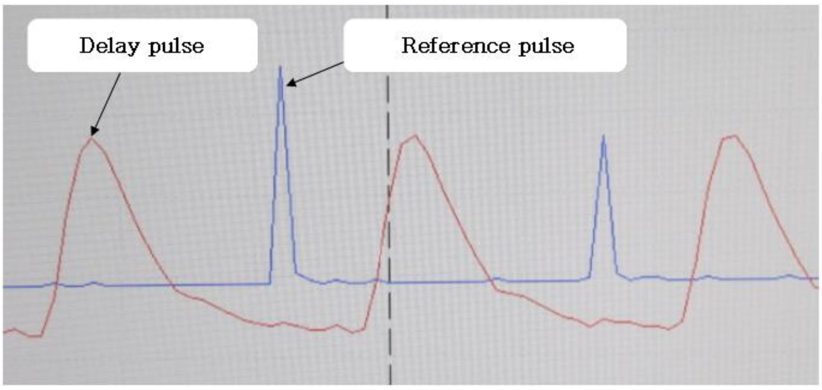

Fig. 9. Reference and Delay pulse shape.

4. Adjust the Calibration delay terminal to coincide with the Reference pulse with Delay pulse. Observe and record the Reference and Delay pulse shape.

5. Remove the short optical fiber. Using a long optical fiber (longer than 15m) link D1 and D2. Observe and record the Reference and Delay pulse shape. Measure the interval between two peaks.

6. Calculate the speed of light. Using theoretical value ($c = 3 \times 10^8\ \mathrm{m/s}$), calculate the error rate.

Delay and Reference pulse shape in the case of connecting a short optical fiber.

Delay and Reference pulse shape in the case of connecting a long optical fiber.

- Length of optical fiber l (m): ____________________

- Interval of two peaks Δt (sec): ____________________

- Velocity of light c (m/s): ____________________

- Error (%) = $\frac{|\text{theoretical value} - \text{experimental value}|}{\text{theoretical value}} \times 100$: ____________________