4. Experimental Procedures

A. Warm up

Turn on the apparatus and warm up for 30 minutes before conducting the experiment.

B. Adjust optical path

Align the reflector on the rail. When the carrier moves back and forth along the rail, the light spot should be at the center on the front surface of the prism with minimal change in spot position.

C. Set up oscilloscope

Set up the oscilloscope as described above.

D. Measure the speed of light

(a) Equal displacement method:

Take a set of points with same interval on the rail, as seen in Figure 6, as x_0, x_1, x_2, x_3, ….x_i while x_1-x_0=D_1, x_2-x_0=D_2, x_3-x_0=D_3, ….x_i-x_0=D_i. Move the carrier to these locations while recording the corresponding phase φ_i. The relationship between D_i and φ_i is: $\frac{\varphi_i}{2\pi} = \frac{2D_i}{\lambda}$ or $\lambda = \frac{4\pi D_i}{\varphi_i}$.

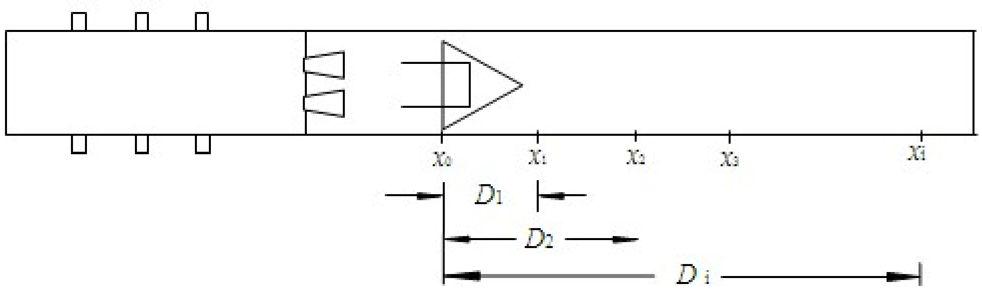

Figure 6 Equal distance method

To determine the wavelength from the above equation, plot D versus φ and do linear curve-fitting to the data. The fitted slope of the line is $\lambda/4\pi$, which can be further multiplied by $4\pi f$ to derive the speed of light (where f=100 MHz).

To minimize the measurement error at each point x_i, the sequence should be as follows x_0-x_1-x_0, x_0-x_2-x_0, …x_i-x_0-x_i. The movement of reflector should be quick and accurate. Average the two phase values at x_0 as the initial phase φ_0. If the phase difference between two measurements at x_0 is larger than 0.1º, the measurements should be re-conducted until a more accurate result is achieved.

(b) Equal phase change method:

Take a group of equal phase points on oscilloscope such as 36º, 72º, 108º, … , and take an arbitrary point on the rail as the origin point x_0 while setting the corresponding point from the waveform on oscilloscope as the zero phase point (0º). Move the carrier quickly until the required phase value is reached to record position as x_1. Next, quickly move the carrier to where zero phase (0º) is achieved to read the carrier position (x_0) again. Average the two positions of zero phase and set it as the origin point x_0. If the two positions of zero phase points differ by 1 mm or larger, redo the measurements.

Similarly, record D_i versus φ_i and obtain the slope by doing linear curve-fitting to the data. Finally, the speed of light is the fitted slope multiplied by $4\pi f$ (where f=100 MHz).

In general, the equal phase change method is more accurate than the equal displacement method.

E. Measure the refractive index of liquid medium using media tube (optional)

Move the reflector to the right end of the rail with its position set as x_0 during this experiment. Record the corresponding phase of the measured signal as φ_0. We have:

$$\varphi_0 = \frac{4\pi x_0}{\lambda} \tag{10}$$

Place the two magnetic carriers on the optical rail and then put the sample tube containing a liquid medium on the magnetic carriers (Note: the sample tube is located between the electric unit and the reflector on carrier). Each carrier can be moved slightly in the transverse direction to include both optical beams to pass through the sample in the tube as much as possible. Due to the presence of the liquid sample in the optical paths, the waveform of the measured signal on the oscilloscope shifts to create a phase change. Record the corresponding phase of the measured signal as φ_1. We have

$$\varphi_1 = \frac{4\pi\,[x_0 + d(n-1)]}{\lambda} \tag{11}$$

where n is the reflective index of the medium, and d is the length of the media tube along the optical path. By subtracting (10) from (11), we get

$$\Delta\varphi = \left|\varphi_1 - \varphi_0\right| = \frac{4\pi d(n-1)}{\lambda} \tag{12}$$

Using the wavelength value acquired in the previous experiment as described in section 4-D-(a) and the phase shift measured per Figure 5, the refractive index of the liquid in the tube can be derived from (12).

5. Operation and Safety Precautions

- Keep the surface of the reflector from finger print, humidity, or scratch. Store the reflector in its original packaging box in dry and dust-free environment. If the coating surface of the mirror needs cleaning, use lens tissue with mixed solution of alcohol and diethyl ether (4:1).
- **Warning**: avoid direct eye exposure to the laser beam (class IIIa laser safety).

6. Examples of Data Recording and Processing

Note: The following data are for reference only, not the criteria for apparatus performance:

As shown in Figure 6, set the reflector at 10 cm, 20 cm, 30 cm, 40 cm, and 50 cm, respectively; while recording the corresponding phase delay of the optical signal via port # 5 based on Figure 5. Record the data in Table 1 as shown below:

Table 1 Position of reflector versus phase delay of optical signal

x_i (cm)	φ_i (rad)
10	0
20	0.314
30	0.799
40	1.142
50	1.599

By curve-fitting the data in Table 1 with a linear equation as shown in Figure 7, the slope of the fitted line is obtained as 0.247 which is equal to $\lambda/4\pi$ (where λ is the wavelength of the laser light). Since $\lambda=c/f$ (where c is the speed of light and f=100 MHz is the frequency of the modulated optical signal), we get $c=0.247\times4\pi\times10^8=3.10\times10^8$ (m/s) yielding an error of approximately 3.3% compared to the well-recognized value of the speed of light.

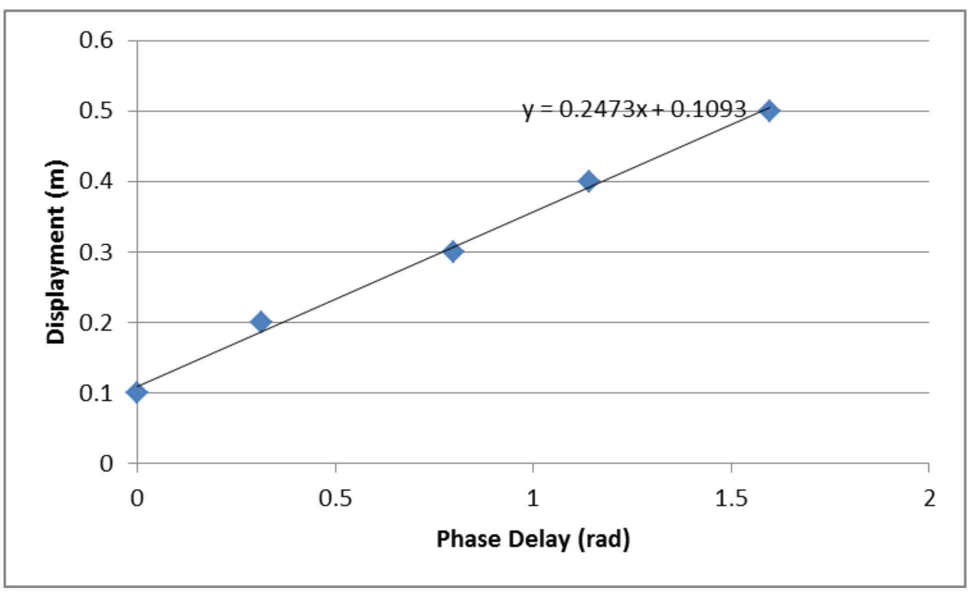

Figure 7 Position of reflector vs phase delay of optical signal