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Introduction to Fiber Optics

Introduction

An optical fiber is a long thin strand of impurity-free glass used as a transport medium for data. A typical point-to-point fiber optic communication network consists of a transmitter (laser), a transport medium (optical fiber) and a receiver (photo-diode) as in Fig.(1).

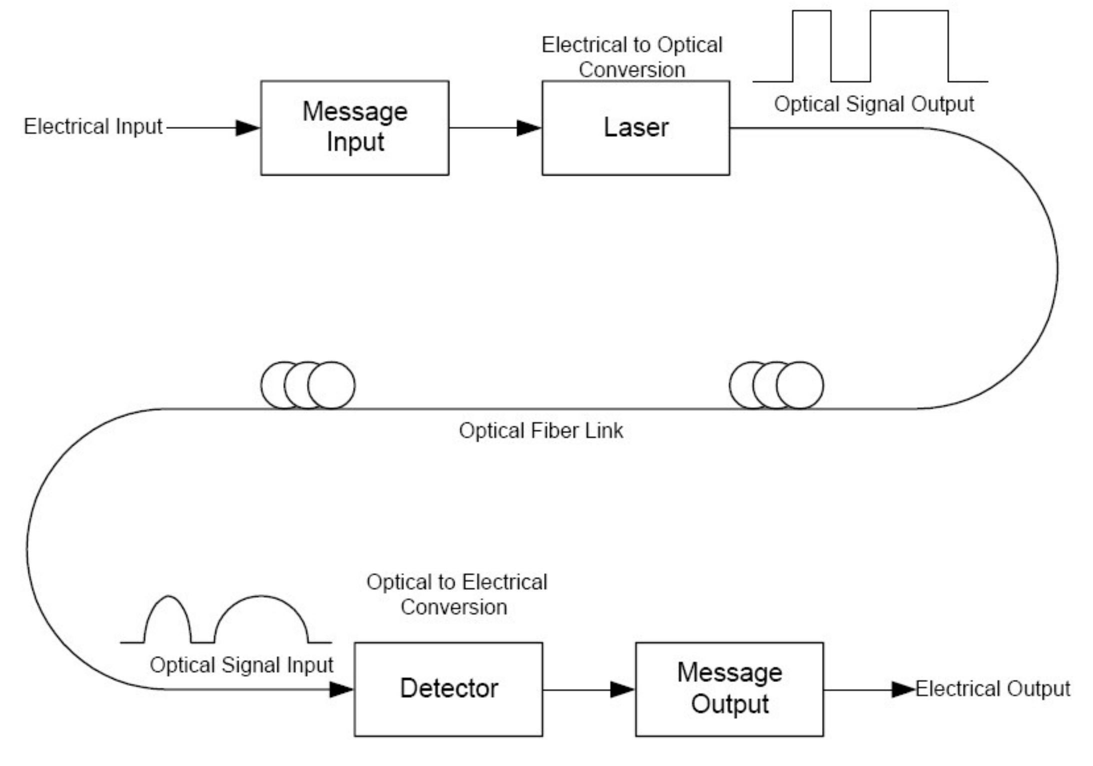


Figure 1: Typical components found in a point-to-point optical communication system

Optical fiber has many advantages over traditional copper cable and free-space microwave networks:

(i) Less signal degradation per meter
(ii) Higher signal carrying capacity / bandwidth
(iii) Less costly per meter
(iv) Lighter and thinner than copper wire
(v) Free from electromagnetic interference.
(vi) Lower transmitter launching power
(vii) Flexible (used in medical and mechanical imaging systems)

Structure of Optical Fiber

The optical fiber is made of two concentric cylindrical strands of silica surrounded by a plastic coating. The center most silica strand is the cone of the fiber with a refractive index1 of approximately 1.48. The core of the fiber physically transports most of the optical power. The core is surrounded by another strand of silica called the cladding. The cladding has a slightly lower refractive index, 1.46 and provides the interface that confines the optical signal to the core. The outermost layer of the optical fiber is the buffer coating. This thin plastic covering protects the glass from mechanical and environmental damage. A pictorial representation of the components that makeup an optical fiber is shown in Fig(2).

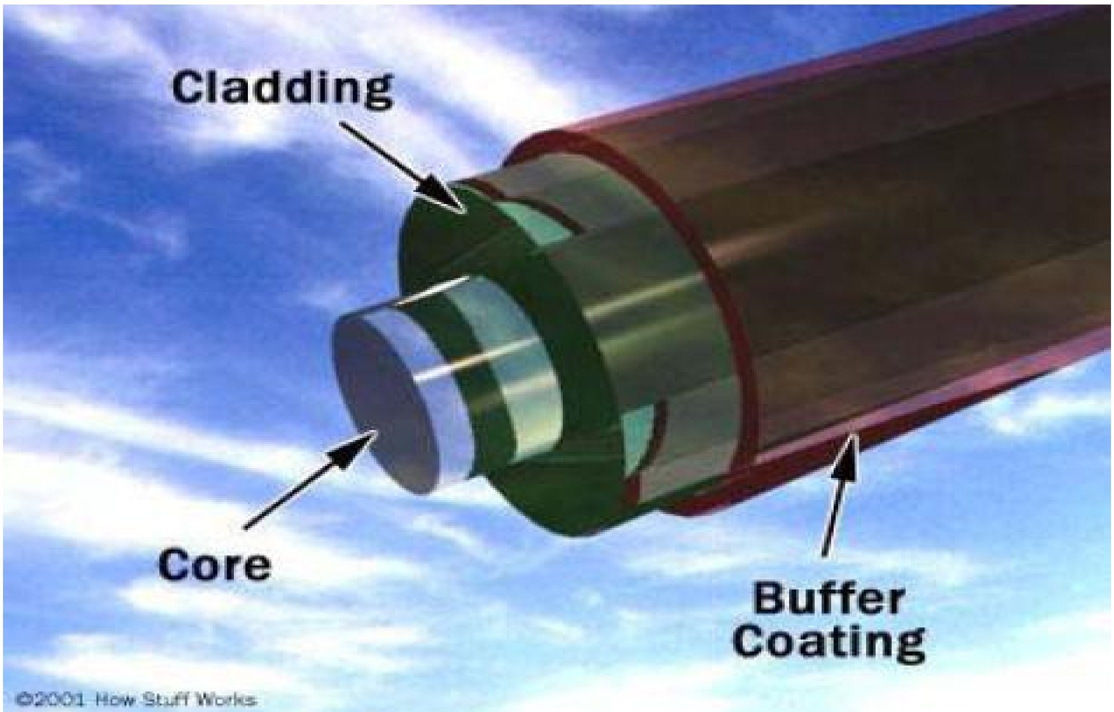


Figure 2: Makeup of an optical fiber

Signal Transport Mechanism

Physics of Total Internal Reflection

Consider a ray of light passing between two media of different refractive indexes n_1 and n_2 as shown in Fig.(3). If $n_1 > n_2$ the light ray as it passes from one media to the next will bend away from an imaginary line (the normal) perpendicular to the media's mating surface. Conversely if $n_1 < n_2$ then the ray will bend towards the normal. Total internal reflection occurs when $n_1 > n_2$ and the incident ray of light makes an angle, Θc, such that it does not enter the adjacent medium but travels along the interface. At angles greater than Θc the ray will be reflected back into medium A.

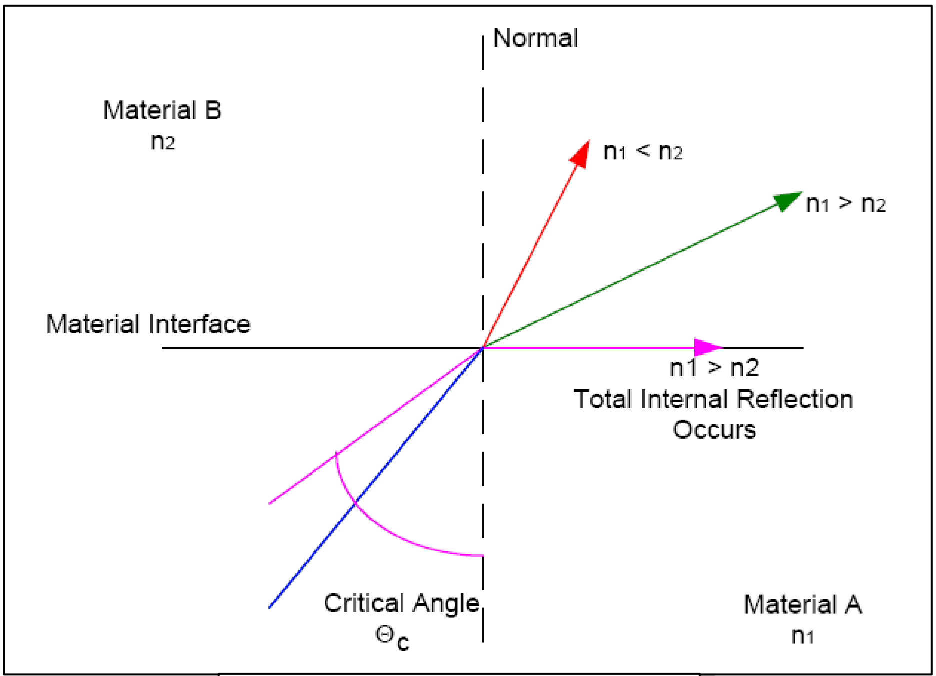


Figure 3: Total Internal Reflection

Ray Theory

Light is confine within the core of the optical fiber through total internal reflection. To understand the phenomenon of total internal reflection and how it is responsible for the confinement of light in an optical fiber consider a ray of light incident on the fiber core as shown in Fig.(4).

Light enters the core of the optical fiber and strikes the core/cladding interface at an angle Θ. If this angle is greater than the critical angle (i.e. $\Theta \geq \Theta c$ where $\Theta c = \arcsin(n_2/n_1)$) then the ray will reflect back into the core thus experiencing total internal reflection. This ray of light will continue to experience total internal reflection as it encounters core/cladding interfaces while propagating down the fiber

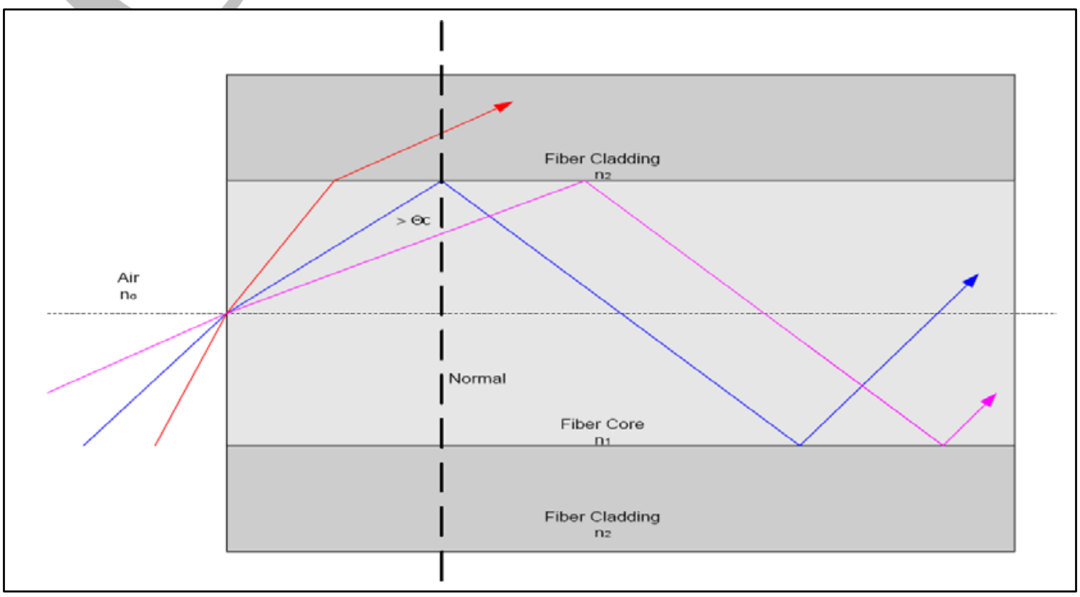


Figure 4: Light Propagates Through a Fiber Due To Total Internal Reflection

Fiber Types

1. Multi-Mode Fiber

Multi-mode fiber is named by its large core. On the order of 50 µm and 62.5 µm, multi-mode fiber allows multiple rays/modes to couple and propagate simultaneously down the fiber as demonstrated in Fig.(5). Large core fiber is attractive due to the ease in which light form a source can be coupled into the fiber, significantly reducing the cost of transmitter design and packaging. As will be discussed later, multimode fiber is very sensitive to dispersion, which tends to limit the distance and bandwidth of an optical system.

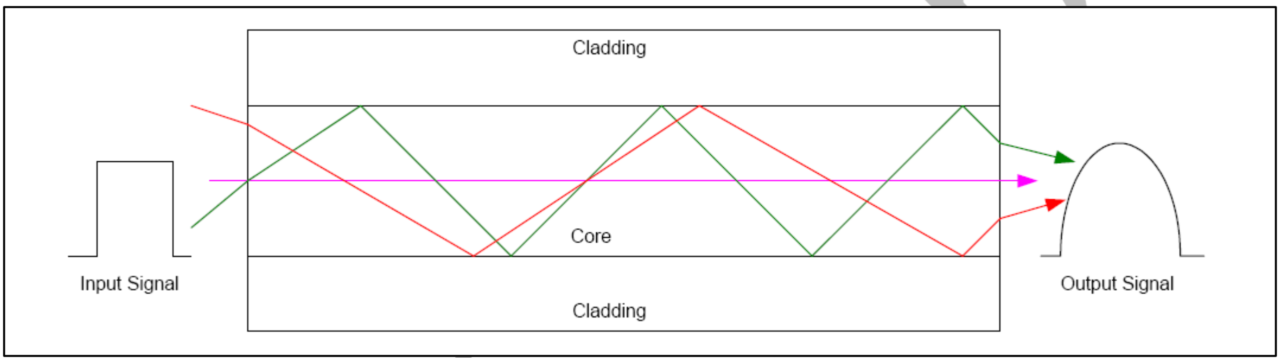


Figure 5: An input pulse is made up of multiple Modes/Rays.

An input pulse made up of multiple Modes/Rays. Each of the three rays takes different paths propagating through the core of the multi-mode fiber. As a result the three light rays shown arrive at different times causing broadening of the input pulse. This is know as dispersion and can lead to inter-symbol interference

2. Single-Mode Fiber

As the name implies, a single mode fiber only allows one ray/mode to propagate through the fiber core. This accomplished by shrinking the core of the fiber to dimensions comparable to that of the wavelength being transmitted. Single mode fiber has a core dimension of ~9µm making transmitter coupling much more difficult. Consequentially single mode fiber systems employ higher costing lasers. However, single mode fiber has an advantage of higher capacity/bandwidth and is much less sensitive to the effects of dispersion than multi-mode fiber. It is also possible to incorporate wavelength division multiplexing techniques to further increase the transmission capacity of a single-mode fiber.

Exp. No. 1
Characteristics of Light Emitting Diode (LED)

Aim of experiment

In this experiment, we study and measure the P-I characteristics of Light Emitting Diode (LED), which used in optical fiber communication as a light source.

Apparatus

1. Optical Fiber Communication Experiment Kit
2. Optical fiber power meter
3. Oscilloscope
4. AVO meter
5. Wires
6. 5m multimode optical fiber

Theory

The role of the optical transmitter is to convert an electrical input signal into the corresponding optical signal and then launch it into the optical fiber serving as a communication channel. The major component of optical transmitters is an optical source. Fiber-optic communication systems often use semiconductor optical sources such as light-emitting diodes (LEDs) and semiconductor lasers because of several inherent advantages offered by them. Some of these advantages are compact size, high efficiency, good reliability, right wavelength range, small emissive area compatible with fiber core dimensions, and possibility of direct modulation at relatively high frequencies [1].

A forward-biased *p–n* junction emits light through spontaneous emission, a phenomenon referred to as electroluminescence. In its simplest form, an LED is a forward biased *p–n* homo-junction. Radiative recombination of electron–hole pairs in the depletion region generates light; some of it escapes from the device and can be coupled into an optical fiber. The emitted light is incoherent with a relatively wide spectral width (30–60 nm) and a relatively large angular spread.

The characteristic curve of output power versus input current for a LED is linear over a suitable range of current for a particular LED as shown in Fig.(1). This range generally extends from a few milli-amperes up to approximately 50 milli-amperes for a LED without a heat sink, or up to 150 milli-amperes for a LED with a heat sink. At lower currents the electron-photon conversion efficiency is low while at higher currents a saturation phenomenon occurs due to the heating of the semiconductor.

Several key characteristics of LEDs determine their usefulness in a given application. These are:

***Peak Wavelength*:** This is the LED emits most power at central wavelength; therefore, it should be matched to the wavelengths (850 nm and 1310 nm) that are transmitted with the least attenuation through optical fiber.

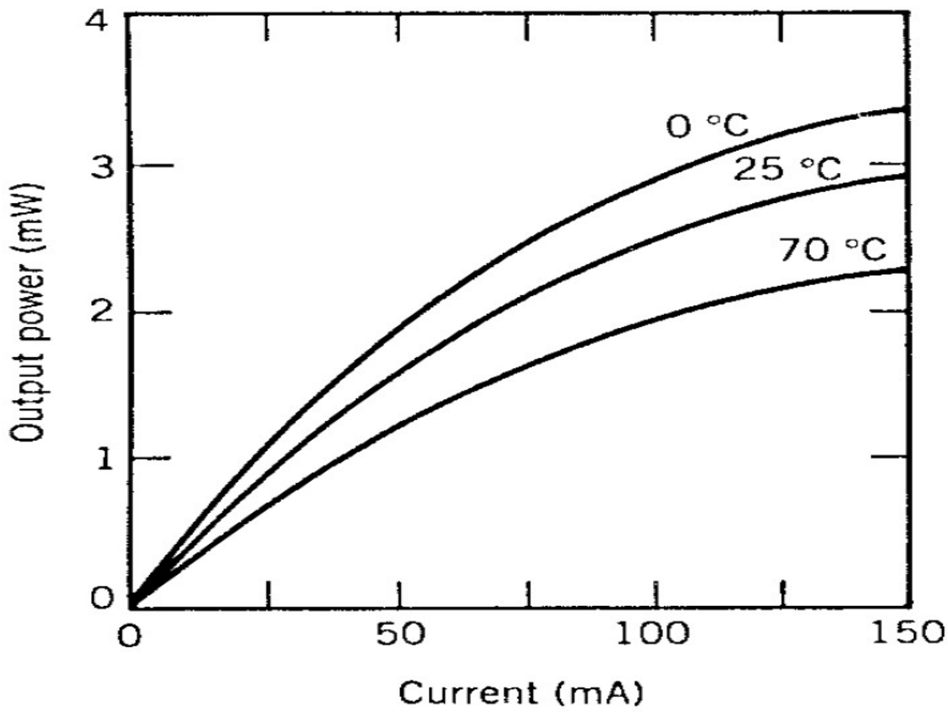


Fig.(1): P-I characteristics of LED at several temperatures

***Spectral Width*:** Ideally, all the light emitted from an LED would be at the peak wavelength, but in practice, the light is emitted in a range of wavelengths centered at the peak wavelength. This range is called the spectral width of the source.

Emission Pattern: The pattern of emitted light affects the amount of light that can be coupled into the optical fiber. The size of the emitting region should be similar to the diameter of the fiber core.

Speed: A source should turn on and off fast enough to meet the bandwidth limits of the system. LEDs have slower rise and fall times than lasers.

Linearity: is another important characteristic for some applications. Linearity represents the degree to which the optical output is directly proportional to the electrical current input.

LEDs are generally more reliable than lasers, but both sources will degrade over time. This degradation can be caused by heat generated by the source and uneven current densities.
LEDs and laser diodes are very similar devices. In fact, when operating below their threshold current, all laser diodes act as LEDs.

Procedure

1. Connect the circuit shown in Fig.(2) by using optical fiber trainer.
2. Connect the optical fiber to the LED.
3. Connected second end of optical fiber to the optical power meter.
4. Switch on optical fiber trainer.
5. Change the injection current by varying the variable resistor in steps and record the voltage of photo diode as in table below.

I_{LD}(mA)	20	25	30	35	40	45	50
P_o(μW)							
P_o(dBm)							

I_{LD}(mA)	55	60	65	70	75	80	65
P_o(μW)							
P_o(dBm)							

6. Plot the relation between the optical power and current.

$$R_b = \frac{V_{cc} - V_d - I_d \times 10}{I_d}$$

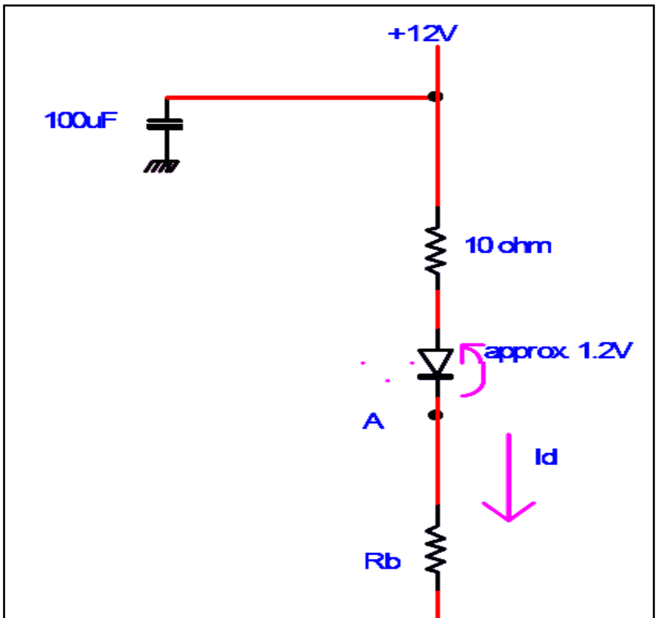


Fig.(2)

Result:

Plot the relationship between the optical output power and emitter current.

Discussion

1. Comment on your results
2. What we mean by spectral width of LED? Is it important? Why?
3. Why we said " **L**EDs are generally more reliable than lasers"?

Exp. No. 2
P-I Characteristics of Laser Diode (LD)

Aim of experiment

In this experiment, we study and measure the P-I characteristics of laser diode, which used in optical fiber communication as a light source.

Apparatus

1. Laser Diode has a wavelength of 1550 nm a maximum output power of 2mW continues wave. The laser diode is integrated in the Controller LDS 1200.
2. Laser Diode has a wavelength of 980 nm a maximum output power of 100 mW continues wave. The laser diode is integrated in the Controller LDS 1200.
3. InGaAs - PIN photo detector.
4. Si - PIN photo detector.
5. Optical Power meter
6. Oscilloscope
7. IR converter screen 800-1200 nm.

Theory

The role of the optical transmitter is to convert an electrical input signal into the corresponding optical signal and then launch it into the optical fiber serving as a communication channel. The major component of optical transmitter is an optical source. Fiber-optic communication systems often use semiconductor optical sources such as light-emitting diodes (LEDs) and semiconductor lasers because of several inherent advantages offered by them. Some of these advantages are compact size, high efficiency, good reliability, right wavelength range, small emissive area compatible with fiber core dimensions, and possibility of direct modulation at relatively high frequencies [1].

The operating characteristics of semiconductor lasers are well described by a set of rate equations that govern the interaction of photons and electrons inside the active region. The *P–I* curve characterizes the emission properties of a semiconductor laser, as it indicates not only the threshold level but also the current that needs to be applied to obtain a certain amount of power. A typical current Vs optical output power is shown in Fig.(1).

For currents underneath the laser threshold, the spontaneous emission is dominant. Stimulated emission is responsible for the strong increase above the laser threshold. The threshold current can be determined by the point of intersection of the extrapolated characteristic lines of the initial and of the lasing working mode. The rounding of the characteristic line is the result of spontaneous emission. It also is the cause for the oscillation of several modes next to the threshold. At higher currents, the mode spectrum becomes more and more clean.

In other words, below the threshold current the optical output power of the laser is essentially zero, any photon emissions are due to spontaneous transitions in the laser's semi-conducing material. Once the applied current crosses the threshold, value the output power rises considerably. The slope of the current Vs power curve above the threshold is a measure of how good the laser is at converting electrical power to optical power otherwise known as the external quantum efficiency.

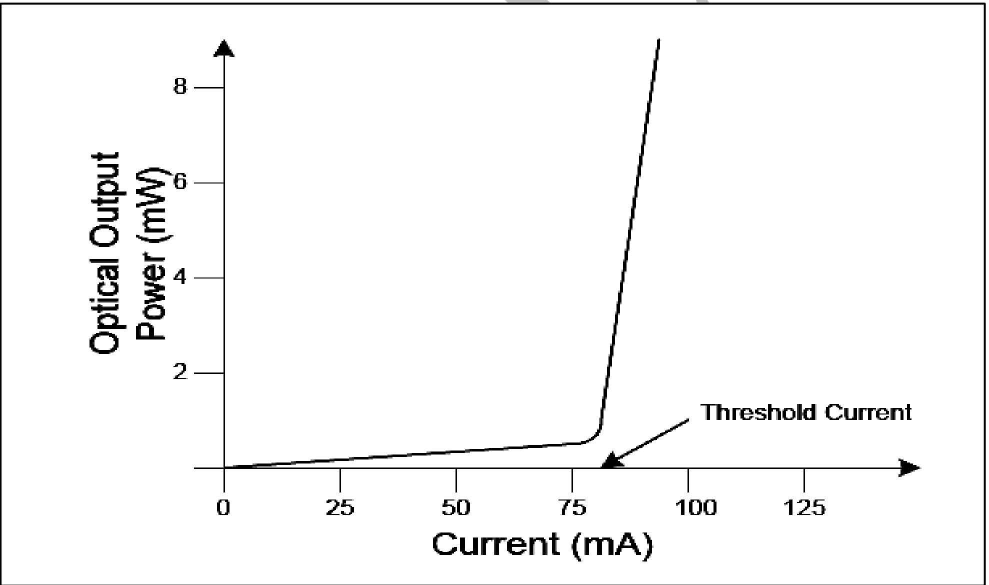
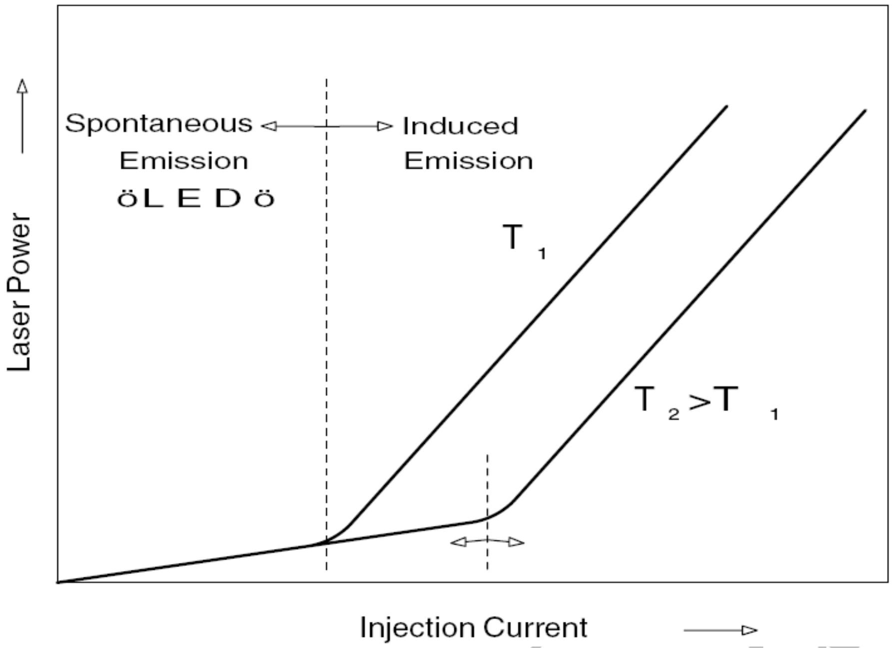


Fig.(1): Typical laser diode response plot

The laser performance degrades at high temperatures. The threshold current is found to increase exponentially with temperature, i.e.,

$$I_{\text{th}}(T) = I_0 \exp(T/T_0)$$

The strong dependence of the current and the output power on the temperature are typical for a semiconductor shown in figure below.



The wavelength increases with increasing temperature. The reason for this is that the refractive index and the length of the active zone, respectively the resonator, increase with increasing temperature. Beyond a certain temperature, the mode does not fit anymore into the resonator and another mode, which faces conditions that are more favorable, will start to oscillate [2].

A similar behavior is observed for the variation of the injection current and in consequence for the laser output power. Here the change in wavelength is mainly the result of an increase in the refractive index, which again is influenced by the higher charge density in the active zone. A higher output power provokes also a higher loss of heat and an increase in temperature of the active zone.

Procedure

6. Connect the optical fiber to the 1550nm laser diode which integrated in the controller LDS 1200.
7. Connected second end of optical fiber to the InGaAs - PIN photo detector
8. Connect the photo detector to the BNC socket ‘Photo Diode Input’ at the rear panel of the controller LDS 1200. Then connect an oscilloscope or a digital voltmeter to the BNC socket ‘Photo Diode Output’.
9. Switch on the controller LDS 1200 by its main switch at its backside. After a few seconds of self-testing, the unit is ready for use.
10. Switch on the laser diode by turning the key switch at the front of the controller to the ‘On’ position.
11. Change the injection current in steps and record the voltage of photo diode as in table below.

I_{LD}(mA)	0								
V_{PIN} (V)									

I_{LD}(mA)									
V_{PIN} (V)									

12. Switch on the modulation of the laser diode. Then select modulation type is triangle.
13. Connect one channel of the oscilloscope to the modulator output BNC socket and the Photo diode output BNC socket to the second channel of the oscilloscope.
14. Display and optimize two signals on the oscilloscope, then switch oscilloscope to XY mode.
15. Plots curve on the graph paper.
16. Repeat steps (1-10) for 980 nm laser diode.

Discussion

1. Comment on your results
2. Why we use the laser diode in optical communication rather than the other types of laser?
3. Explain the relation between the injection current and temperature and output power.
4. Discuss the operation of the laser diode with constant wavelength operation.
5. Why the wavelength increased with increase temperature?

References

1. Govind P. Agrawal," Fiber-Optic Communication Systems", John Wiley & Sons, Inc, 2002.
2. User Manual , "EXP-12: fiber optics", MEOS Com.
3. User Manual , "Laser Education Kit CA-1920 Wavelength Division Multiplexing ", MICOS Com., Germany.

Exp. No. 3
Measuring Numerical Aperture of Optical Fiber

Aim of experiment: In this experiment, we measure the numerical aperture.

Theory

Consider the geometry of Fig.(1), where a ray making an angle θ_i with the fiber axis is incident at the core center. Because of refraction at the fiber–air interface, the ray bends toward the normal. The angle θ_r of the refracted ray is given by:

$$n_0 \sin\theta_i = n_1 \sin\theta_r \qquad (1)$$

where n_1 and n_0 are the refractive indices of the fiber core and air, respectively. The refracted ray hits the core–cladding interface and is refracted again. However, refraction is possible only for an angle of incidence ϕ such that $\sin\phi < n_2/n_1$. For angles larger than a *critical angle* ϕ_c, defined by:

$$\sin\phi_c = n_2/n_1 \qquad (2)$$

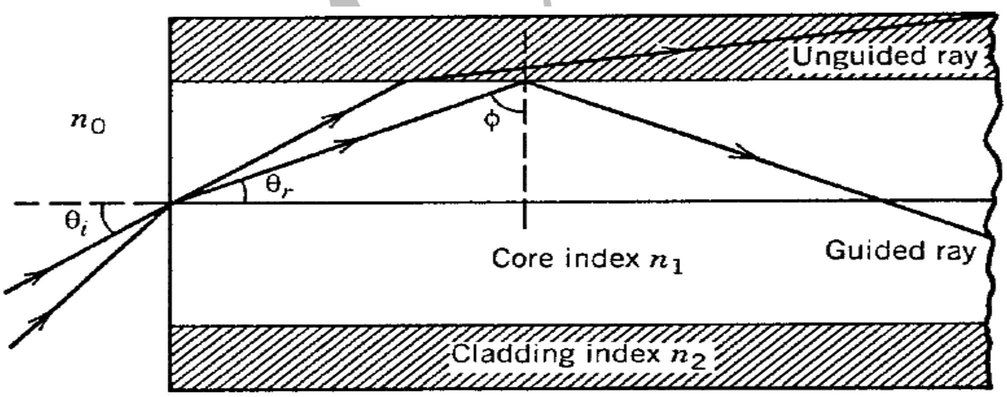


Fig.(1): Light confinement through total internal reflection in step-index fibers. Rays for which $\phi<\phi_c$ are refracted out of the core.

One can use Eqs. (1) and (2) to find the maximum angle that the incident ray should make with the fiber axis to remain confined inside the core. Noting that $\phi_r = \pi/2 - \phi_c$ for such a ray and substituting it in Eq. (1), we obtain:

$$n_0 \sin\theta_i = n_1 \cos\phi_c = (n_1^2 - n_2^2)^{1/2} \qquad (3)$$

In analogy with lenses, $n_0 \sin\theta_i$ is known as the ***numerical aperture*** (NA) of the fiber. It represents the light-gathering capacity of an optical fiber. For $n_1 \cong n_2$ the NA can be approximated by[1]:

$$\mathrm{NA} = n_1(2\Delta)^{1/2}, \qquad \Delta = (n_1 - n_2)/n_1,$$

The most important parameter of a glass fiber is the numerical aperture. This value is very important to know for the design of coupling optics to get light into a fiber and it has influence on coupling losses e.g. of fiber connectors.

The numerical aperture is calculated with the index of refraction and the angle of acceptance at the face of the glass fiber. Due to the fact that the optical path is reversible the relations are valid for both, coupling of light into the fiber and radiant emitting at the fiber output. By definition the angle of acceptance is achieved if the emitted power is down at 5%[2].

Procedure

1. Adjust the system as shown in Fig.(2).

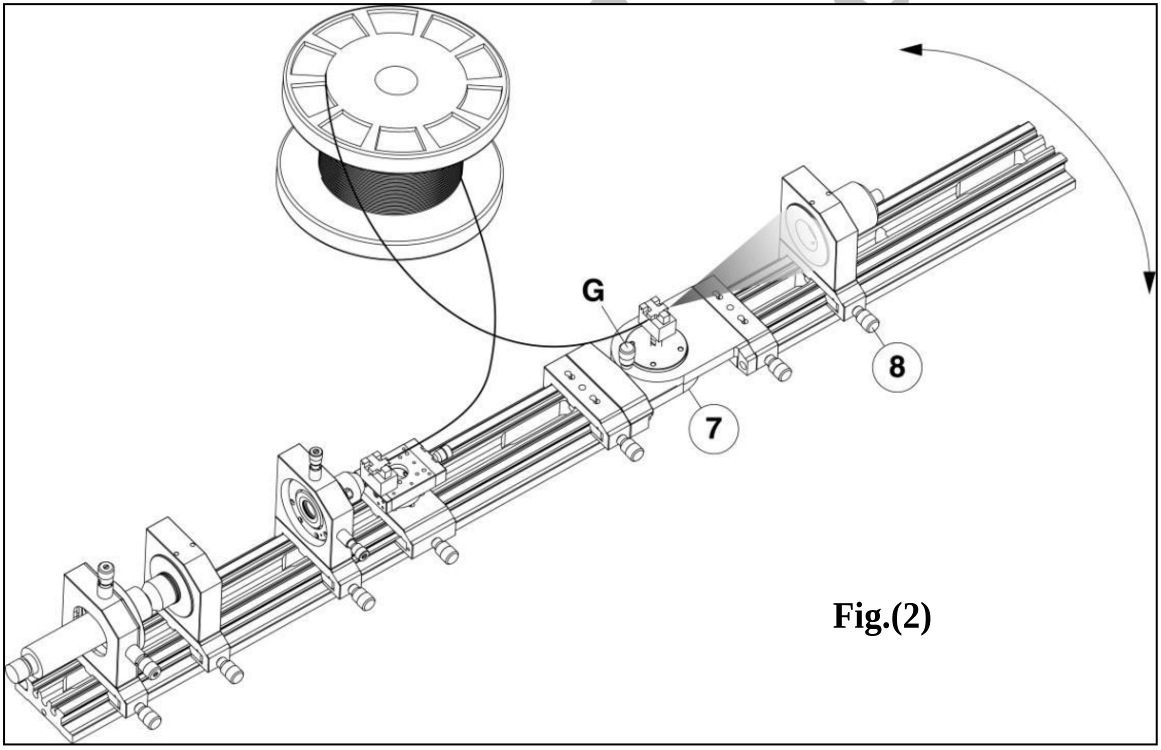


Fig.(2)

2. Release the locking screw G. then buckle the articulated connector (part 7) of the flat rails to defined angles.
3. Measure the output power of the fiber with an oscilloscope or with an digital voltmeter.
4. Vary the angle of the rails to find the maximum output power. At this variation, record the value angle Φ_1.

5. Shift the rail to the value where the output power is dropped to 5% of the maximum value measured in previous step. This angle is Φ_2.
6. Calculate the acceptance angle with following formula:

$$\Phi_a = \Phi_2 - \Phi_1$$

7. Calculate the numerical aperture by using measured acceptance angle as follows:

$$NA = n_0 \cdot \sin \Phi_a$$

Discussion

1. Comment on your results
2. Why we consider the numerical aperture is important characteristic of optical fiber?

References

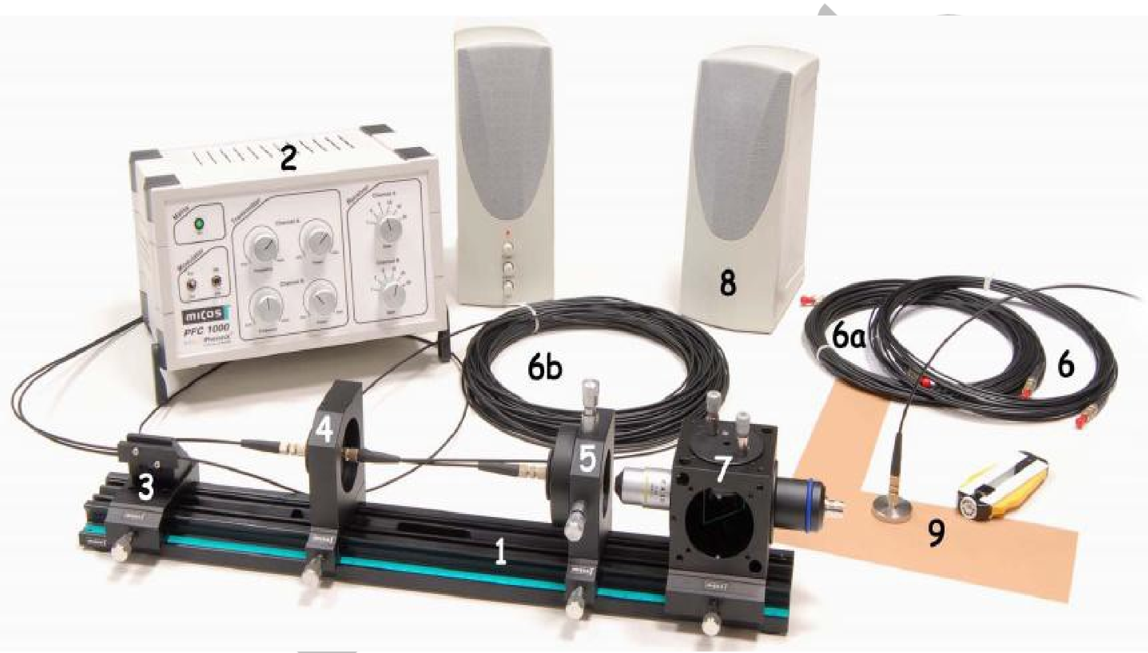
1. Govind P. Agrawal," Fiber-Optic Communication Systems", John Wiley & Sons, Inc, 2002.
2. User Manual , "Laser Education Kit CA-1[illegible]00 Plastic Fiber Optics", MICOS Com.

Exp. No. 4

Attenuation Measurements of Plastic Fiber Lines

Aim of experiment: To study and measure

1. To learn plastic fiber preparation and connector assembly
2. To measure the attenuation coefficient of plastic fiber



Apparatus: the above picture shows the experiment parts and they named as follows:

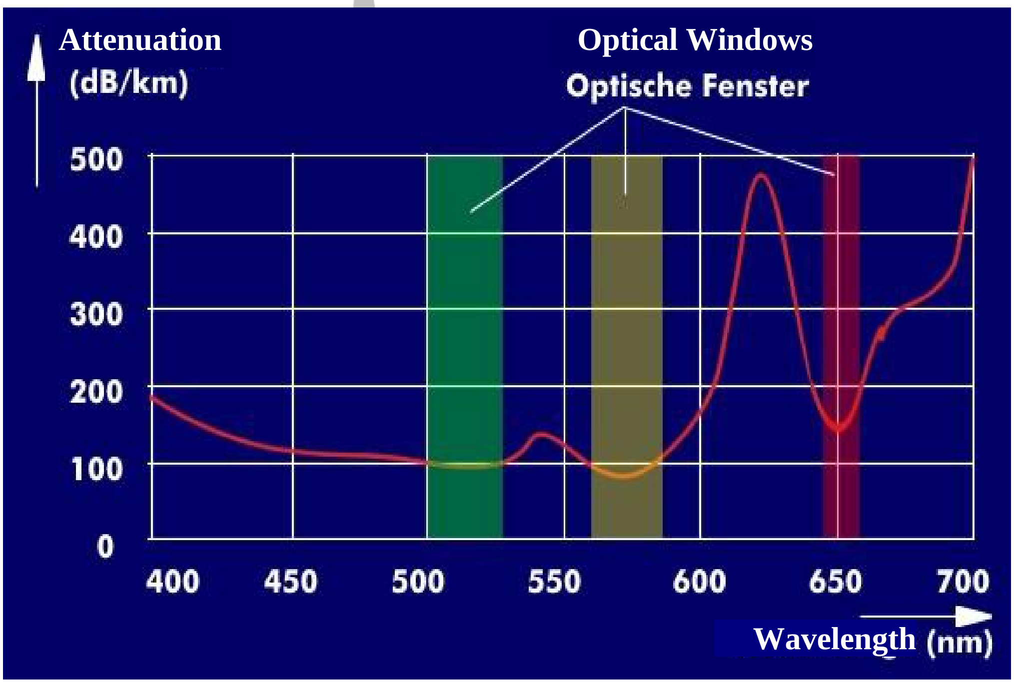
1. Part 1: Flat rail 500 mm with scale
2. Part 2: Plastic Fiber Controller PFC 1000
3. Part 3: POF Y-coupler on carrier
4. Part 4: FSMA coupler in holder on carrier
5. Part 5: FSMA coupler in XY adjustment holder on carrier
6. Part 6, 6a and 6b: POF cables with two FSMA connectors
7. Part 7: Wavelength separator unit on carrier
8. Part 8: Pair of active stereo speakers
9. Part 9: Set of tools for FSMA connector assembling
10. Part 10: Set of BNC cables (not shown)

Theory

Plastic fiber works in the same manner as glass optical fiber but uses plastic instead of glass and usually has a much larger core area. The large core area and easy-to-cut and terminate properties of plastic optical fiber have long held the promise of a low cost, easy to install communications medium that offers all the benefits of optical fiber with the ease of termination of copper.

By contrast, glass fiber requires highly trained technicians and expensive equipment; this is a major difference, and one of the reasons for interest in plastic fiber for the do-it-yourself installations of homes and small offices. A significant inhibitor to wider use of optical links in this environment is the high cost of installation compared with the more reasonable cost of hardware and raw materials.

Both step index and graded index plastic fiber are available, although only step index is considered a commercial product at this time. While there are many potential plastics that could be considered, the most commonly used is Poly (Methy1 MethylAcrylate) or PMMA. Attenuation is very high compared with glass fiber at all wavelengths. PMMA has attenuation minima occurring at 570 nm (yellow) , 520 nm (green), and 650 nm (red) as shown in Figure below. Both 650 nm (red) and 520 nm (green) devices have long been available and they found in the laboratory



Plastic fiber links are also used with visible light sources around 570 nm to 650 nm wavelength; this makes alignment of the fibers easier to perform, and high-power visible sources are readily available at low cost. Table 1 shows typical specifications of POF used for communication applications.

***Table 1*: Typical specifications of plastic optical fiber**

Parameter	*Specification*
Core diameter	980 μm
Cladding diameter	1000 μm (1 mm)
Jacket diameter	2.2 mm
Attenuation (at 850 nm)	<18 dB/100 m (180 dB/km)
Numerical aperture	0.30
Bandwidth (at 100 m)	Step index: 125 MHz Graded index: 500 MHz

How measure the attenuation coefficient

In general, the output power from a fiber cable at a given length is defined by the equation:

$$P_{\text{out}} = P_{\text{in}} \exp(-\alpha L) \quad \textbf{And,} \quad \alpha\,(\text{dB/km}) = -\frac{10}{L}\log_{10}\left(\frac{P_{\text{out}}}{P_{\text{in}}}\right)$$

P_{in} – *input power*
P_{out} – *output power*
L – *length of fiber in km*
α – *attenuation coefficient*

From the equation above, another equation can be derived to determine the attenuation coefficient, α, from having measured the optical power output at two different optical fiber lengths. That equation is:

$$\alpha = \frac{\ln(P_1/P_2)}{L_2 - L_1}$$

P_1- output power of optical fiber with length 1
P_2- output power of optical fiber with length 2
L_1- length of fiber 1
L_2- length of fiber 2

Procedure

Part I: Fiber preparation and connector assembly

1. Cut from the provided bare fiber a short piece (about 15 –20 cm).

2. By using the fiber stripper tool, strip about 1 cm of coating of the two fiber ends as shown in the picture.

Set the stripper blade distance to 1 cm (maximum width) to avoid damaging of the fiber core. Then press the yellow grips and gently pull on the stripper to peel off the black fiber coating. The transparent plastic fiber core is clearly visible now.

3. Add a FSMA connector to the fiber end. Unscrew the black connector sleeve and pull it over the fiber end. Insert the fiber tip fully in the connector. The bare fiber end has to poke out of the connector tip. With help of a sharp cutter cut the fiber end off about 1 mm above the connector tip. Finally, screw the connector sleeve tightly together with the connector.
4. **<u>NOTE:</u>** The tool kit contains a polishing disc and sheets of two types of polishing paper, the brown one with coarse grain and the white one with fine grain. Additionally it is recommended to use **isopropyl alcohol** as cooling agent.
5. Screw the connector in the polishing disc threaded nipple. Start with the brown paper and wetter a part of it with the alcohol. At the wetter place, polish the fiber by moving the disc in the shape of the figure 8, as shown in the picture. When the surface of the fiber tip looks homogeneous, repeat the same procedure with the white polishing paper to achieve the fine polish. If the surface looks clear and without scratches, the connector is ready to use.
6. Repeat the whole procedure with the other fiber end as well.

Part II: Attenuation measurements of plastic fiber lines

1. Symmetry of POF Y-coupler

For the following measurements, use the modulator in the AM operation mode.

i) Unplug one of the Y-coupler input lines from one channel of the **PO-Fiber Out** section on the rear plate. Now one color is transmitted only.

ii) Detect the relative intensity transmitted to the photo detector.

iii) Exchange the input lines that the same color is fed in the second line now.

iv) Detect the relative signal intensity again and compare with the previous value.

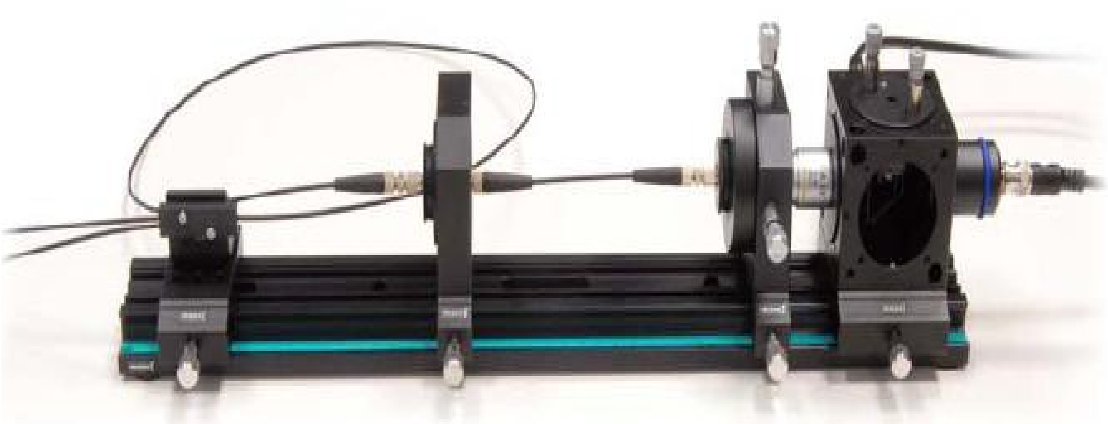
v) Repeat the measurement for the other channel (other color) in the same way.

2. Attenuation of connector pair

i) Plug the two input lines of the Y-coupler in the two channels of the **PO-Fiber Out** section and measure again the signal intensities of the two channels as a reference.

ii) Unplug the output line of the Y-coupler from the XY adjustment holder and connect it with the FSMA coupler in holder (Part 4).

iii) Install the short fiber line with two connectors prepared in **Part I** between the FSMA coupler and the XY adjustment holder as shown in the picture below.



iv) Do not change the alignment of the XY adjustment holder!. Now detect the signal value of the two channels and calculate the attenuation of the two connectors. The attenuation of the short fiber piece may be neglected in first approximation.

3. Attenuation of plastic optical fiber

i) Exchange the short fiber line by optical fiber has length of 10 m. Then measure attenuation value of the optical fiber. The attenuation of the two connectors measured in step 2 has to be subtracted to get the value of the fiber attenuation.

ii) Repeat this measurement with the optical fiber length of 20m.

iii) Repeat this measurement with the optical fiber length of 30m.

v) Plot the attenuation values as a function of the optical fiber length and calculate the attenuation per meter and per km.

vi) Repeat the measurements for FM modulation as well.

Discussion

1. Comment on your results.
2. Compare between the plastic optical fiber and glass optical fiber.
3. State the advantage and disadvantage of plastic optical fiber.
4. Is there a difference of the attenuation for the red and the green channel?

References

1. Casimer M. DeCusatis and Carolyn J. Sher DeCusatis, "Fiber Optic Essentials", Academic Press is an imprint of Elsevier, 2006.
2. Barry Elliott and Mike Gilmore, "Fiber Optic Cabling", Newnes, Second edition 2002.
3. User Manual , "Laser Education Kit CA-1400 Plastic Fiber Optics", MICOS Com.

Experiment No. 5
Attenuation-Limited Fiber Length

Objective: To calculate the attenuation-limited fiber length based on the power budget equation. Simulate the resulting system and verify that it meets performance objectives.

Theory

The power budget equation states that the power budget in a transmission system must equal the sum of all power losses plus the power margin. The power budget is the difference between the transmitter output power and the receiver sensitivity in dBm. The equation is thus

$$P_T - S_R = AL_F + L_C + L_A + M$$

Where

- PT = transmitter output power (dBm)
- SR = receiver sensitivity (dBm)
- A = fiber attenuation (dB/km)
- LF = fiber length (km)
- LC = coupling loss (dB)
- LA = additional known losses (dB)
- M = power margin (dB)

In this exercise, all parameters in the above equation are given except the fiber length, which must be determined.

The receiver sensitivity is defined here to be the minimum power required in order to achieve a BER of 10^{-9}, which corresponds to a Q factor of 6. The receiver sensitivity depends on the bit rate. The fiber attenuation depends on the operating wavelength.

Pre-lab Calculations

Using the power budget equation above and the parameters listed below, determine the attenuation-limited fiber length.

Transmitter output power	0 dBm
Operating wavelength	1550 nm
Bit rate	2.5 Gb/s
Receiver sensitivity	-30 dBm
Fiber attenuation	0.19 dB/km
Number of connectors	2
Loss per connector	0.5 dB
Additional known losses	0 dB
Power margin	6 dB

Layout

The system has been created using OptiSystem and exported as an OptiPerformer file. There are two versions; one for 2.5 Gb/s and one for 10Gb/s. Work with the 2.5 Gb/s first. An optical attenuator has been used to represent the connector loss and the system margin. When you open up the OptiPerformer file, there will be a list of parameters that you can adjust. They are located near the bottom right hand corner. Adjust the parameters according to the above table. Also, the dispersion and nonlinear effects in the fiber have been disabled.

To set the receiver sensitivity to -30 dBm for 2.5GB/s, make sure the

thermal noise parameter in the receiver is set to 8.97e-24 W/Hz.

The necessary visualizor components to have been placed in the OptiPerf

Simulation

1. Run the simulation and record the following data:

- **Optical power levels (dBm)**
  - Both ends of fiber
  - Receiver input
- **BER analysis**
  - BER
  - Q factor
  - Eye diagram

2. Set the fiber length to 125% of the value calculated in the pre-lab and repe

Analysis and Report

1- Compare the results of the simulations and your pre-lab calculations, and record your observations and explanations of differences in your lab report.

2- Written summary of your observations

Experiment No. 6
Optical Fiber Driver (Transmitter)

Experiment Aim

To design and study the Laser diode and Light Emitting Diode (LED) driver electronic circuit for optical fiber (optical fiber transmitter).

List of equipment

- Oscilloscope
- Optical Fiber Communication Experiment Kit
- Signal generator
- Optical fiber power meter
- AVO meter
- Wires
- Optical fiber: 3m multi-mode

Introduction:

The most commonly used optical source is the *LASER* diode (**L**ight **A**mplification by **S**timulated **E**mission of **R**adiation). Physically, a laser converts electrical current to light, which is in turn coupled into an optical fiber. An important characteristic of a laser is its threshold current. A typical current Vs optical output power is shown in Fig.(1)

A simple circuit to operate a laser diode (LD) or LED (remember that semiconductor lasers and LED's are just forward-biased PN-junction diodes) is shown in Fig.(1). Generally, signal sources can only supply tens of milliamps with any amount of speed. Therefore our circuit in Fig.(1) cannot even be realized. We need a driver!

The simplest scheme for driving an LED or LD requires a transistor as shown in Fig.(2-a). A description of how the circuit works given in Figures (2-b) and (2-c).

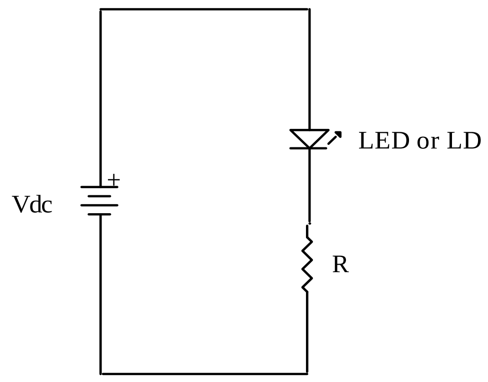


Fig.(1)

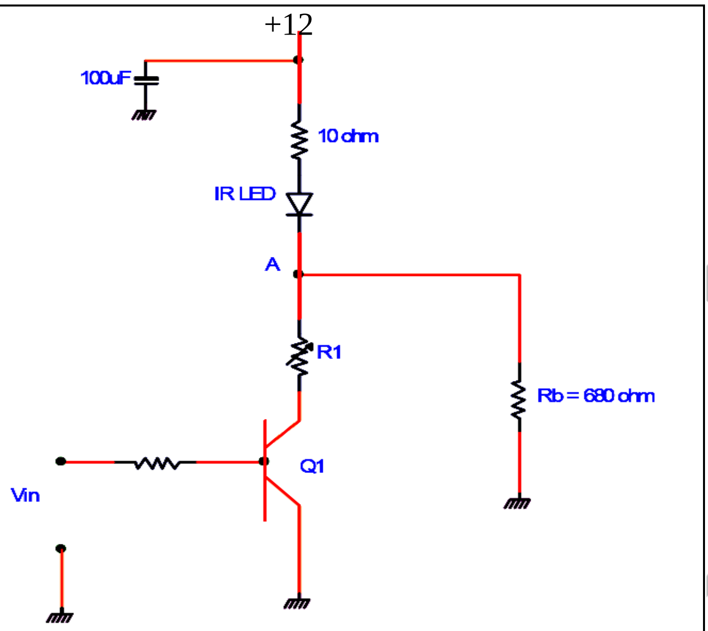


Fig.(2-a): A simple LED driver

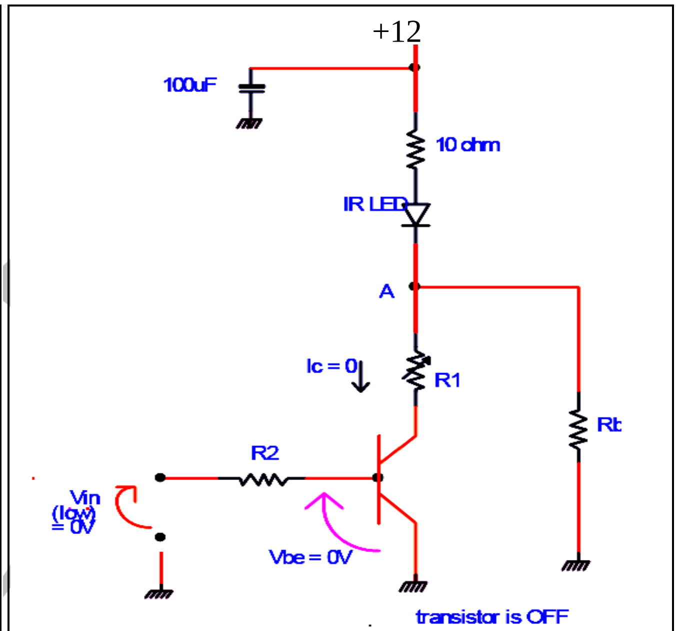


Fig. (2-b) Biasing of LED in the "low" state

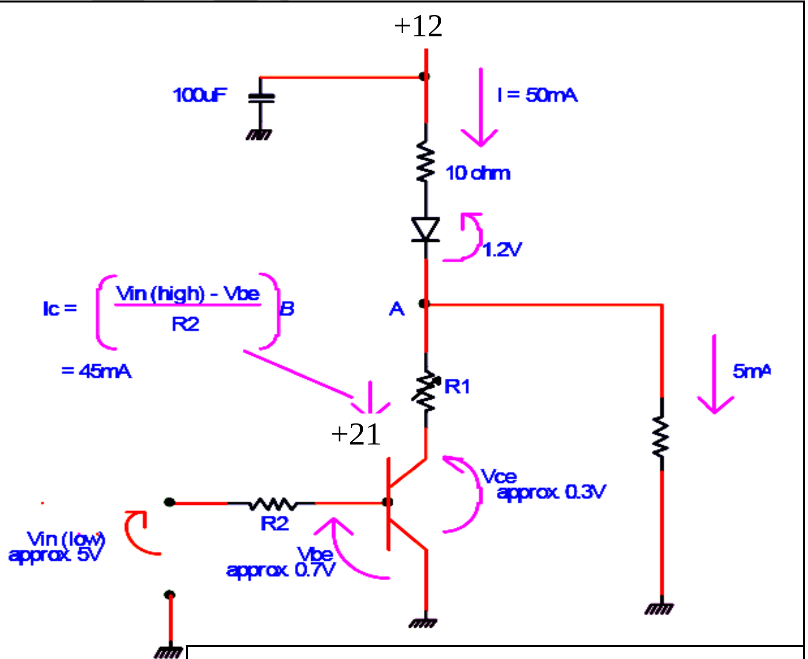
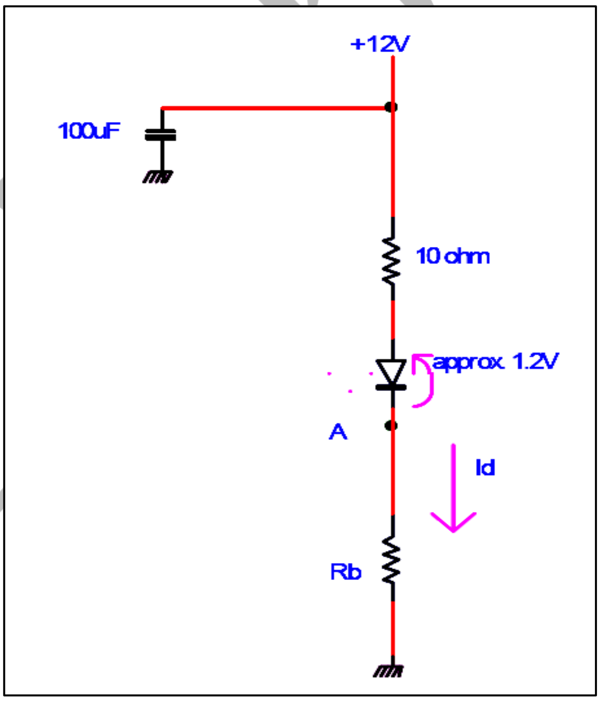


Fig. (2-c) Biasing of LED in the "high" state

1. *At low state*, the equivalent circuit of the circuit in Fig.(2-b) is show below.



let I_d =5mA, then:

$$R^b = \frac{V_{cc} - V_d - I_d \times 10}{I_d}$$

$$R_b = \frac{12 - 1.2 - 5mA \times 10}{5mA}$$

$$=2150\Omega$$

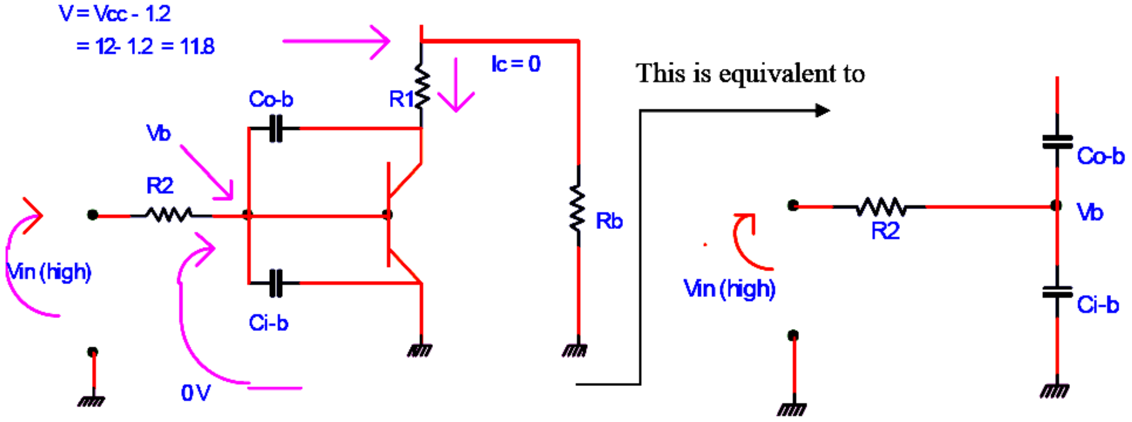
2. *At high state,* the circuit in Fig.(2-c) represent the laser diode driver operate in the high state (ie. the input voltage = 5volt, and the Vce=0.3V)

Let the maximum diode current =70mA
Then,

$$R_1 = \frac{12 - (10\Omega)(50mA) - 1.2V - Vce(sat)}{70mA} = 142\Omega$$

3. Discuss the effect of the transistor base charge

i. "just at turn-on" when $V_{in} = V_{in}$(high)



The delay time, the time for Vb(α) = VBE(n) (i.e. to turn on the transistor),

$$t = -\tau \ln \left\{ 1 - \frac{V_{be}(m)}{V_{in}(high)} \right\}$$

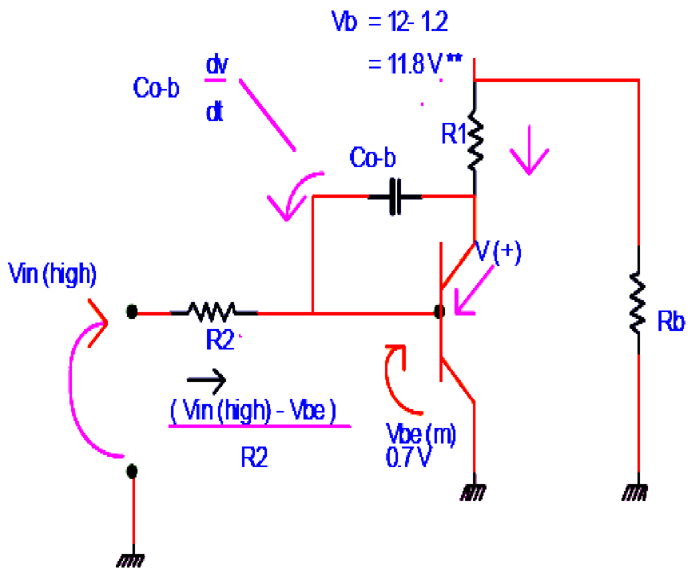
Now, we must include the charging of minority carriers in the base. From the transistor data sheets, the charge in the base "to just turn-on the transistor" is given at I_c = 70mA, $\theta_A \approx$ 150pC. We can define an equivalent base-emitter junction capacitance as follows:

$$\frac{\theta_A}{V_{be}} = C = \frac{150pC}{0.7} = 214pF$$

$$\text{So } \tau \approx (C_{ib} + C_{ob} + C)\,R_2$$
$$\approx (15pF + 8pF + 214pF)\,1000\Omega \approx 237ns$$

$$t \approx -237\ln\left(1 - \frac{.7}{3}\right) = 244ns$$

ii. Transistor is "on", current begins to rise



$$\left(\frac{V_{in}(high) - V_{be}(m)}{R_2} + C_{ob}\frac{dV}{dt}\right)\beta + C_{ob}\frac{dV}{dt}$$

Therefore:

$$V(t) = V_b - \left(\frac{V_{in}(high) - V_{be}(m)}{R_2}\right)\beta \cdot R_1 + (1+\beta)\, C_{ob}\frac{dV(t)}{dt} R_1$$

Solving this differential equation with $V_b \approx$ constant yields:

$$V(t) = -\beta\,\{ V_{in}(high) - V_{be}(m)\}\frac{R_1}{R_2} \times \left(1 - e^{(-t/\tau)}\right) + V_b$$

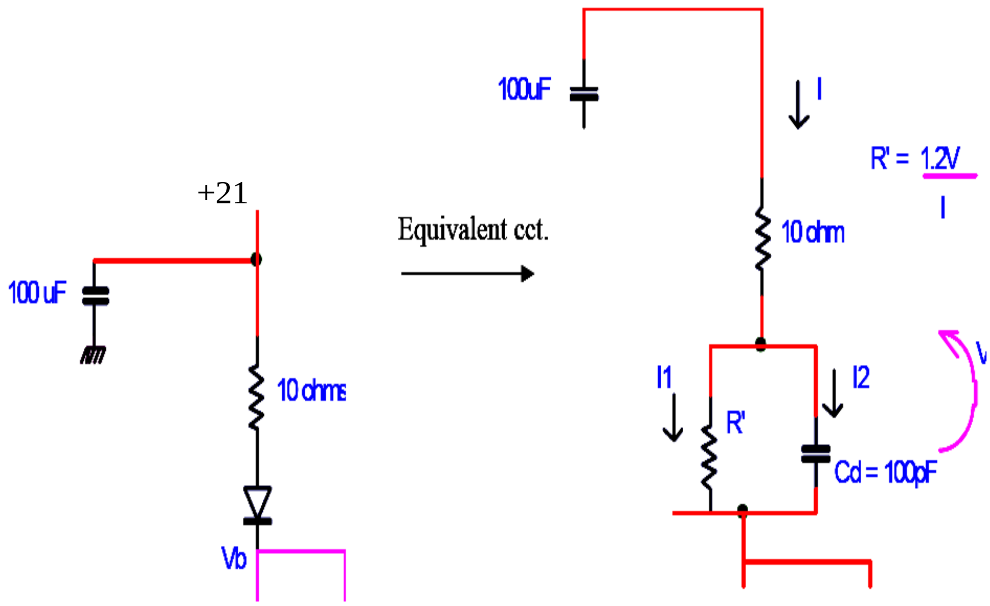
$$Z = (1+\beta)\, C_{ob} \cdot R_1$$

The turn-on time is roughly the time for V(t) ≈ Vce(sat) (ie. To put the transistor into saturation), or:

$$t = -\ln\left(1 - \frac{V_b - V_{ce}(sat)}{\beta\,(V_{in} - V_{be})\,(R_1/R_2)}\right)\tau$$

4. Discuss the effect of the LD capacitance

The LED capacitance effect into the rise time calculation. The "top" part of the circuit is shown below.



Note that it is generally difficult to solve for the rise time exactly because R' varies strongly during the turn-on period.

We can estimate the effect of the LED capacitance by the following argument:

$$I_2 \approx C_d \frac{dV}{dt} \approx C_d \frac{V_{d1} - V_{d2}}{\Delta t}$$

$$I = I_1 + I_2$$

Procedure

1. Connect the circuit shown in Fig. (2-a). The center of the optical fiber is mounted in an optical emitter.
2. Set the signal generator at square wave with Vpp= 3V, and frequency 100 kHz. Attach to the circuit as V_{in} and monitor the voltage at point ***A*** with a 10x probe and the signal out of the function generator on the other scope channel. Always use the probes instead of a direct input to the scope to prevent the reflections.
3. Check the voltage at point A on the oscilloscope, and adjust the resistor to the correct "on" current. The peak-to-peak voltage seen on the oscilloscope should be the difference in the "on" and "off" currents of the LD times 10 (10 Ω resistor).
4. Measure the rise and fall times of the signal generator. Then measure the rise and fall times of the diode current on the oscilloscope (by measuring point A).

5. Measure the falling edge on the time scale with the function generator waveform superimposed, and attaches a capacitor across R_2. Observe what happens. This is know as a speed-up capacitor, and decreases the storage time by storing charge to neutralize the base charge "just after turn-off". You can calculate the voltage across the resistor "just before turn off", and then calculate the minimum capacitance by the Q=CV relationship.
6. The LD capacitance can be a limiting factor in the turn-on time. Just as a rough guide of the switching time to turn on the LD, assume that this time is just the time to charge the LD capacitance with the collector current and use $I = C\, dV/dt$.

Results and discussion Results and discussion

1. The rise, fall, storage and delay times limits the maximum frequency which you can transmit digital information. Explain this statement. Hint: Use diagrams to illustrate your point by taking V_{in} as a square wave and roughly draw the LD optical output.
2. Why the laser diode has internal capacitance?
3. What effects of the internal laser diode capacitance on the output optical power?

Experiment No. 7
Optical Fiber Receiver

Experiment Aim

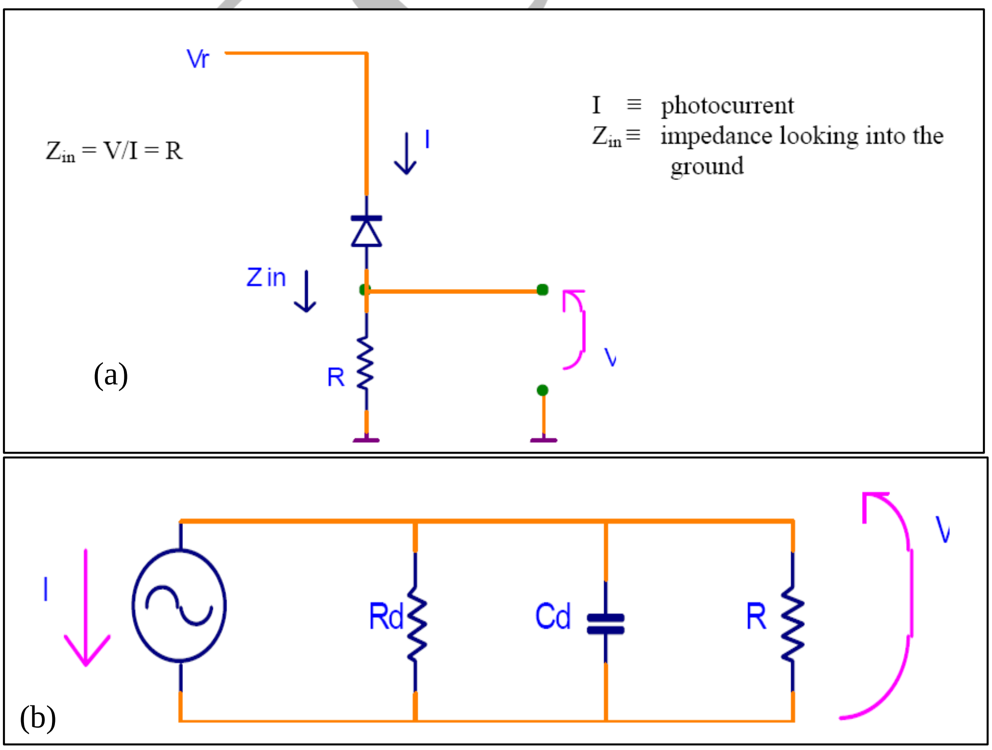
To design and study the optical fiber receiver.

List of Equipment

- Oscilloscope
- Optical Fiber Communication Experiment Kit
- Signal generator
- AVO meter
- Wires
- Optical fiber: 3m multi-mode

Theory

It can detect optical signals by using a reversed biased diode and a resistor as shown in Fig(1-a). The voltage across the resistor is just given by the product of the photocurrent and the resistance. The small-signal equivalent circuit for sinusoidal optical signals incident on the detector, is shown in Fig.(2-b). Note that the voltage at low frequencies is still given by the V=IR relation, but the diode capacitance rolls off high frequencies with a 3dB point at $f=1/(2\pi RC)$.



Fig(1): a) Circuit to measure optical power incident on a reverse-biased detection.
b) Small signal AC equivalent circuit

But with low received optical power, the photodiode can't delivered enough current. Therefore, the trans-impedance amplifier used to amplify the photodiode current. The trans-impedance amplifier in this experiment is constructed from a resistor and an op-amp, shown schematically in Fig.(2-a). It converts current into voltage. An explanation of this is given in Figure (2-b) using the simplified circuit model for the op-amp. An important point is that the input impedance of the trans-impedance amplifier is R_f/A, where A is the frequency dependent open loop gain. This lower effective impedance affects the bandwidth and the dynamic range of the amplifier.

If we attach the reverse-biased photodiode as shown in Fig.(3-a), the amplifier now gives a voltage V=I×R, except that now the resistance "seen" by the photodiode is R_f/A. Therefore, the operation amplifier gives us A times the bandwidth of amplifier.

$$V_a = V + IR_f$$

Or $$V_a = -AV_a + IR_f$$

Or $$(1 + A)V_a = IR_f$$

Or $$\frac{-V}{A}(1+A) = IR_f \rightarrow V = \frac{-A}{1+A} IR_f$$

$$\approx -IR_f \quad \text{for } A>>1$$

$$Z_{in} = \frac{V_a}{I} = \frac{IR_f}{1+A} \times \frac{1}{I} = \frac{R_f}{1+A} \approx \frac{R_f}{A}$$

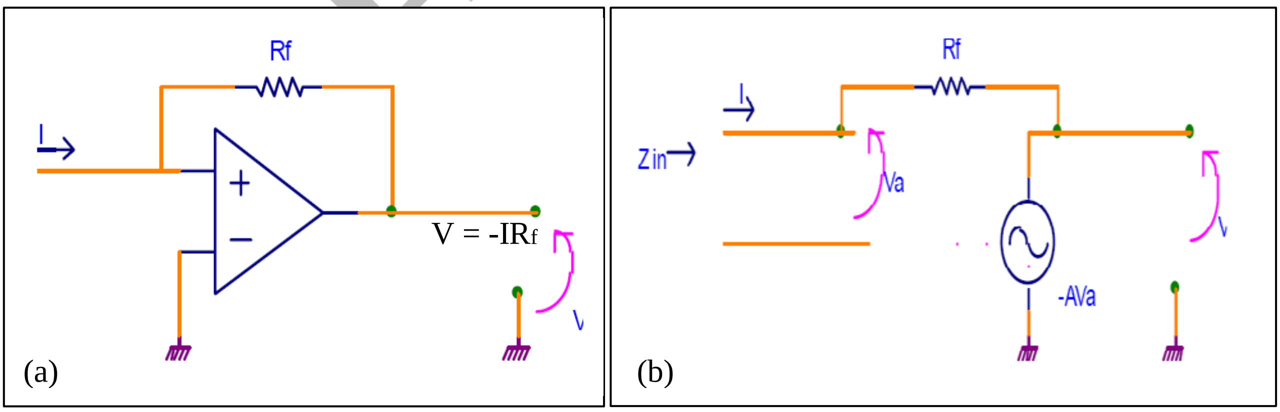


Fig.(2): a) Trans-impedance Amplifier
b) Equivalent circuit of trans-impedance amplifier.

For enhanced the operation of receiver, It can add an addition to the receiver, which converts the distorted detected pulses into digital logic signals again. For this, we will be using a LM311 comparator with ground as our decision level. Connect the output of the trans-impedance amplifier to the input of the comparator. Then by using the DC offset of the op-amp, position the amplifier waveform about the decision level (halfway between the high and low voltages) so that the comparator can make its decision. The comparator circuit is shown in Fig. (4). Connect one scope input to point A and the other to point B, and both scope inputs should be on DC since we are interested in some absolute DC threshold.

Procedure

1. Connect the amplifier circuit shown in Fig.(3) on the Optical Fiber Trainer "OPF". The circuit consists of the trans-impedance amplifier, a voltage reference, and a reverse biased photodiode as a current source. A current limit is imposing on the photodiode without changing the RC time constant of the circuit at high frequencies. ***Be very careful*** that the photodiode is connected in the correct polarity in the circuit.
2. Compare the two waveforms "the detector output at point C of Fig.(3) and LED drive current as before".
3. Measure the rise and fall times (Remember that this is an inverting amplifier, so a rising edge will look like a falling edge on the scope).
4. Look at the detected waveform rising and falling edge when one of the 2.2pF feedback capacitors is removed.
5. Increase the frequency, examine simultaneously on the scope the electrical pulse of the LD drive current, and compare to the detected pulse as you increase the frequency.
6. Examine in detail the frequency "roll-off" of the detected signal by measuring the peak-to-peak amplitude of the received signal versus frequency.
7. As shown in Figure (3), a voltage adjust on the positive op amp input provides an output offset adjustment. Observe that this adjustment is working.

Discussion

1. Explain the circuit operation in your report.
2. From results, determine the bandwidth of trans-impedance amplifier and the rise times you have measured.
3. Comment on the relationship between the output voltage and frequency. Explain why these changes might occur.
4. Explain the relation between the input impedance "Zin" and photo current amplifier gain.

5. What difference between bipolar transistor operational amplifier and FET operational amplifier. What type of OP-AMP used in the optical fiber receiver circuit? Why?.

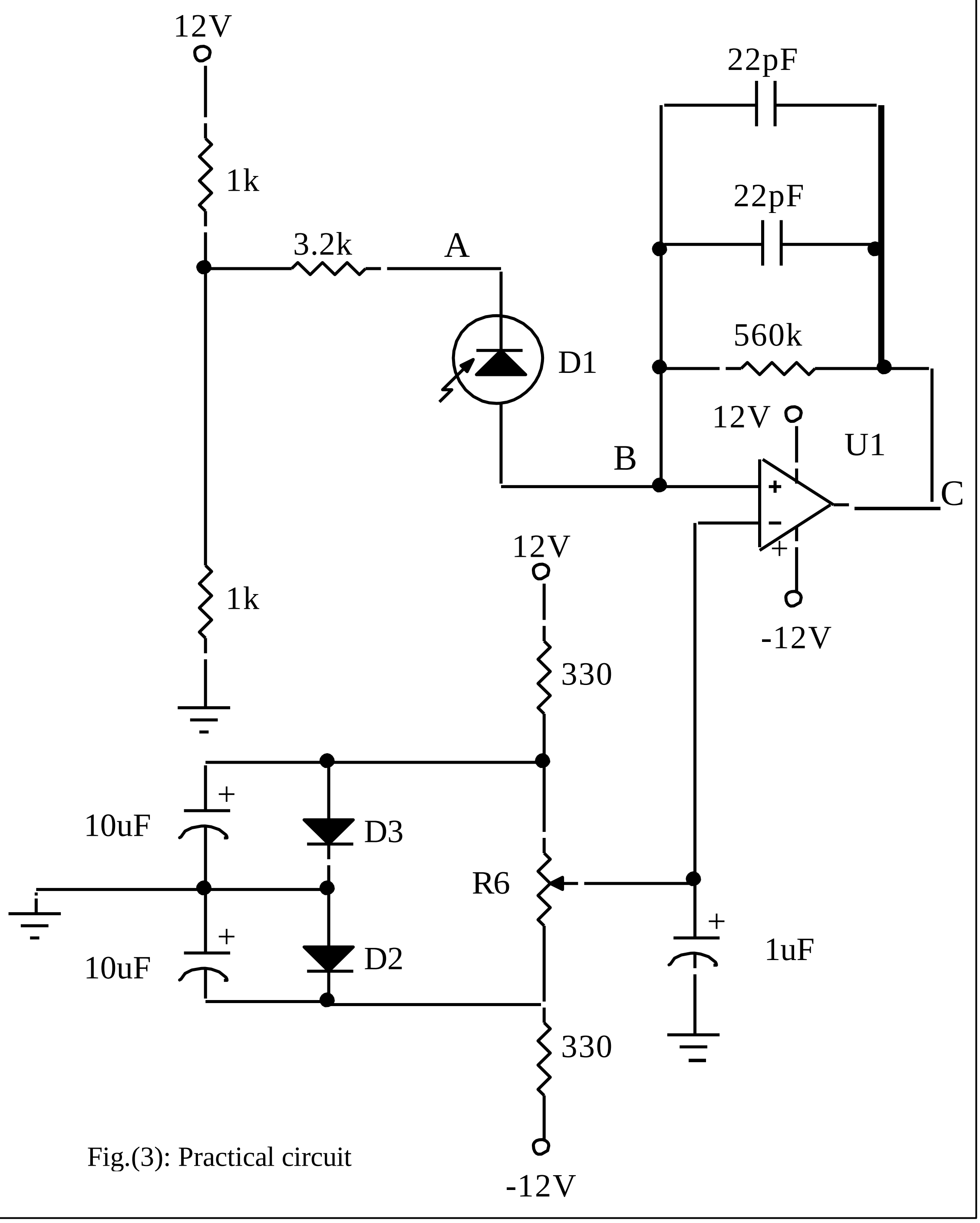


Fig.(3): Practical circuit

Experiment No. 8
Receiver Performance Analysis
"Eye Diagrams, Noise and Bit Error Rate"

Experiment aim

The aim of Experiment is to analyze the receiver performance by using the eye Diagrams, noise and bit error rate.

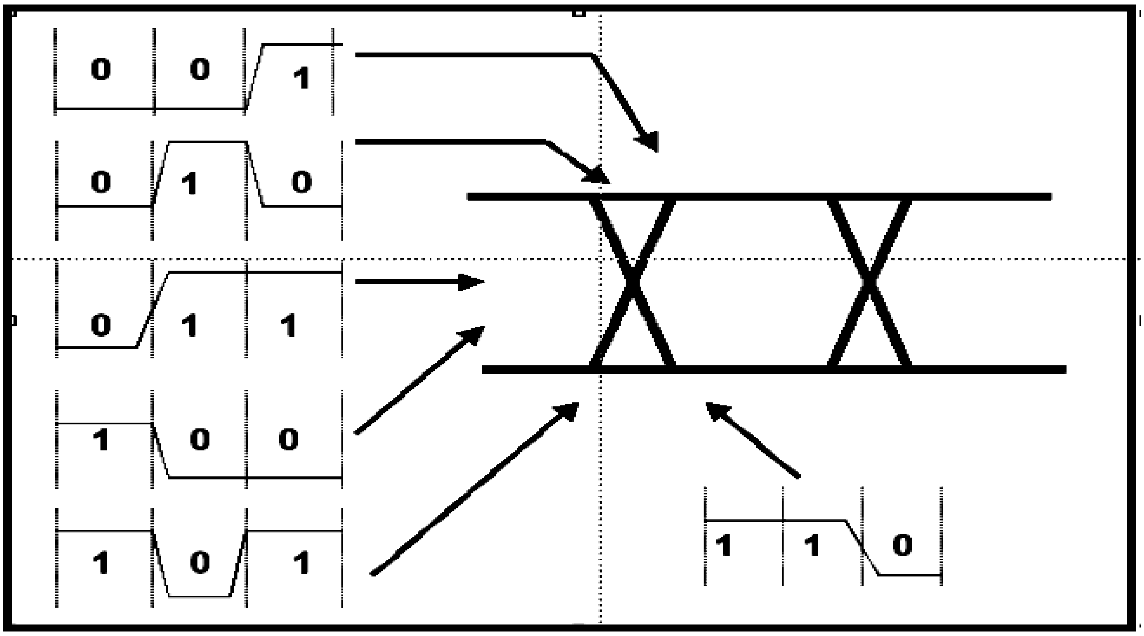
Apparatus

- Oscilloscope
- Optical Fiber Communication Experiment Kit
- Signal generator
- Pulse Counter
- AVO meter
- Wires
- Optical fiber: 3m multi-mode

Theory

Eye diagrams are generated on a digital oscilloscope and are used to measure the reliability and performance of the communication system. It can be used to measure the quality of the transmission link.

An eye diagram is a display showing overlapping of all the possible one-zero combinations . Eye diagram are known as multi-valued displays, because each point in the time axis has multiple voltage values. The width of the eye represents the pulse width or bit period. As the eye closes horizontally, it signifies that the bits are more closely together, increasing the possibility of ISI. The vertical aspect of the eye diagram shows how accurate the system can distinguish a bit ‘1’ and ‘0’. If the eye closes vertically, it signifies that the system will not be able to distinguish ‘1’s and ‘0’s accurately.

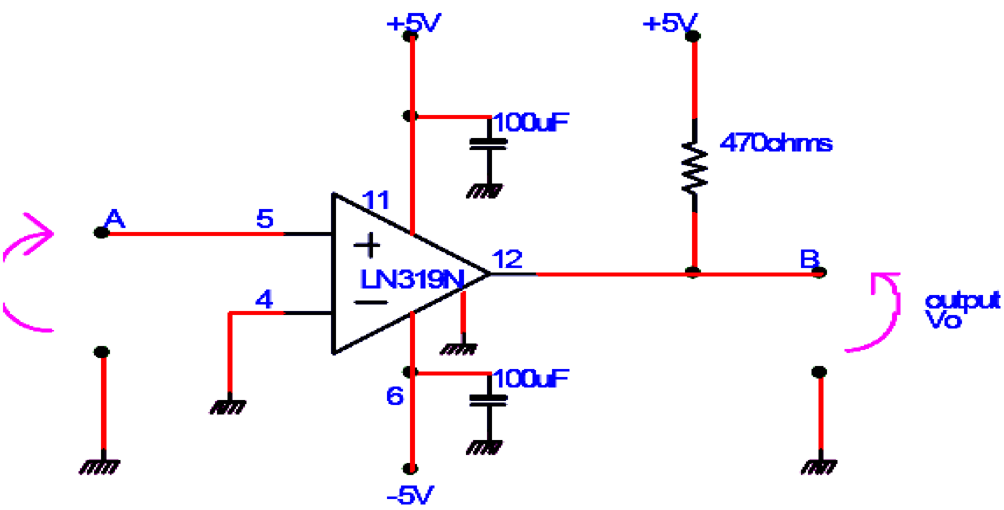


Procedure

We now make an addition to the receiver, which converts the distorted detected pulses into digital logic signals again. For this, we will be using a LM311 comparator with ground as our decision level.

1. Connect the output of the trans-impedance amplifier to the input of the comparator. Then by using the DC offset of the op-amp, position the amplifier waveform about the decision level (halfway between the high and low voltages) so that the comparator can make its decision. The comparator circuit is shown in Fig. (1).

2. Connect one scope input to point A and the other to point B, and both scope inputs should be on DC since we are interested in some absolute DC threshold.



3. Set the signal generator for a 100 kHz, 0V to +3V square wave. Connect a coax cable from the Sync-Out on the frequency generator to the external trigger on the oscilloscope for all future triggering. When the diode is driven by the random output, the detected waveform should be your eye diagram.

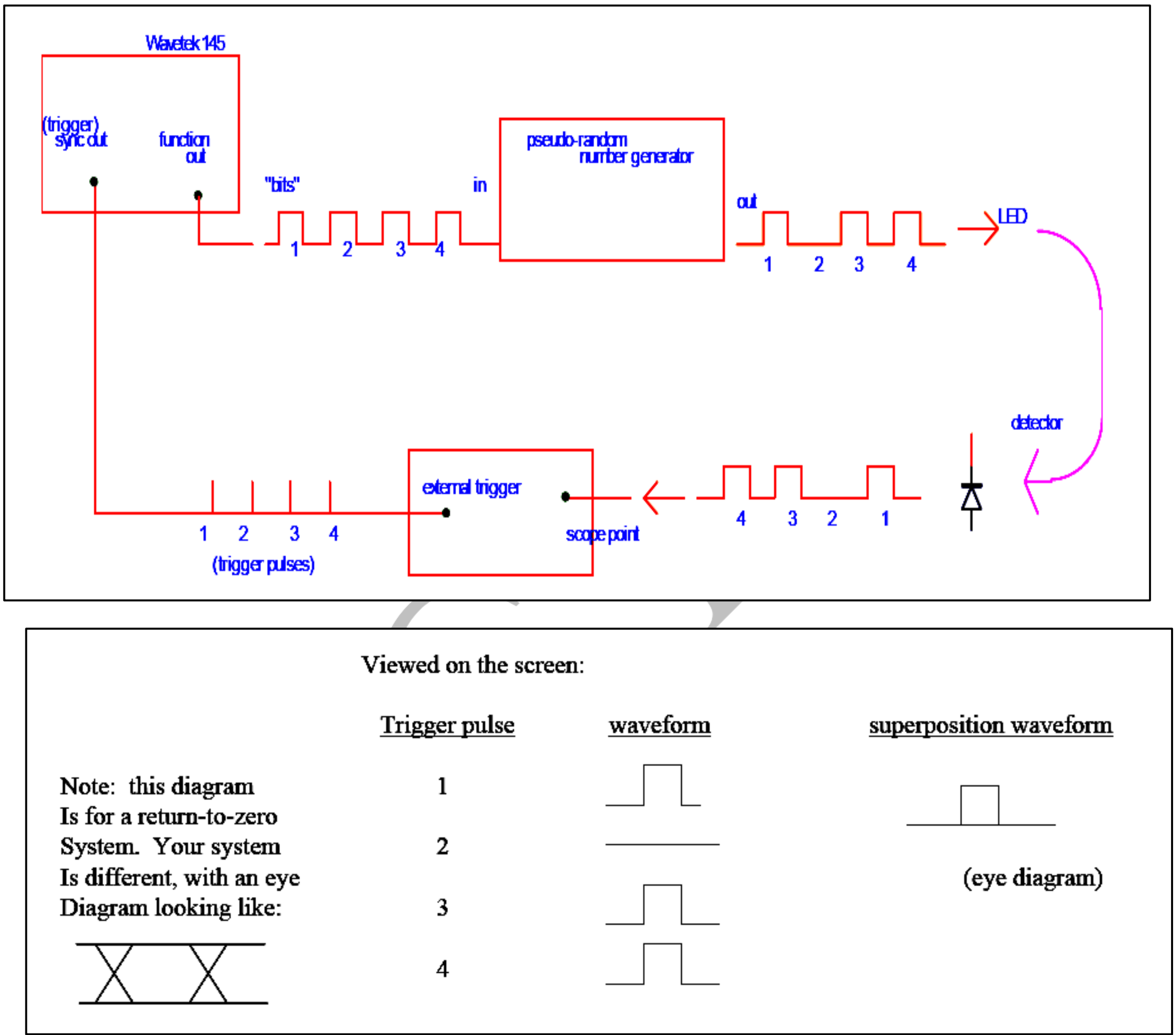


Fig.(4) shows the circuit for generating eye diagrams using a 4-bit pseudo-random number generator.

Discussion

1. Comment on your results.
2. Why you use the PN-generator to show eye diagram?
3. Plot the relationship between the bending radius and attenuation.

Experiment No. 9
Bending Losses in Optical fiber

Experiment aim

To measure the bend loss in several samples of grade index multi mode fiber as a function of bend radius.

Equipments

1. Bend board
2. 62.5/125µm (ST-to-ST) optical fiber
3. Reference light source
4. Optical power meter

Bending losses

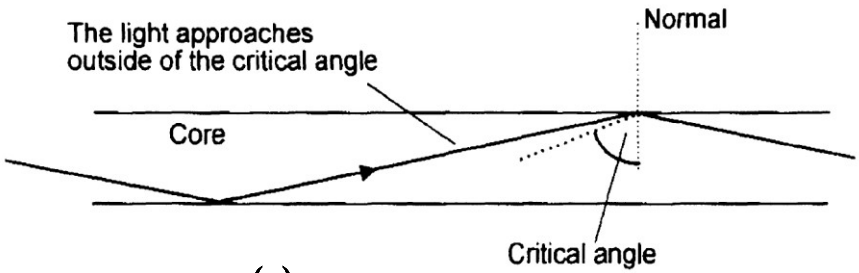
Radiative losses occur whenever an optical fiber undergoes a bend of finite radius of curvature. Fibers can be subject to two types of bend:

a. Macroscopic bends having radii that are large compared to the fiber diameter.

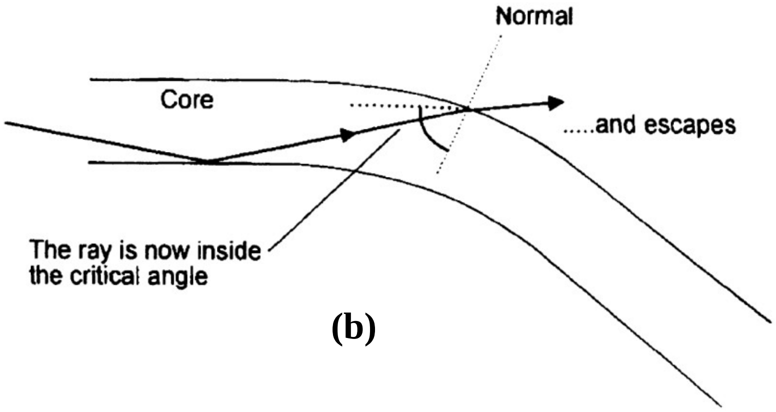
b. Random microscopic bend of the fiber axis that can arise when the fibers are incorporated into cables.

Let us examine large–curvature radiation losses, which are known as macrobending losses. For slight bend the excess loss is extremely small and is essentially unobservable. As the radius of curvature decrease, the loss increases exponentially until at a certain critical radius the curvature loss becomes observable. A sharp bend in a fiber can cause significant losses as well as the possibility of mechanical failure. The ray shown in Fig.(1-a) is safely outside of the critical angle and is therefore propagated correctly. Now, if the core bends, as in Fig.(1-b), the normal will follow it and the ray will now find itself on the wrong side of the critical angle and will escape.

The tighter the bend cause the worse the losses. Therefore; the critical radius determined by attached instruments indicated a loss of over 6 dB. If bending radius is smaller than critical radius causes damage in optical fiber.

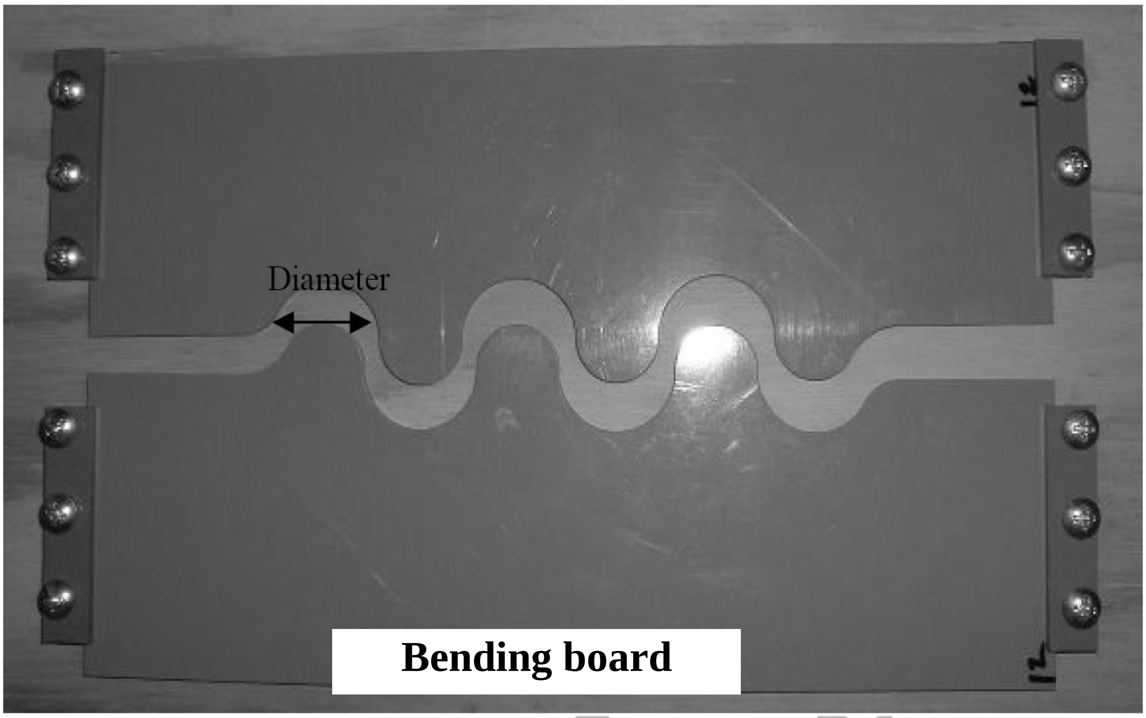


(a)



(b)

Fig.(1)



Procedure

1- Connect the first ST end of optical fiber to the reference light source and the second ST end to the optical power meter. Make sure the optical fiber straight line no loops or bend.
2- Turn on both reference light source and optical power meter, and then write the measured value of optical power.
3- By using bend board (25mm diameter part); bend the optical fiber according to the figure of bending.
4- Record the optical power against as shown in table below.
5- Repeat steps (3, 4) with bending diameters (17.5mm, 15mm, 10mm).
6- Connect the digital transmitter and receiver on the training optical fiber board. Then insert the optical fiber.
7- Start to transmit the data over optical fiber. Make sure the optical fiber with no loops or bend.
8- Plot the output signal on the graph paper

9- By using bend board (25mm diameter part); bend the optical fiber according to the figure of bending. Then plot the output signal on the graph paper.

10- Repeat step (9) with bending diameters (17.5mm, 15mm, 10mm, and 8mm).

Bending diameter (mm)	Bending radius (mm)	Optical power (dBm)	Attenuation (dB)

Results and Discussion

a. Using the data from the table, carefully plot on a single graph the bending loss in dB as a function of bend radius.

b. Comment on the results.

State the some application of the bending losses concept.

Experiment No. 10
Digital Communication over Fiber Optics System

Experiment aim

The experiment aim of this experiment is to analyze the operation of Non-Return to Zero(NRZ), Return to Zero(RZ) and Pulse ration encoders and decoders. Construct a digital transmission system applying these data codes to optical transmitter and analyze the decoding of data through a fiber optic cable.

Apparatus:

- Oscilloscope
- Optical Fiber Communication Experiment Kit
- Signal generator
- Wires
- Optical fiber: 3m multi-mode

Theory

In digital communication systems, data bits are represented through electric signals. The simplest format uses two levels, to represent the binary digits **1** and **0** (**+5V for 1 and 0 V for 0**). Normally the level is kept fixed for the duration of a bit. This is called **Non Return to Zero** (**NRZ**) format.

Generally, the level changes that occur in a **PCM** transmission are used to keep the receiver clock synchronized to the transmitter. Every time the transmitted signal changes its level, the sudden change in voltage is detected by the receiving circuit and used to ensure that the receiver clock remains locked on to the transmitter clock. There are problems when the incoming signal stays at a low level or a high level for a long period of time as shown in Figure (1). The constant voltage level gives an output of continuous ones or zeros and the timing information would be lost and the receiver clock would drift out of synchronization.

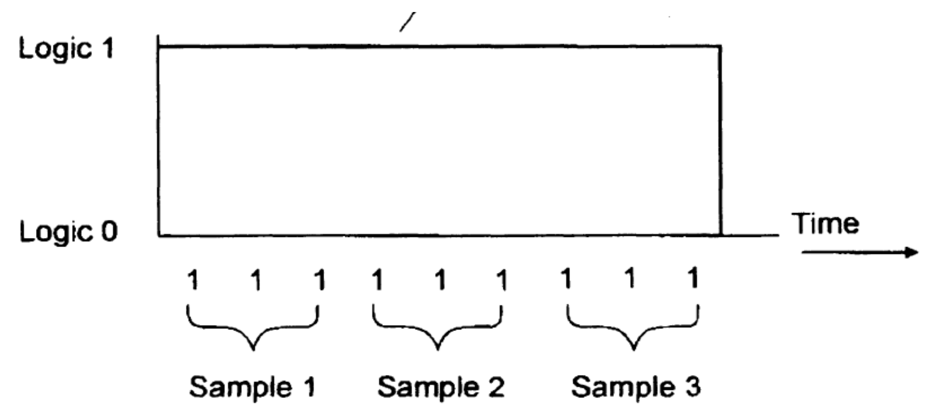


Fig.(1): The data is at a constant value and there are no changes

There are several different methods of coding the data prior to a digital transmission that overcomes the problem of continuous levels. These methods of coding are:

1. *Non-return to zero code (NRZ)*
The transmitted data with non-return to zero are identical to the input data as shown in Fig.(2).

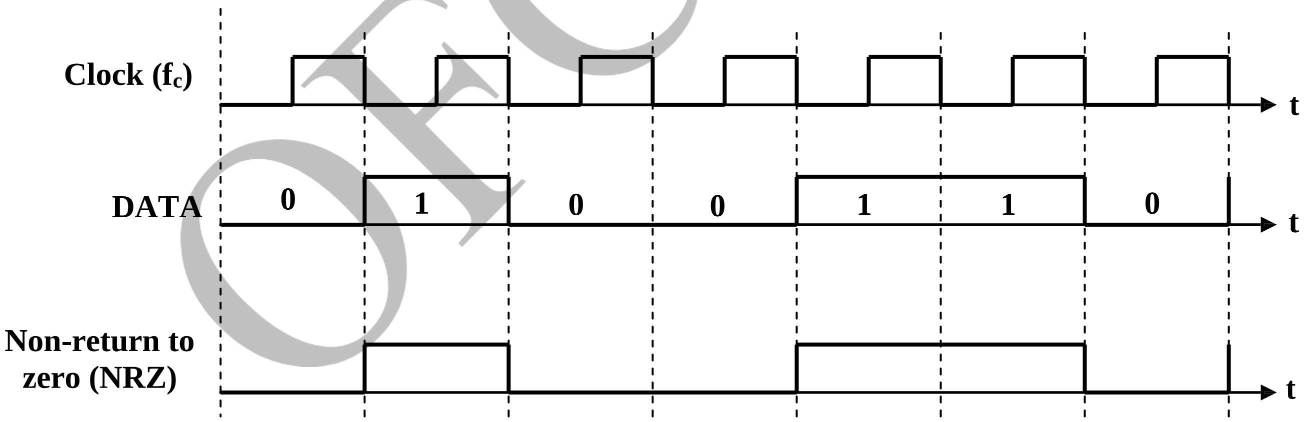


Fig.(2): Non-Return to Zero pulse encoding format

2. *Return to Zero code (RZ)*

In Return to Zero code (RZ), each bit interval begins with a transition, either high to low or low to high. If the datum being encoded is a 1, a second transition occurs at mid-interval. If the datum is 0, there is no transition as shown in Fig.(3).

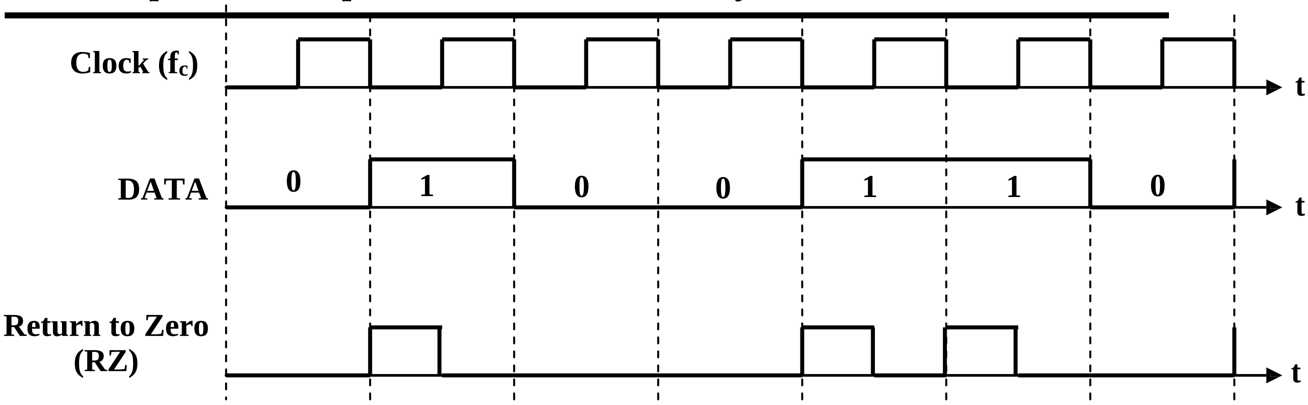


Fig.(3): Return to Zero pulse encoding format

3. Pulse ratio code (Manchester Code)

In the pulse ratio code, if the data is logic **1**, the transition will be from high to low level with pulse width is large (equal to 75% of clock time), if it is **0** the transition will be high to low level with pulse width is small (equal to 25% of clock time) as shown in Fig.(4). Theses transitions can be used as reference edges for regenerating the clock in the receiver.

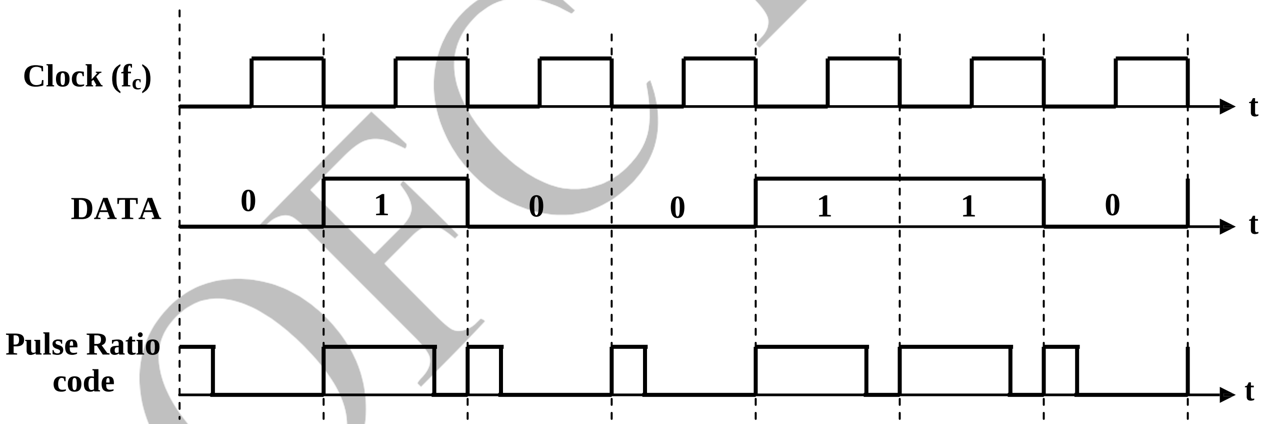


Fig.(4): Pulse Ratio encoding format

Procedure

1. Connect power cables to the fiber optics trainer system.
2. Connect the output of Data Source to input of NRZ encoder.
3. By using oscilloscope, plot on graph paper "same axes" the output of digital clock and output of NRZ encoder.
4. Connect the output of NRZ encoder to the optical fiber transmitter. Then connect the optical fiber to optical receiver after connect the wires between the output of optical detector and NRZ decoder.

5. By using oscilloscope, plot on the same graph paper "same axes" the output of optical receiver and output of NRZ decoder.
6. Repeat the steps (2-5), by using the Return to Zero (RZ) encoder and decoder blocks.
7. Repeat the steps (2-5), by using the Pulse Ratio encoder and decoder blocks.

<u>Discussion</u>

4. Comment on your results.
5. Why you use the coding in digital system?
6. Compare between the RZ code and Pulse ratio code.
7. From comparison, is the RZ is better than Pulse ratio code? Why?
8. Design a digital circuit to produce the RZ coding and decoding
9. Design a digital circuit operate as Pulse ration encoder and decoder.

Experiment No. 11
Fiber Dispersion

Objective:

Calculate the dispersion-limited fiber length for a fiber optic transport system that employs standard single-mode fiber and a directly-modulated single-mode laser diode transmitter.
Simulate the resulting system and verify that it meets performance objective.

Theory:

The maximum allowable dispersion (or pulse spread) Δt_{max} is given in terms of the transmission rate R by the following engineering guideline

This guideline provides reasonable assurance that there will be no significant intersymbol interference (ISI) due to pulse spread.

For standard single-mode fiber driven by a directly-modulated laser diode transmitter, the pulse spread due to chromatic dispersion is given by

$$\Delta t = LD(\lambda)\Delta\lambda$$

Where

- Δt = pulse spread (ps)
- L = fiber length (km)
- $D(\lambda)$ = chromatic dispersion factor (ps/nm-km)
- λ = operating wavelength (nm)
- $\Delta\lambda$ = spectral width of the transmitter output (nm)

The chromatic dispersion factor can be calculated from the formula

where

- S0 = zero dispersion slope (ps/nm2-km)

- $\lambda 0$ = zero dispersion wavelength (nm)

The dispersion-limited fiber length is the value of L such that $\Delta t = \Delta t_{max}$.

Note that there can be additional pulse spread due to the transmitter and receiver rise times. The somewhat conservative engineering guideline allows for this, but the results of the simulation should be checked to verify acceptable system performance.

Pre-lab Calculation:

The specifications for the system are summarized in the table below

Transmitter	Transmission rate	2.5	Gb/s
	Output power	0	dBm
	Operating wavelength	1550	nm
	Spectral width	0.6	nm
Fiber	Zero-dispersion slope	0.09	ps/nm2-km
	Zero-dispersion wavelength	1312	nm
	Input/output coupling efficiency	0	dB

The fiber attenuation factor and coupling efficiencies are set to 0 in order to isolate the effects of dispersion from those of attenuation.

Using the data in the table (and in the fiber data sheet) and the theory summarized above, determine the dispersion-limited fiber length.

Layout:

Open up the Opti Performer file called “Dispersion Limited Fiber.osp”. This layout uses the Laser Rate Equations laser diode component with default parameters. It models a directly modulated laser diode based using a standard rate equation model. One of the effects of this model is that it generates a signal with a spectral width of about 0.6 nm for the default parameters with 2.5 Gb/s, return to zero modulation.

Within the layout, there are several “Visualizers.” The “Optical Time Domain Visualizers” allow the user to the view the simulated signal as a function of time. There is one at the output of the laser and one at the end of the fiber. This allows the user to directly observe the changes in the pulses due fiber dispersion. The “Optical Spectrum Analyzer” allows the user to view the spectral content of the signal. It this lab it is used to verify that the spectral width is about 6 nm. The “BER analyzer” provides calculations of the Q factor, the bit error rate (BER) and provides a plot of the eye diagram.

Simulation:

Set the laser power such to achieve a transmitter output power of 0 dBm. The transmitter power can be viewed by double clicking the “Output Power Meter Visualizer.” The power will read -100 dBm until the first run is made. Using the chromatic dispersion factor equation, determine the dispersion of the fiber at 1550 nm and set the fiber dispersion parameter accordingly.

Using the equations above, determine the dispersion-limited fiber length.

Run the simulation 5 times with the following values for fiber length:

Iteration	Fiber Length
1.	Calculated dispersion-limited fiber length
2.	25 km
3.	50 km
4.	75 km
5.	100 km

After the first run, use the optical spectrum analyzer to verify that the
spectral width at the transmitter output is about 0.6 nm. To do this, right click on the spectrum plot and choose “Marker”. Place one marker on either side of the main signal. The spectrum is noisy so a precise measurement can not be obtained in this way, but it should be clear that the spectral width is about 0.6 ± 0.1 nm

For each iteration:

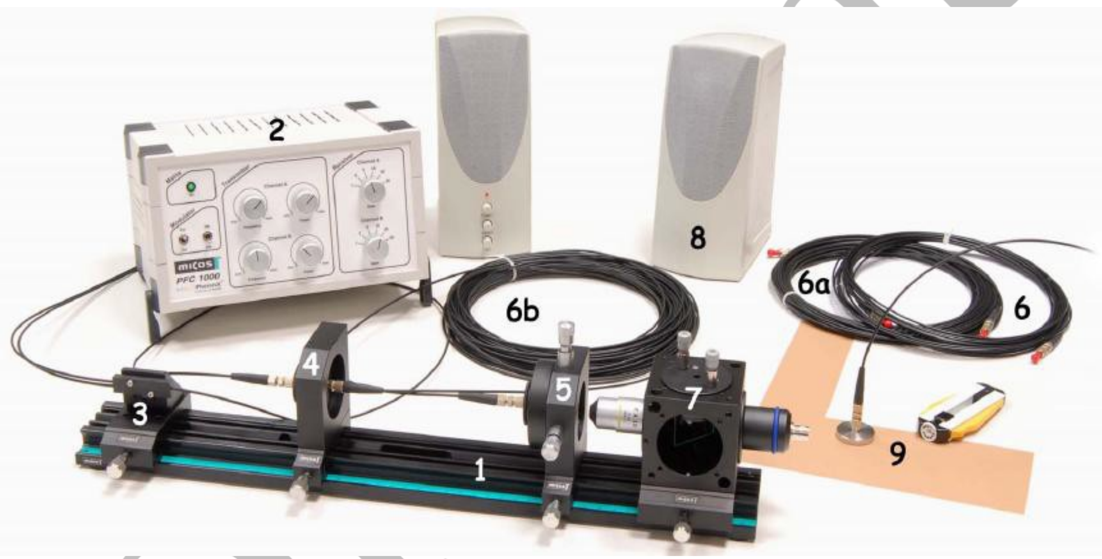
- Use the BER analyzer to measure and record the Q factor, the bit error rate and the eye diagram.
- Use optical time domain analyzers to compare the pulse width at the input
and output of the fiber.

Analysis:

Compare the result of the simulations and your pre-lab calculations and record your observations. Provide an explanation for any differences between the pre-lab calculations and the simulation results.

Experiment No. 12
Transmission of AM signals carried by two wavelengths over plastic optical fiber

Aim of experiment: To transfer two AM signals over plastic optical fiber.



Apparatus: the above picture shows the experiment parts and they named as follows:

1. Part 1: Flat rail 500 mm with scale
2. Part 2: Plastic Fiber Controller PFC 1000
3. Part 3: POF Y-coupler on carrier
4. Part 4: FSMA coupler in holder on carrier
5. Part 5: FSMA coupler in XY adjustment holder on carrier
6. Part 6, 6a and 6b: POF cables with two FSMA connectors
7. Part 7: Wavelength separator unit on carrier
8. Part 8: Pair of active stereo speakers
9. Part 9: Set of tools for FSMA connector assembling
10. Part 10: Set of BNC cables (not shown)

Amplitude modulation

In optical communications systems, the source of light used is called a **transmitter**. There are several different types of transmitters, including light emitting diodes (LEDs) and various types of lasers. Their purpose is to convert an electrical signal into an optical signal, which can be carried by the optical fiber. This process is called **modulating** the source of light. For example, imagine a flashlight being switched on and off very quickly; the pattern of optical pulses forms a signal, which carries information, similar to the way a telegraph or Morse code system, operates.

Turning a light source on and off in this way is called **direct modulation** or **digital modulation**. The light can also be adjusted to different levels of brightness or intensity, rather than simply being turned on and off, this is called **analog modulation**. The simplest type of modulation involves changing the intensity or brightness of the light; this is known as **amplitude modulation** [1].

An important issue is related to the choice of the physical variable that is modulated to encode the data on the optical carrier. The optical carrier wave before modulation is of the form

$$\mathbf{E}(t) = \hat{\mathbf{e}} A \cos(\omega_0 t + \phi)$$

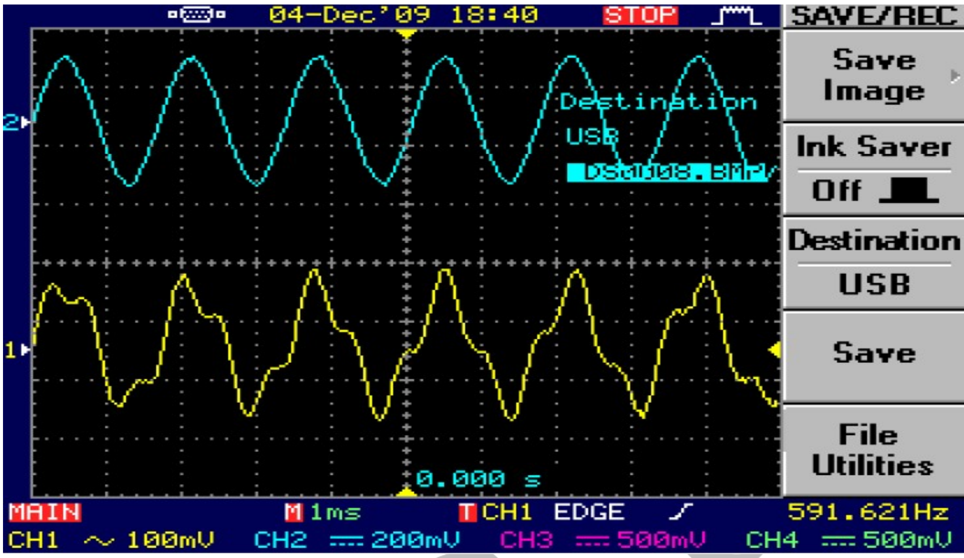
where **E** is the electric field vector, ˆ**e** is the polarization unit vector, *A* is the amplitude, ω_0 is the carrier frequency, and ϕ is the phase. The spatial dependence of **E** is suppressed for simplicity of notation. One may choose to modulate the amplitude *A*, the frequency ω_0, or the phase ϕ. In the case of analog modulation, the three modulation choices are known as amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM) [2].

Plastic optical fibers (POF)

Typically, Plastic optical fibers made from poly-methyl methacrylate (PMMA). Plastic optical fibers have larger cores (120–1000 microns) than standard multimode fiber, which makes it easier to align connectors. They are easy to install, but have high transmission losses (often several dB/km) which limit their applications to short distance. They are used for applications that do not require long transmission distances, such as medical instrumentation, automobile and aircraft control systems, and consumer electronics. There is also some interest in using plastic fiber for the small office/home office (SOHO) environment. POFs can be used for short distance links <100m, with red light sources (650 nm) [1].

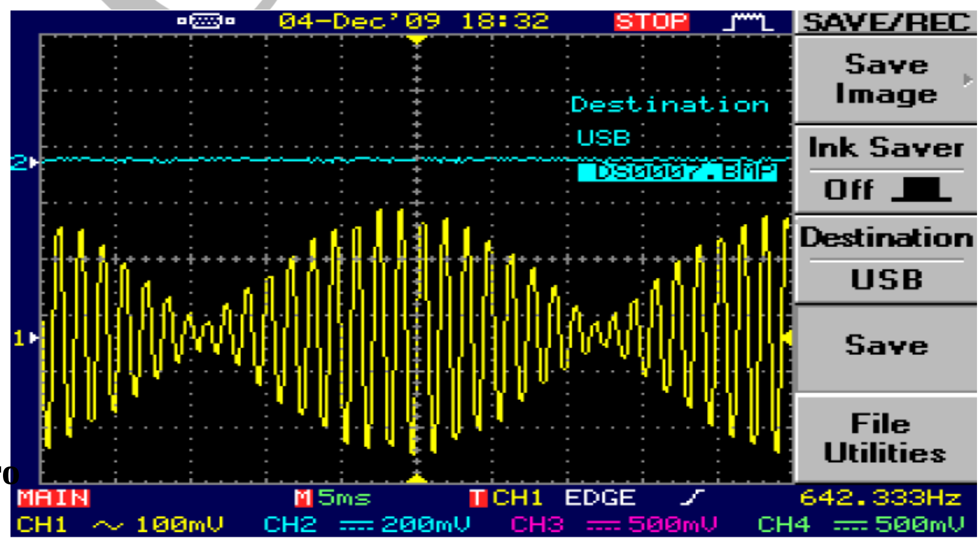
Signal crosstalk

If one signal channel has much higher amplitude than the other, the effect of cross talk may appear, i.e. the signal of one channel is more or less present at the other channel as well. This behavior is presented in the next graph, which shows the "pure" signal from the **Modulator Output** in the upper curve and the same signal overlaid by the second channel's signal from the **Demodulator Output** in the lower curve [3].



Signal beating

If the two input signals have almost the same frequency, one can observe a signal beating which is the result of alternating constructive and destructive interference of the two signals. This beating is nicely observed if the two signals are detected by one photo detector and the amplitude of the two signals are the same. Forward the beating signal also to the active speakers and tune the signal frequency and amplitude for a long beating and maximal beat modulation (i.e. you may not hear anything at a modulation minimum)[3].



Pro

i) Set the controller to the AM modulator.

ii) Feeding the two **Modulator Output** signals to the oscilloscope. Then Set the two channels with the same amplitude.

iii) Adjust the first channel frequency to about three times the frequency of the other signal. For example, the frequency of first channel is 660 Hz and other is 220 Hz.

iv) Plot the modulator and demodulator output signals carefully on graph paper for first channel. In an ideal case, the signals of the transmitter and receiver may look similar, but different in their amplitude.

v) Repeat step ii for second channel.

vi) Adjust the amplitude of one channels much higher than the other, the effect of cross talk may appear.

vii) Appear the signals from modulator output and demodulator output on the oscilloscope.

viii) Plot the two signals on the same graph paper.

ix) Now, adjust the two input signals to have almost the same frequency and same amplitude.

x) Connect the output of one detector to the oscilloscope and plot the signal on graph paper.

xi) Connect the active speakers to the controller and tune the signal frequency and amplitude for a long beating and maximal beat modulation

Discussion

1. Comment on your results.
2. Explain the influence of crosstalk on communication system.

References

1. Casimer M. DeCusatis and Carolyn J. Sher DeCusatis, "Fiber Optic Essentials", Academic Press is an imprint of Elsevier, 2006.
2. Govind P. Agrawal," Fiber-Optic Communication Systems", John Wiley & Sons, Inc, 2002.
3. User Manual , "Laser Education Kit CA-1400 Plastic Fiber Optics", MICOS- Campus Com.

Exp. No. 13
Measuring the runtime of light in the fiber

Aim of Experiment

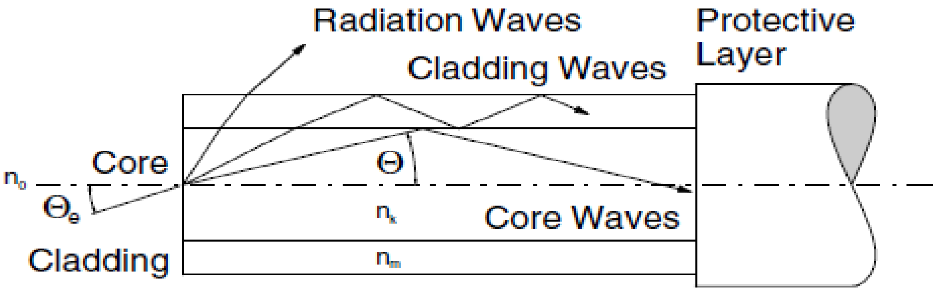
The aim of experiment is measuring the runtime of light in optical fiber with length of 1 km and the refractive index of optical fiber. Also we know how the coupling light to the optical fiber.

Apparatus

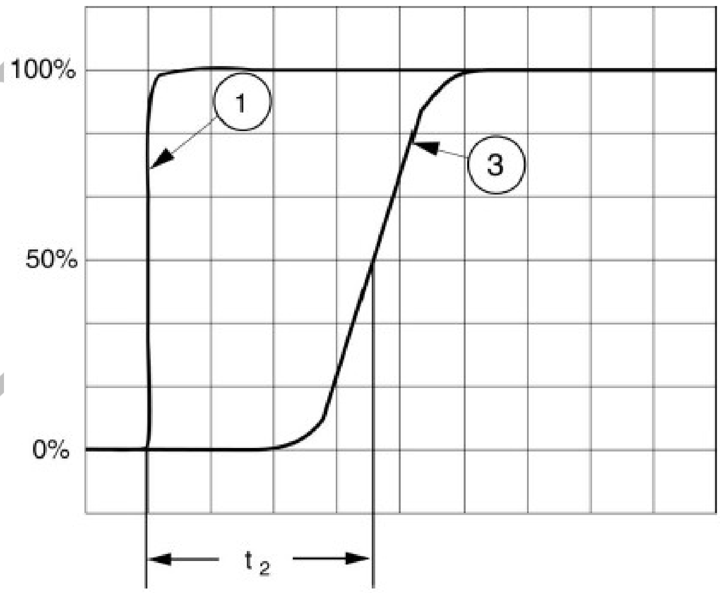
1. Two 500 mm optical rails are joined with an articulated connector.
2. Laser diode has a wavelength of 850 nm +/- 15 nm and a maximum output power of 50 mW. It is mounted in a XY adjustment holder on a carrier.
3. Laser Diode Supply LDS 1200
4. Beam expanding optics is used to form the divergent elliptical beam of the laser diode to a parallel beam. For collimation a high quality microscope objective (20x) is used. It has a working distance of app. 1 mm and a large input aperture.
5. Beam focusing optics with the help of this element the collimated laser diode beam is focused into the glass fiber. Here a high quality microscope (10x) objective is used. It has a working distance of app. 5 mm. The objective is mounted in an XY-adjustment holder, which supports an easy adjustment of the laser light into the fiber.
6. Fiber holder on translation stage
7. Fiber holder on articulated connector holds the fiber output face in the fiber holder and enables the user to rotate the photo detector around the fiber output face for a measurement.
8. Photo detector
9. Optical glass fibers: Two drums with 1000 m ± 10 m of optical single mode and multimode glass fiber, respectively.
10. Three BNC cables: For connection of Photo detector and oscilloscope
11. IR converter screen 800-1200 nm.

Theory

We can consider a glass fibers as wave conductors have a circular cross section. They consist of a core of refractive index n_1. The core is surrounded by a glass cladding of refractive index n_2 slightly lower than n_1. Generally the refractive index of the core as well as the refractive index of the cladding are considered homogeneously distributed. Between core and cladding there is the boundary as described in the previous chapter. The final direction of the beam is defined by the angle Θe under which the beam enters the fiber.



After proper alignment of the fiber coupling finally the oscilloscope shows a picture similar to the right graphics. Curve **1** is again the modulator output and curve **3** is now the signal coming through the glass fiber.
The new runtime **t2** can be taken now at 50% again.



The runtime of light in the available fiber with the following formula:

$$T = t_2 - t_1$$

With **T** and a given parameter of the fiber-index of refraction **n** we can calculate the length of the given glass fiber:

$$L = \frac{T \cdot c}{n}$$

Where L is fiber length, c is light speed and n is a fiber-index of refraction n
<u>Procedure</u>

Part I: Adjustment of the laser diode: to measure the signal runtime of the electronics path.

1. Adjust the laser diode by mount the laser diode with its holder (part **2**) is at the left end of the optical rail (part **1**). Then insert the beam collimator (part **4**) in front of the laser diode. The rough distance to the laser diode should be around 1 mm as shown in Fig.(1)**.**
2. Position Part **8** with the alignment target like shown in Fig.(1). The alignment target helps to define the optical axis of the system**.**
3. Switch on the controller LDS 1200 (part **3**) by its main switch at its backside. After a few seconds of self-testing, the unit is ready for use.
4. Switch on the laser diode by turning the key switch at the front of the controller to the 'On' position.
5. Set the laser diode current to its maximum with the push button (▲) in the section "Laser Current".
6. Vary the position of part **4** until the beam outline on the IR converter is reach roughly parallel. Also, adjust the X/Y position of the beam with the adjustment screws 'A'. The goal of the alignment is to adjust the diode laser beam roughly parallel running.
7. Connect the photo diode (part 8) to the corresponding BNC socket (PHOTO DIODE INPUT) at the rear of the controller LDS-1200. **Then,** connect the Modulator Output signal to the first channel of an oscilloscope and the PHOTO DIODE OUTPUT signal is connected to the second channel.
8. Switch on the laser diode with the key switch and set to its maximum power at the controller LDS-1200 by the current buttons.
9. Switch on the modulation of laser and select the square modulation.
10. Start to measure the signal runtime of the electronics path.
11. Switch off the laser diode by decreasing the Laser Current to zero. Then Switch off the laser diode by turning the key switch at the front of the controller LDS1200 to the "Off" position.

Part II: Get the laser light into the fiber: to measure the runtime of light in the optical fibers.

1. Use the set-up shown in Fig.(2) to measure the runtime of light in the optical fibers.
2. Insert the beam focusing (part 5) into the collimated beam as shown in Fig.(2).
3. Insert the translation stage with the fiber holder (part **6**) the focusing unit as shown in Fig.(2). The distance between the fiber holder and microscope objective should be app. 6 mm while the slide of the stage is app. moved into center position with screw **E**.

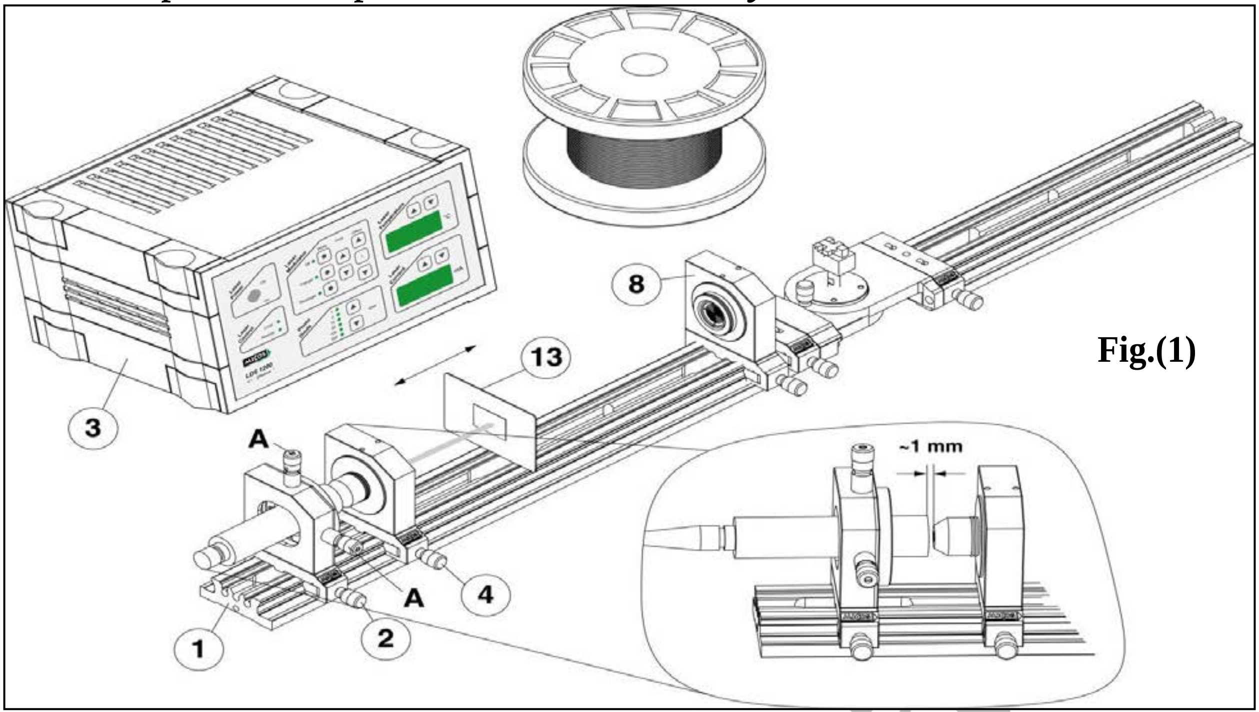


Fig.(1)

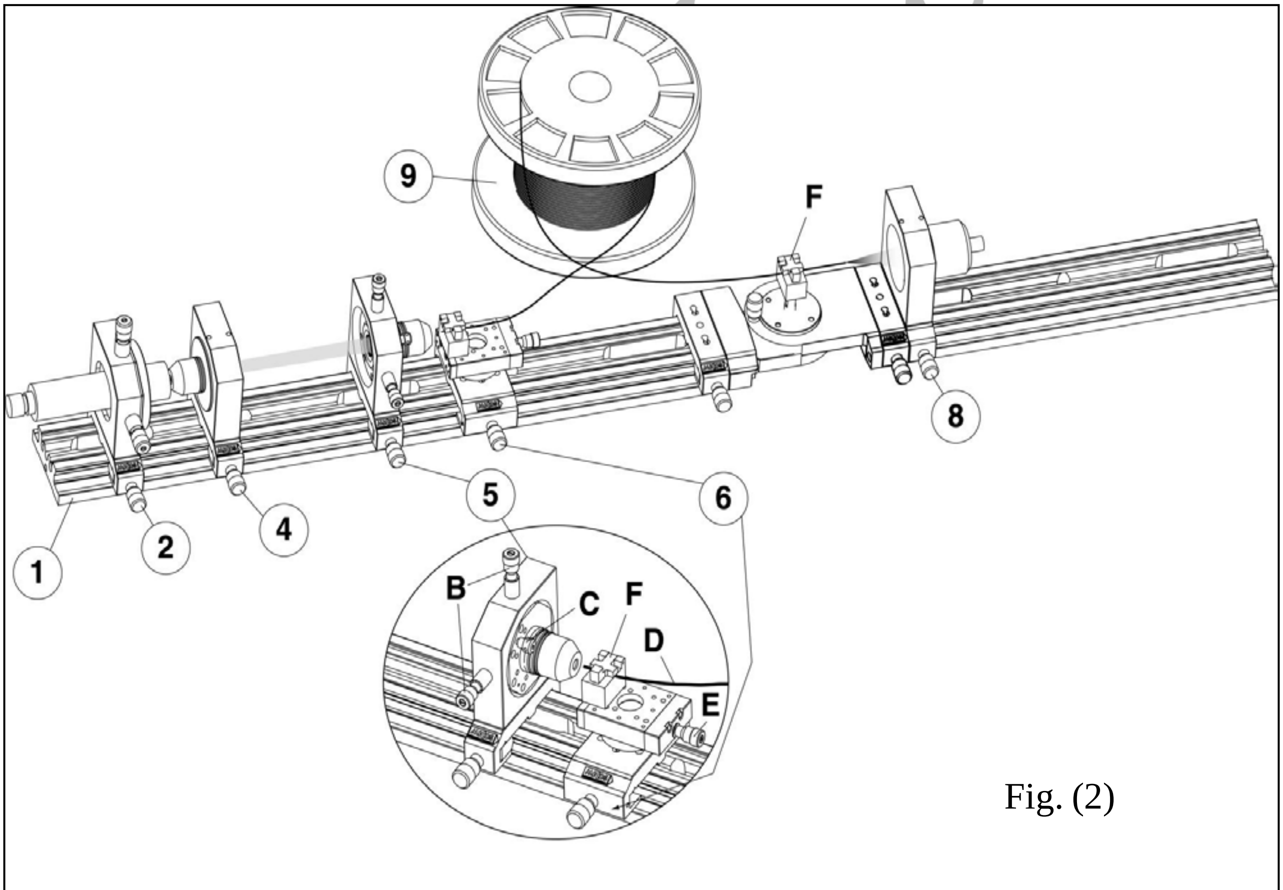


Fig. (2)

4. Insert the photo detector unit (part **8**) as shown in Fig.(2) .
5. Flip the magnetic fiber holder (**F**) to its open position and positioning the multi mode fiber into the v-groove of the holder. Then Flip back holder smoothly to avoid a break of the fiber.

6. Position the fiber end at the photo detector (part 8) in front of the photo
   diode to catch the output light of the fiber onto the detector
   as shown in Fig.(3).
7. Connect the photo diode (part 8) to the corresponding BNC socket (PHOTO DIODE INPUT) at the rear of the controller LDS-1200. Then, connect the Modulator Output signal to the first channel of an oscilloscope and the PHOTO DIODE OUTPUT signal is connected to the second channel.
8. Switch on the laser diode with the key switch and set to its maximum power at the controller LDS-1200 by the current buttons.
9. Switch on the modulation of laser and select the square

modulation. 10.After proper alignment of the fiber coupling, show the detector signal on
   oscilloscope then plot it and measured runtime of light.

11. Switch off the laser diode by decreasing the Laser Current to zero. Then Switch off the laser diode by turning the key switch at the front of the controller LDS1200 to the "Off" position.

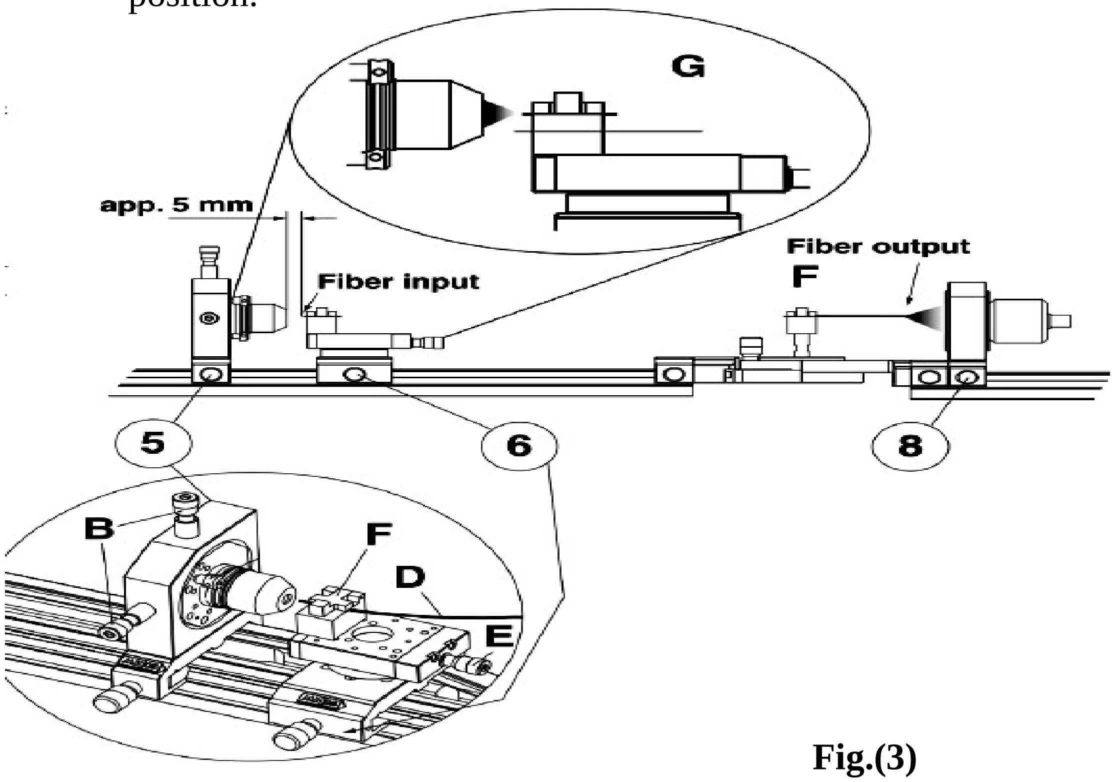


Fig.(3)

Discussion

1. Comment on your results

References

1. User Manual , "Laser Education Kit CA-1410 Plastic

Fiber Optics", MICOS- Campus Com.

EXP NO 14
Transmission of FM signals carried by two wavelengths over plastic optical fiber

Aim of experiment: To transfer FM signals over plastic optical fiber.

Apparatus: the above picture shows the experiment parts and they named as follows:

1. Part 1: Flat rail 500 mm with scale
2. Part 2: Plastic Fiber Controller PFC 1000
3. Part 3: POF Y-coupler on carrier
4. Part 4: FSMA coupler in holder on carrier
5. Part 5: FSMA coupler in XY adjustment holder on carrier
6. Part 6, 6a and 6b: POF cables with two FSMA connectors
7. Part 7: Wavelength separator unit on carrier
8. Part 8: Pair of active stereo speakers
9. Part 9: Set of tools for FSMA connector assembling
10. Part 10: Set of BNC cables (not shown)

Frequency modulation

In optical communications systems, the source of light used is called a **transmitter**. There are several different types of transmitters, including light emitting diodes (LEDs) and various types of lasers. Their purpose is to convert an electrical signal into an optical signal, which can be carried by the optical fiber. This process is called **modulating** the source of light.

The light can also be adjusted to different levels of brightness or intensity, rather than simply being turned on and off, this is called **analog modulation**. The simplest type of modulation involves changing the frequency of carrier with constant light level; this is known as **frequency modulation**. The optical carrier wave before modulation is of the form

$$\mathbf{E}(t) = \hat{\mathbf{e}} A \cos(\omega_0 t + \phi)$$

where **E** is the electric field vector, ˆ**e** is the polarization unit vector, *A* is the amplitude, ω_0 is the carrier frequency, and ϕ is the phase. The spatial dependence of **E** is suppressed for simplicity of notation. One may choose to modulate the amplitude *A*, the frequency ω_0, or the phase ϕ. In the case of analog modulation, the three modulation choices are known as amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM) [2].

The extinction ratio of a modulator is the ratio of the optical power level generated when the light source is “on,” compared to when the light source is “off.” It is typically expressed as a fraction at a specific wavelength, or in dB. For frequency modulators, it can be defined the maximum frequency deviation, D(max), given by[1]:

$$D(\text{max}) = \frac{|f_m - f_0|}{f_0}$$

where f_m is the maximum frequency shift of the carrier frequency f_0. Some specification sheets define the **degree of isolation**, in dB, which is given by 10 times the log of either the extinction ratio or the maximum frequency deviation.

Procedure

i) Set the controller to the FM modulation mode
ii) Feed the Modulator Output signal directly to the oscilloscope. Then plot the FM modulated signal on graph paper.
iii) Feed the photo detector signal directly to the oscilloscope. Then, plot the FM modulated optical signal on the same graph paper.
iv) Connect photo detector to the demodulator, then show it on the oscilloscope.

v) Plot the demodulator output carefully on the graph paper.

Discussion

1. Comment on your results
2. Compare between the AM modulation and FM modulation over the optical fiber.

Refrerences

1. Casimer M. DeCusatis and Carolyn J. Sher DeCusatis, "Fiber Optic Essentials", Academic Press is an imprint of Elsevier, 2006.
2. Govind P. Agrawal," Fiber-Optic Communication Systems", John Wiley & Sons, Inc, 2002.
3. User Manual , "Laser Education Kit CA-1400 Plastic Fiber Optics", MICOS- Campus Com.

Experiment No. 16
Splicing of optical fibers

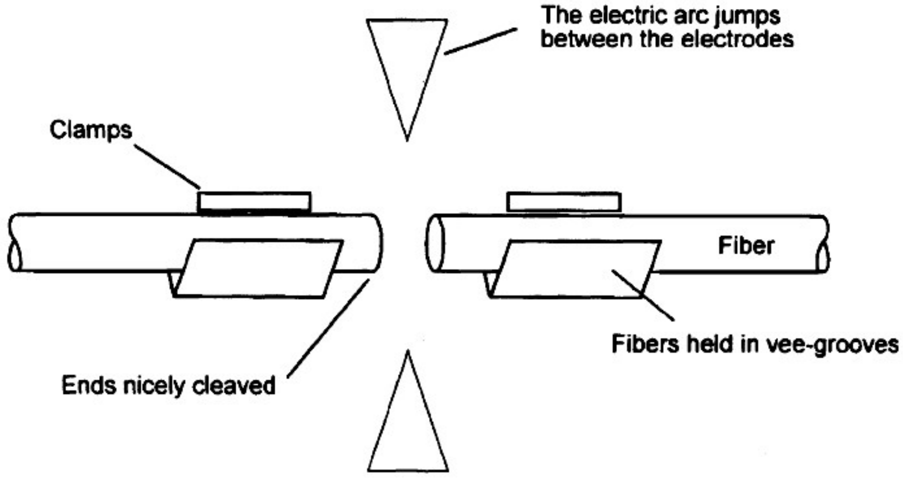
Aim: The aim of this experiment is giving the skills for splice the glass optical fibers.

Apparatus

1. Splice fusion set.
2. Two optical fibers.
3. Optical power meter

Theory

Fusion splicing is the most permanent and lowest loss method of connecting optic fibers. In essence, the two fibers are simply aligned then joined by electric-arc welding (*The arc that occurs between the two electrodes is about 7000 volts with an adjustable current up to 25 mA*). The resulting connection has a loss of less than 0.05 dB, about 1% power loss. Most fusion splicers can handle both single mode and multimode fibers in a variety of sizes, but due to the losses involved, we only splice multimode to multimode or single mode to single mode. There are also splicers that can automatically splice multi-core and ribbon cable up to 12 fibers at a time.



Splicing fusion process

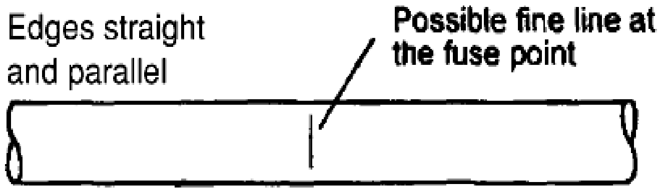
The fibers must first be stripped, cleaned and cleaved. To allow spare fiber for easy access and to allow for several attempts, a length of at least five meters of jacket should be removed. The primary buffer is only stripped to about 25 mm. The exact length is determined by the fusion splicer in use.

After the fiber is cleaned and cleaved then the vee-groove is cleaned by a lint free cloth, tissue or a 'cotton bud' moistened with isopropyl alcohol. The fiber is gently pressed into the vee-groove by a magnetic or gravity clamp. Once the fibers are safely clamped into their vee-grooves, they are moved, vee-grooves and all, until the fibers are aligned with each other and positioned directly under the electrodes from which the electric arc will be produced. We are aiming to achieve positioning with an accuracy of better than 1 μm.

All fusion splicers are fitted with some means to observe the fiber positioning and the condition of the electrodes. This is achieved by either a microscope or by a CCD camera (CCD = charge coupled device - a semiconductor light sensor) and a liquid crystal display (LCD). The trend is towards CCD cameras since they are more pleasant to use and have the safety advantage of keeping our eyes separated from the infrared light which can, of course, cause irreparable damage to the eyes if we accidentally observe an active fiber through the microscope.

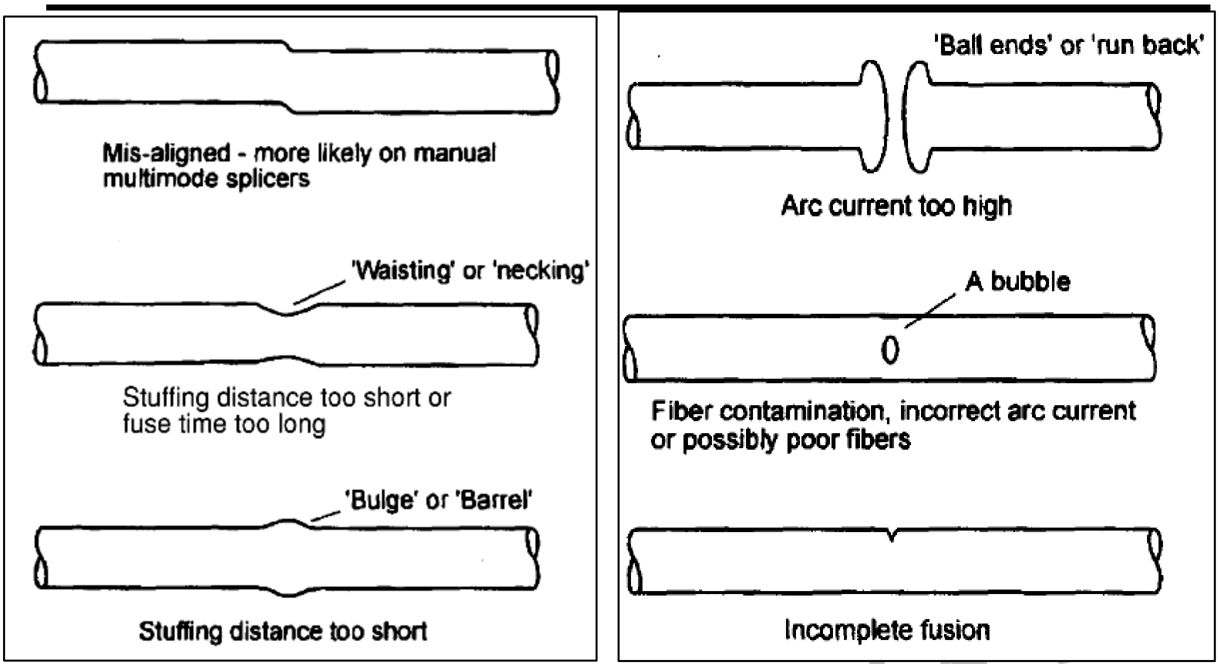
The main fusing arc is more powerful and lasts for a longer period of time, between 10 and 20 seconds.

Once fusing is completed, have a good look at the splice. If it is difficult to see where the splice is, then it's probably a good one (Figure below). We are looking for the outer edges of the cladding to be parallel, just like a new continuous length of fiber. Sometimes a small white line appears across the core but this is not important and can be ignored.



This is what we hope to see

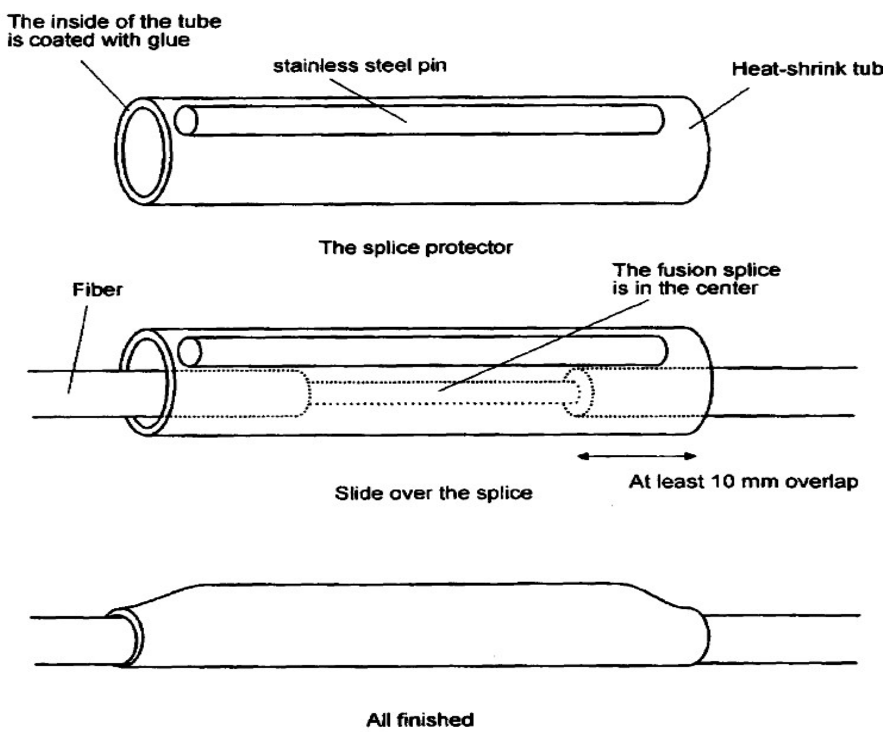
If it is appear at shown in figure below, then it's a worst one. In this case, it must be re-splice the optical fibers until we see the spliced fibers as shown in figure above.



Splicing disasters!

Splice protector

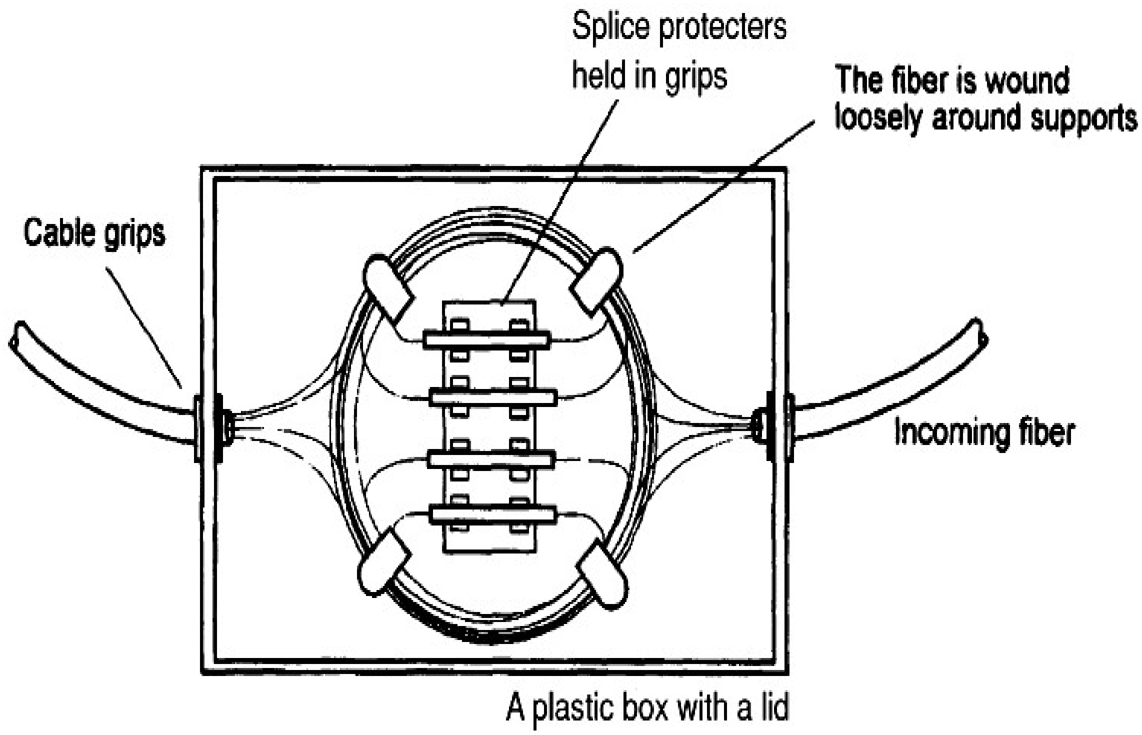
In the preparation phase, we have stripped the fiber of all its mechanical and waterproof protection. Once the fiber has been spliced, some protection must be restored since the splicing process will have reduced the fiber strength to less than 30% of its former value. This is achieved by a device called a splice protector. It consists of a short length (about 60 mm) of heat-shrink sleeving enclosing some hot-melt glue and a stainless steel wire rod as seen in Figure below.



Prior to joining the fiber, the splice protector is slid onto the fiber. After the splice is completed, the protector is centered over the splice and heated, usually in a purpose-built oven although a hot-air gun can be used. The oven is a simple tray with a lid, a heater and a timer which are normally built-in features of the splicers. The hot-melt glue keeps the protector in position whilst the stainless steel rod provides proof against any bending that may occur. The outer sleeve offers general mechanical and water protection to replace the buffer that has been removed. To ensure that the fiber is fully protected along its length, at least 10 mm of the protector must overlap the primary buffer at each end of the splice.

Enclosure

After the splice is completed, we are left with a length of fiber deprived of its outer jacket. The fiber must be protected from mechanical damage, and from water. This is achieved by an enclosure. They are readily available in different sizes to hold everything from 4 to 240 fibers. Each fiber must be identified; otherwise a simple job could become a real nightmare. This is achieved by attaching labels to the fibers or splice protectors and by using colored splice protectors.



Procedure

1. Consult the instruction books of the splicer and the splice protector to find the recommended stripping lengths of the primary buffer.
2. Strip off the outer jackets and the required length of the primary buffer.
3. Slip on a splice protector.
4. Clean the fiber.
5. Cleave it.
6. In a typical case, the fibers are inserted into the vee-grooves and moved until the ends of the fibers meet guide lines visible through the lens or camera.
7. Clamp fibers in position. Have a look at the standard of cleaves and, if necessary, take the fiber out and try again.
8. Set the splicing program to match the fiber in use. The handbook will provide guidance.
9. Press the start button and leave it to it. The program will run through its positioning and splicing procedure, and then stop.
10. Carefully lift it out of the vee-grooves and slide the splice protector along the fiber until it is centered over the splice. Make sure you have at least 10 mm of primary buffer inside the splice protector and place it gently in the oven.
11. Switch on the oven and in a minute or two it will switch off.

Discussions

1. Comment on your results
2. What advantage of using a CCD camera in splicing fusion set?

Explain the benefits of the splice protector and the enclosure

Experiment 17

Dispersion Compensation

Objective:

Design and simulate a fiber optic system using dispersion-compensating fiber to reduce chromatic dispersion.

Theory:

Dispersion-compensating fiber (DCF) provides an optical medium with a relatively large negative chromatic dispersion factor ($D(\lambda)$) at the operating wavelength. If a transmission fiber of length LTF is connected in series with a DCF of length LDCF, then the total chromatic dispersion is given by

$$\Delta t = L_{TF} D_{TF}(\lambda)\Delta\lambda + L_{DCF} D_{DCF}(\lambda)\Delta\lambda$$

where $D_{TF}(\lambda)$ is the chromatic dispersion factor for the transmission fiber, $D_{DCF}(\lambda)$ is the chromatic dispersion factor for the DCF and $\Delta\lambda$ is the transmitter spectral width. Similarly, the total attenuation loss of the two-fiber combination is given by

$$Loss = L_{TF} A_{TF} + L_{DCF} A_{DCF}$$

Therefore, given target values for chromatic dispersion and attenuation loss plus specifications of the transmitter, fiber and receiver, one can determine the lengths of the transmission fiber and the DCF by solving the above two equations simultaneously

Specifications:

Transmitter	Output power	0 dBm
	Spectral width	To be determined
	Operating wavelength	1550 nm
	Bit rate	2.5 Gb/s
Transmission Fiber	Corning SMF-28	
DCF	See below	
Receiver	Sensitivity	-35 dBm
System margin + coupling loss	Attenuation	6 dB

The DCF has the same parameters as the transmission fiber except that the chromatic dispersion factor is –200 ps/nm-km at 1550 nm and the attenuation is 0.5 dB/km at 1550 nm.

Calculations:

1. Determine the maximum allowable fiber loss.
2. Determine the maximum allowable chromatic dispersion.
3. Based on the results of (1) and (2) determine the lengths of the transmission fiber and the DCF.

Layout:

The main physical components of this layout are:

1. Transmitter: bit sequence generator, non-return to zero pulse generator and a laser.
2. Transmission fiber
3. Dispersion compensation fiber (DCF)
4. Receiver: PIN detector and electrical filter.

The modulation scheme in this lab is different from the previous lab. Here the non-return to zero (NRZ) scheme is used. The signal does not return to zero between successive 1 bits. This results in a narrower spectral width than a return to zero modulation scheme.

Several visualizer components are included in the layout. Three Optical Time Domain visualizers are placed: at the output of the transmitter, after the transmission fiber and at the end of the DCF. An optical spectrum analyzer is placed at the output of the transmitter. This can be used to estimate the spectral width of the signal.

Procedure:

Adjust the laser power to obtain 0 dBm transmission output. The output power recorded by the optical power meter will be less than the peak output power of the laser due to modulation of the signal.
Use the optical spectrum analyzer to determine the spectral width of the signal. There will be some significant uncertainty with this number since the spectrum is not clean. Use your best judgment. Provide a screen capture of the spectrum analyzer that shows the markers you used to determine the spectral width.

Set the appropriate fiber lengths based on your pre-lab calculations.

Run the simulation with all parameters set according to the above specifications. Generate appropriate screen captures to be included in your report.

Measure the optical power at the receiver input, the maximum Q factor and the minimum BER. Record the eye diagram and the optical waveforms at the transmitter output, the junction between the two fibers and the receiver input.

Further Simulation and Analysis:

Set the length of the DCF length to 0 and run the simulation again. Make and record similar measurements.

Conclusions:

Discuss the effectiveness of dispersion-compensating fiber and the ability of the calculations to engineer a viable system.