JEPPIAAR
ENGINEERING COLLEGE

JEPPIAAR NAGAR, CHENNAI - 600119

Department of Electronics & Communication Engineering

QUESTION AND ANSWER BANK

CEC345-OPTICAL COMMUNICATION & NETWORKS

V SEMESTER
Regulation – 2021

Academic Year 2024 – 2025

CEC345 OPTICAL COMMUNICATION & NETWORKS L T P C 3 0 0 3

COURSE OBJECTIVES:

● To Study About The Various Optical Fiber Modes, Configuration Of Optical Fibers
● To Study Transmission Characteristics Of Optical Fibers.
● To Learn About The Various Optical Sources, Detectors And Transmission Techniques.
● To Explore Various Idea About Optical Fiber Measurements And Various Coupling Techniques.
● To Enrich The Knowledge About Optical Communication Systems And Networks.

UNIT-I INTRODUCTION TO OPTICAL FIBER COMMUNICATION 9

Introduction - The General Systems - Advantages of Optical Fiber Communication- Ray Theory Transmission : Total Internal Reflection, Acceptance Angle, Numerical Aperture, Skew Rays - Electromagnetic Mode Theory for Optical Propagation: Modes in a Planar Guide, Phase and group velocity - Cylindrical Fiber: Step index fibers, Graded index fibers - Single mode fibers: Cutoff wavelength.

UNIT-II TRANSMISSION CHARACTERISTICS OF OPTICAL FIBERS 9

Attenuation - Material absorption losses in silica glass fibers: Intrinsic absorption, Extrinsic absorption - Linear scattering losses: Rayleigh Scattering, Mie Scattering -Nonlinear scattering losses: Stimulated Brillouin Scattering, Stimulated Raman Scattering – Fiber Bend Loss – Dispersion- Chromatic dispersion: Material dispersion, Waveguide dispersion- Intermodal dispersion : Multimode step index fiber, Multimode graded index fiber.

UNIT-III OPTICAL SOURCES AND OPTICAL DETECTORS 9

The laser : Introduction - Basic concepts: Absorption and emission of radiation, Population inversion , Optical feedback and laser oscillation, Threshold condition for laser oscillation- Optical emission from semiconductors: The PN junction, Spontaneous emission, Carrier recombination, Stimulated emission and lasing, Hetero junctions- LED: Introduction- Power and Efficiency - LED structures: Planar LED, Dome LED, Surface emitter LED, Edge emitter LED- LED Characteristics. Optical Detectors:Introduction ,Optical Detection Principles, Quantum Efficiency, Resposivity, P-N Photodiode ,P-I-N Photo Diode and Avalanche Photodiode.

UNIT-IV OPTICAL FIBER MEASUREMENTS 9

Introduction- Total Fiber Attenuation Measurement, Fiber Dispersion Measurements In Time Domain and Frequency Domain, Fiber Cut off Wavelength Measurements, Numerical Aperture Measurements. Fiber Diameter Measurements,.Reflectance And Optical Return Loss, Field Measurements

UNIT-V OPTICAL NETWORKS 9

Introduction- Optical Network Concepts: Optical Networking Terminology, Optical Network Node And Switching Elements, Wavelength Division Multiplexed Networks, Public Telecommunications Network Overview- Optical Network Transmission Modes, Layers And Protocols: Synchronous Networks, Asynchronous Transfer Mode, Open System Interconnection Reference Model, Optical Transport Network, Internet Protocol- Wavelength Routing Networks: Routing And Wavelength Assignment- Optical Switching Networks: Optical Circuit Switched Networks, Optical Packet Switched Networks, Multiprotocol Label Switching, Optical Burst Switching Networks- Optical Network Deployment : Long Haul Networks, Metropolitan area networks, Access networks, Local Area Networks- Optical Ethernet: Network protection, restoration and survivability.

COURSE OUTCOMES

At the end of the course, the student will be able to understand the
CO1:Realize Basic Elements In Optical Fibers, Different Modes And Configurations.
CO2:Analyze The Transmission Characteristics Associated With Dispersion And Polarization Techniques.
CO3:Design Optical Sources And Detectors With Their Use In Optical Communication System.
CO4:Construct Fiber Optic Receiver Systems, Measurements And Techniques.
CO5:Design Optical Communication Systems And Its Networks.

TEXT BOOKS:

1. John M.Senior, “Optical Fiber Communication”, Pearson Education, Fouth Edition.2010.

REFERENCES:

1. Gred Keiser,"Optical Fiber Communication”, McGraw Hill Education (India) Private Limited. Fifth Edition, Reprint 2013.
2. Govind P. Agrawal, “Fiber-Optic Communication Systems”, Third Edition, John Wiley & Sons, 2004.
3. J.Gower, “Optical Communication System”, Prentice Hall Of India, 2001
4. Rajiv Ramaswami, “Optical Networks “ , Second Edition, Elsevier , 2004.
5. P Chakrabarti, "Optical Fiber Communication”, McGraw Hill Education (India)Private Limited, 2016

UNIT -1 INTRODUCTION

PART A

1. **why do we prefer step index single mode fiber for long distance communication?[APR/MAY 2019]**
   Step index single mode fiber has (1) low attenuation due to smaller core diameter, (2) Higher bandwidth, (3)Low dispersion.
2. **What is the necessity of cladding for an optical fiber? [APR/MAY 2019]**
   a) To provide proper light guidance inside the core b) To avoid leakage of light from the fiber c) To avoid mechanical strength for the fiber d) To protect the core from scratches and other mechanical damages
3. **Distinguish between meridional rays from skew Rays. [NOV/DEC 2018]**
   A **skew ray** is a **ray** that travels in a non planar zig zag path and never crosses the axis of an optical fibre! A **meridional ray** is a **ray** that passes through the axis of an optical fiber.
4. **Manufacturing engineer wants to to make an optical fibre that has core intex of 1.40 and cladding intex of 1.47 8 what should be the core size for single[NOV/DEC 2018]**

$$V = \frac{2\pi a}{\lambda} NA$$

5. **A silica optical fiber with a large core diameter has a core refractive index of 1.5 and a cladding refractive index of 1.47.Determine the acceptance angle in air for the fiber. [April 2017, APR 2018]**

Given data:

$n_1 = 1.5$

$n_2 = 1.47$

Formula:

$$\theta_a = \sin^{-1}\sqrt{n_1^2 - n_2^2}$$

Solution:

$$\theta_a = \sin^{-1}\sqrt{1.5^2 - 1.47^2}$$

$$\theta_a = 17.36^\circ$$

6. Write short notes on ray optics theory.

Laws governing the nature of light are called as ray optics. These laws are stated as:

1. Light rays in homogenous media travel in straight lines.
2. Laws of reflection: Angle of reflection θ_r equals angle of incidence θ_i
3. Snell's Law: The angle of refraction θ_t is related to angle of incidence θ_i by

$$n_1 \sin\theta_i = n_2 \sin\theta_t$$

7. What are the advantages and disadvantages of the ray optics? [April 2017]

The advantages of ray optics are:

a) Ray optics is used to develop some of the fundamental parameters like acceptance angle, numerical aperture that are associated with optical fiber transmission.

b) It provides an excellent approximation, when the wavelength is very small compared with the size of structures, with which the light interacts.

The disadvantages of the ray optics are:

a) Ray optics fails to account for optical effects such as diffraction and interference.

8. **Define Phase and group velocity. (Nov-Dec 2015)**

The group velocity of a wave is the velocity with which the overall shape of the waves amplitude known as modulation or envelope of wave propagates through space.

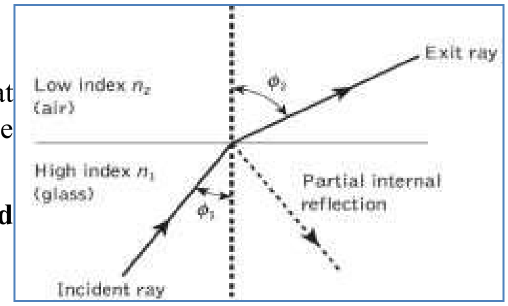
$$v_g = \frac{d\omega}{d\beta}$$

The Phase velocity of a wave is the rate at which the phase of the wave propagates in space. This is the velocity at which the phase of any one frequency component of wave travel.

$$v_p = \frac{\omega}{\beta}$$

9. **Define – Critical Angle [DEC 2016]**

The critical angle is defined as the minimum angle of incidence (φ1) at which the ray strikes the interface of the two medium and causes an angle of refraction (φ2) equal to 90°.



10. Assume that there is a glass rod of refractive index 1.5, surrounded by air. Find the critical incidence angle.[MAY 2016]

Given data:

$n_1 = 1.5$

$n_2 = 1$

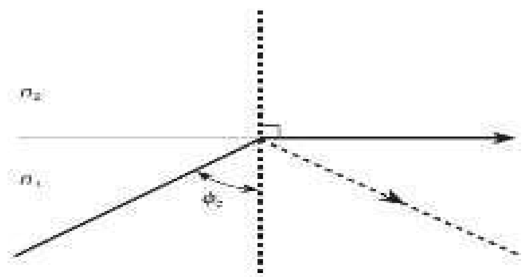
Formula: $\phi_c = \sin^{-1}\frac{n2}{n1}$

Solution:

$$\phi_c = \sin^{-1}\frac{1}{1.5} = 41.81°$$

11. State Snell's law.[DEC 2013, MAY 2016]

The Snell's law is an expression that describes the relationship between the angles of incidence θ_1 and refraction θ_2 and to the refractive indices of the dielectrics, when referring to waves passing through a boundary between two isotropic medium.



$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

where n_1 is the refractive index of the core and n_2 is the refractive index of the cladding.

12. What are the conditions for total internal reflection? [NOV 2015]

The conditions for total internal reflection are:

a) The ray should travel from denser to rarer medium i.e. from core to clad region of the optical fiber.

b) The angle of incidence in the denser medium should be greater than the critical angle of that medium.

13. Calculate the critical angle of incidence between two substances with different refractive indices, where n1 =1.5 and n2 =1.46. (Apr-May 2015)

$n_1 = 1.5$

$n_2 = 1.46$

$\emptyset = \sin^{-1}\frac{n_2}{n_1}$

$= \sin^{-1}\frac{1.46}{1.5}$

$\emptyset = 76.74°$

14. List any two advantages of single mode fibers.(Nov-Dec 2014)

Single mode fiber has only one ray passes through fiber. Ray passes along the axis-axial ray. Core diameter is small (typically 10 -12 µm). Intermodal dispersion is not present. Coupling efficiency is less.

15. **Define - Numerical Aperture [NOV2014]**

Numerical Aperture (NA) of the fiber is the light collecting efficiency of the fiber and is the measure of the amount of light rays that can be accepted by the fiber. It is equal to the sine of acceptance angle θ_a

$$NA = \sin\theta_a = (n_1^2 - n_2^2)^{1/2}$$

where n1 and n2 are the refractive indices of core and cladding respectively.

16. For n1 = 1.55 and n2 =1.52 , Calculate the critical angle and numerical aperture.(May-June 2013)

Critical angle

$$\emptyset_c = \sin^{-1}\left(\frac{n_2}{n_1}\right) = \sin^{-1}\left(\frac{1.52}{1.55}\right) = 78.7°$$

Numerical aperture NA = $\sqrt{n_1^2 - n_2^2}$ = 0.3

17. Define – Relative Refractive Index Difference

The relative refractive index difference is the ratio of the refractive index difference between core and cladding and refractive index of core.

$$\Delta = \frac{n_1 - n_2}{2n_1}$$

Where,

Δ is the relative refractive index

n1 is the numerical aperture of the core

n2 is the numerical aperture of the cladding

18. What is the energy of the single photon of the light whose λ = 1550nm in eV? (N/D2011)

The energy of the single photon of the light is given by the equation

$E = h \times f$

Sub $f = \frac{c}{\lambda}$ in the above equation

$E = h \times \frac{c}{\lambda}$

Given data:

$h = 6.625 \times 10^{-34}$

$c = 3 \times 10^{8}$ m/sec

$\lambda = 1550 \times 10^{-9}$ m

$$E = \frac{6.625 \times 10^{-34} \times 3 \times 10^{8}}{1550 \times 10^{-9}}$$

$= 0.0128 \times 10^{-17}$ J

19. step index fiber has the normalized frequency of 26.6 at 1300nm. If the core radius is 25μm, find the numerical aperture.

Given data: V= 26.6 , $\lambda = 1300 \times 10^{-9}$m a = 25×10^{-6}m

Formula:

Normalized frequency V is given by V= 2πa (NA) / λ

NA = λV/2πa

Solution:

Numerical Aperture = λV/2πa

$$NA = \frac{1300 \times 10^{-9} \times 26.6}{2 \times 3.14 \times 25 \times 10^{-6}}$$

NA = **0.22**

20. What is meant by refractive index of the material?

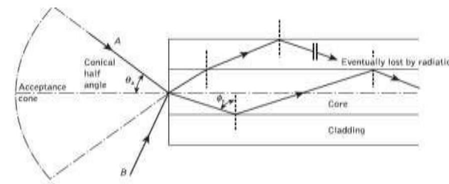
The refractive index (or index of refraction) 'n' is defined as the ratio of the velocity of light in vacuum to the velocity of light in the medium.

$$n = \frac{c}{v}$$

c = speed of light in free space

v = speed of light in a given material

21. Define - Acceptance angle

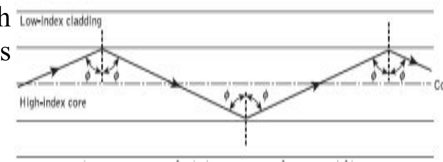


The acceptance angle θ_a when launching light into an optical fiber

The maximum angle 'θ_a' with which a ray of light can enter through the fiber and still be totally internally reflected is called acceptance angle of the fiber.

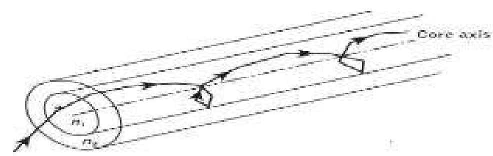
22. What are meridional rays?

Meridional rays are the rays following zig- zag path when they travel through fiber and for every reflection it will cross the fiber axis. The figure below shows the meridional rays.



23. What are skew rays?

Skew rays are the rays following the helical path around the fiber axis when they travel through the fiber and they would not cross the fiber axis at any time. The figure below shows the propagation of skew rays.



24. Write the acceptance angle condition for the skew rays.

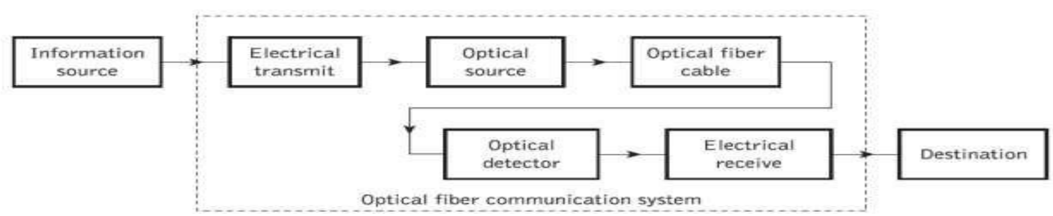
The acceptance conditions for skew rays is given by the equation

$$\theta_{as} = \sin^{-1} \frac{NA}{\cos\gamma}$$

where NA is the numerical aperture and γ is the angle between the projection of the ray in two dimensions and the radius of the fiber core at the point of reflection.

25. Draw the block diagram of an optical communication system.

The block diagram of an optical communication system is represented as,



26. The relative refractive index difference (Δ) for an optical fiber is 1%. Determine the critical angle at the core cladding interface if the core refractive index is 1.46.

$$\Delta = \frac{n1 - n2}{n1} \quad (1)$$

$$\phi_c = \sin^{-1}\frac{n2}{n1} \quad (2)$$

Find n_2 from equation (1)

$$n_2 = n1(1 - \Delta) \quad (3)$$

Solution:

$$n_2 = 1.46(1 - 0.01)$$

$$= 1.4454$$

$$\phi_c = \sin^{-1}\frac{1.4454}{1.46}$$

$$\phi_c = 81.19^\circ$$

27. Which photodiode is used for a low power optical signal and Why?

Avalanche Photo Diode (APD) is used for a low power optical signal because it has a greater sensitivity due to an inherent internal gain mechanism produced by avalanche effect.

28. What is V number of a fiber?

Normalized frequency or V number is a dimensionless parameter and represents the relationship among three design variables of the fiber i.e. core radius **a**, relative refractive index Δ and the operating wavelength **λ**. It is expressed as V= 2πa (NA)/λ.

29. What are guided modes?

Guided modes are a pattern of electric and magnetic field distributions that is repeated along the fiber at equal intervals.

30. Define – Phase Velocity

As a monochromatic light wave propagates along a waveguide in the *z* direction the points of constant phase travel at a phase velocity $V_\mathbf{p}$ given by

$$V_\mathrm{p} = \frac{\omega}{\beta}$$

where ω is the angular frequency and β is the propagation constant

31. Define – Group Velocity

Group of waves with closely similar frequencies propagate so that their resultant forms packet of waves. This wave packet does not travel at the phase velocity of individual but it moves with the group velocity V_g given by

$$V_\mathrm{p} = \frac{\omega}{\beta}$$

where ω is the angular frequency and β is the propagation constant

32. What is meant by mode coupling? What causes it?

The effect of coupling energy from one mode to another mode is known as mode coupling. The cause of mode coupling is due to waveguide perturbations such as deviations of the fiber axis from straightness, variations in the core diameter, irregularities at the core -cladding interface and refractive index variations.

33. What are the uses of optical fibers?

The uses of optical fiber are

- To transmit analog and digital information.
- To transmit the optical images.(Endoscopy Images)
- To act as a light source at the inaccessible places.
- To act as sensors for mechanical, electrical and magnetic measurements.

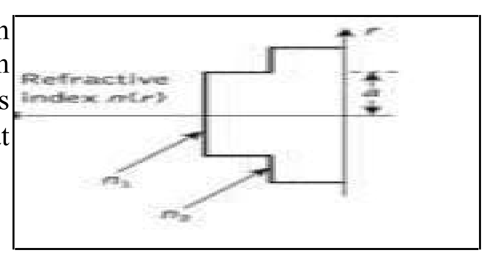
34. What is the necessity of cladding for an optical fiber?

The necessity of cladding for an optical fiber is:

- To provide proper light guidance inside the core.
- To avoid leakage of light from the fiber.
- To provide mechanical strength for the fiber.
- To protect the core from scratches and other mechanical damages

35. What is step index fiber?

Step index fiber is a cylindrical waveguide that has the central core with uniform refractive index of n_1, surrounded by outer cladding with refractive index of n_2.The refractive index of the core is constant and is larger than the refractive index of the cladding. It makes a step change at



the core cladding interface as indicated in the figure,

36. Write the refractive index expression for step index fiber.

In step index fiber, the refractive index of a core is constant and is larger than the refractive index of the cladding. The refractive index profile is defined as

$$n(r) = \begin{cases} n_1; & r < a \text{ (core)} \\ n_2; & r \geq a \text{ (cladding)} \end{cases}$$

37. What are the advantages of Graded Index Fiber?

The advantages of Graded Index Fiber are

- It exhibits **less intermodal dispersion** because the different group velocities of the modes tend to be normalized by the index grading.
- It provides **higher bandwidth**

38. Write the refractive index expression for graded index fiber.

Graded index fibers does not have a constant refractive index in the core but a gradually decreasing core index $n(r)$ with radial distance from a maximum value of n_1 at the axis to a constant value n_2 beyond the core radius 'a' in the cladding. This index variation may be represented as:

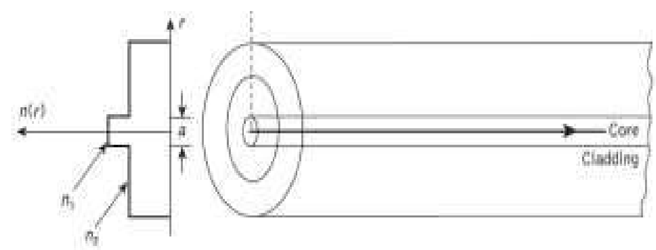
$$n(r) = \{ n_1 = (1 - 2\Delta(r/a)^{\alpha})^{1/2} \quad ; \quad r < a \text{ (core)}\}$$

$$\{n_1 (1 - 2\Delta)^{1/2} = n_2 ; \quad r \geq a \text{ (cladding)}\}$$

Where, n_1 is the refractive index of the core and n_2 is the refractive index of the cladding Δ is the index difference, α is the index profile

39. Write a short note on single mode fiber.

For single-mode operation, only one mode (the fundamental LP_{01}) can exist and it does not suffer from mode delay. The core diameter is small so that there is only one path for light ray to propagate inside the core. Typical core sizes are 2μm to 5μm. It provides larger bandwidth and less coupling efficiency. It is used for long haul transmission.



40. List out the advantages of multimode fiber over single mode fibers. (A/M2008) The advantages of multimode fiber are:[DEC 2016]

- The larger core radii of multimode fibers make it easier to launch optical power into the fiber. Connecting together of similar fibers is easy.
- Light can be launched into a multimode fiber using an LED source, whereas single-mode fibers with LASER diodes. LED's are easier to make, less expensive, less complex circuitry and have longer life times.

41. List the advantages and disadvantages of monomode fiber.

The advantages of single mode fiber are:

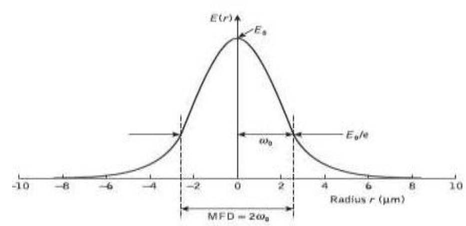
- No intermodal dispersion
- Information capacity of single mode fiber is large

The disadvantages of single mode fiber are:

- Launching of light into single mode and joining of two fibers are very difficult
- Fabrication is very difficult and so that fiber is so costly

42. Define – Mode Field Diameter

Mode-Field Diameter is an important parameter for characterizing single mode fiber properties that accounts the wavelength dependent field penetration into the fiber cladding. This can be determined from the mode field distribution of the fundamental LP_{01} mode. The MFD equals $2\omega_0$ where ω_0 is the nominal half width of the input excitation.



43. Why is step index single mode fiber preferred for long distance communication?

The step index single mode fiber is preferred for long distance communication because,

- They exhibit higher transmission bandwidth because of low fiber losses.
- They have superior transmission quality because of the absence of modal noise.
- The installation of single mode fiber is easy and will not require any fiber replacement over twenty plus years.

44. Define – Birefringence

Manufactured optical fibers have imperfections, such as asymmetrical lateral stresses, non circular cores, and variations in refractive index profiles. These imperfections break the circular symmetry of the ideal fiber and lift the degeneracy of the two modes. These modes propagate with different phase velocity and it is called as fiber birefringence. Birefringence is expressed as

$$B_f = \beta_x - \beta_y / \frac{2\pi}{\lambda}$$ where β is the propagation constant.

45. **State the reasons to opt for optical fiber communication.**

- **Broad bandwidth**: A single optical fiber can carry over 3,000,000 full-duplex voice calls or 90,000 TV channels.
- **Immunity to electromagnetic interference:** Light transmission through optical fibers is unaffected by otherelectromagnetic radiation nearby. The optical fiber is electrically non-conductive, so it does not act as an antenna to pick up electromagnetic signals. Information traveling inside the optical fiber is immune to electromagnetic interference, evenelectromagnetic pulses generated by nuclear devices.
- **Low attenuation loss over long distances:** Attenuation loss can be as low as 0.2 dB/km in optical fiber cables, allowing transmission over long distances without the need for repeaters.
- **Electrical insulator:** Optical fibers do not conduct electricity, preventing problems with ground loops and conduction oflightning. Optical fibers can be strung on poles alongside high voltage power cables.
- **Material cost and theft prevention:** Conventional cable systems use large amounts of copper. Global copper prices experienced a boom in the 2000s, and copper has been a target of metal theft.
- **Security of information passed down the cable:** Copper can be tapped with very little chance of detection.

45. Differentiate between Mono Mode Fiber and Multimode Fiber.

S.No	Mono Mode Fiber	Multi Mode Fiber
1	Only one ray passes	More than one ray passes
2	Ray passes along the axis-axial ray	MMSI – Meridional and Skew MMGI – Paraxial
3	Core diameter is small typically10 - 12μm	Core diameter is large typically 50 - 200μm
4	Intermodal dispersion is not present	Intermodal dispersion is present

5	Fabricating single mode fiber is difficult	Fabricating multimode fiber is easy
6	Coupling efficiency is less	Coupling efficiency is large
7	LED is not suitable source for single mode	LED is suitable for multimode

46. Point out the limitations of Optical Fiber Communication system?

- Optical fiber is made up of glass because of the impurities present within the fiber result in absorption leads to loss of light in the Optical fiber.
- Maximum limitation of the bandwidth of the signals can be carried by the fiber due to spreading of pulse.
- It is costly.
- Optical fiber has limited band radius (10mm)

47. Distinguish between Step Index fiber and Graded Index fiber.

S.No	Step Index Fiber	Graded Index Fiber
1	The core has uniform refractive index but step change in core-cladding interface.	The core has high refractive index along the axis which gradually decreases towards the clad-core interface (radially decreases)
2	Axial ray – SMSI, Meridonial rays & Skew - MMSI	Paraxial rays – MMGI
3	Intermodal dispersion is present in MMSI	Intermodal dispersion is reduced in MMGI
4	Numerical Aperture is constant	Numerical Aperture is a function of radius
5	Step index profile	Graded index profile profile Factor
6	No of modes, m v^2 / 2. Step index supports twice the number of modes than GI	No of modes, m v^2 / 4
7	Fabrication is easy	Fabrication is difficult

48. Compare Ray Optics with Wave Optics.

S.No	Ray Optics	Wave Optics
1	It is used to represent the direction of light propagation	It is used to analyze mode theory
2	It is used to study reflection and refraction of light	It is used to analyze diffraction and Interference of light waves

49. Define Mode.

Mode is the pattern of distribution of electric and magnetic fields

- Transfers Electric Mode TE_{02}
- Transfers Magnetic Mode TM_{02}

50. List out the ways to minimize leaky modes.

A mode remains guided as long as β satisfies the condition $n_2K<\beta n_1K$.

n1,n2 → Refractive index of core are cladding $K = 2\pi/\lambda$

$\beta \geq n2K$ = To prevent power leaks out of the core.

51. What are the three windows of Optical Communication?

The three wave lengths 850nm, 1300nm and 1500nm are three optical windows of optical communication system. Since only at this wavelength silica fiber loss is minimum.

PART B & C

1. **a. Explain a neat block diagram of fundamentals of optical fibre communication.[8]**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. NO.8**[DEC 2016, APR 2018]**
   b. Discuss the mode theory of circular waveguides. [Nov 2008]
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 43
2. **For multi-mode step-index fibre with glass core (n1 =1.5) and a fused quartz cladding (n2 =1.46), determine the acceptance angle θ_{in}) and numerical aperture. The source to fibre medium is air. (Apr-May 2015, NOV/DEC 2018)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 37
3. **Explain the ray propagation into and down an optical fibre cable. Also derive the expression for acceptance angle. (Apr-May 2015 , 2019)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 37
4. **Contrast the advantages and disadvantages of step-index, graded- index, single-mode propagation and multi-mode propagation. (Apr-May 2015)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 37
5. **Classify fibers and explain them. (Nov-Dec 2015)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 37
6. **Describe and derive the modes in planar guide. (Nov-Dec 2015)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 43
7. **Define the normalized frequency for an optical fiber and explain its use.(Nov-Dec 2014)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 25
8. **Explain the features of multimode and single mode step index fiber and compose them. (Nov-Dec 2014)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 37
9. **A Single mode step index fiber has a core diameter of 7µm and a core refractive index of 1.49. Estimate the shortest wavelength of light which allows single mode operation when the relative refractive index difference for fiber is 1%. (Nov-Dec 2014)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 37
10. **a. Discuss briefly about linearly polarized modes. [6][APR/MAY 2019]**
    Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 56
    b. Draw the structure of single and multi mode step index fibres and graded index fibres with typical dimensions. [6] [Apr 2018]
    Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 37
    c. Mention the advantage of optical fibre system [4]. [Nov 2008]
11. **Explain mode propagation in circular waveguides. Obtain its wave equation and modal equations for step index fibers. [Nov-2009]**
    Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 43
12. **A typical refractive index difference for an optical fiber designated for long distance transmission is 1% .Determine the NA and the solid acceptance angle in air for the fiber when the core index is 1.46.calculate the critical angle at the core-cladding interface with in the fiber [Nov2009]**
    Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 23
13. **Draw and explain the working principle of single mode and multimode fiber(Nov 2010)**
    Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 37
14. **Distinguish step index and graded index fiber [DEC2016] (Nov 2011)**
    Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 37
15. **Derive the mode equations for a circular fibre using maxwell's equations (May 2012)**

Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 43

UNIT- II
TRANSMISSION CHARACTERISTICS OF OPTICAL FIBER

1. **Distinguish between intra model and inter modal dispersion[NOV/DEC 2018]**
   Intramodal dispersion:
   Pulse broadening within a single mode is called as intramodal dispersion or chromatic dispersion
   Intermodal dispersion:
   • Dispersion caused by multipath propagation of light energy is referred to as intermodal dispersion.
2. **Give the measure of information capacity in optical wave guide.[Apr /May 2019]**
   It is usually specified by bandwidth distance product in MHz.For a step index fiber the various distortion effects tend to limit the bandwidth distance product to 20MHz.
3. **What is elastic and inelastic scattering? Give examples. [Apr 2018]**

   Purely elastic scattering means all the pre-collision kinetic energy of the colliding objects goes into kinetic energy of the post-collision objects. A collision between two hard things, like billiard balls, is a good example of a collision that's *mostly* elastic.
   Inelastic scattering means that at least *some* of the pre-collision kinetic energy ends up somewhere else, besides post-collision kinetic energy. For example, the pre-collision kinetic energy can be used to cause an internal state change in one of the colliding objects.
4. **What is meant by attenuation coefficient of a fiber? (N/D2011)[DEC2016]**
   Attenuation coefficient is defined as the ratio of the input optical power P_i launched into the to the output

$$\propto_{dB} = \frac{10}{L} \log_{10}^{\frac{P_i}{P_o}}$$

   optical power P_o from the fiber.

   where $\propto_{dB}$ is the attenuation coefficient in decibels per kilometer.

5. **A 30 km long optical fiber has an attenuation of 0.8 dB/km. If 7 dBm of optical power is launched into the fiber, determine the output optical power in dBm. (M/J 2012)**

Given Data: $P_i = 7$ dBm

$L = 30$ km $= 3\times10^4$ m;

$\alpha_{dB} = 0.8$dB/km $= 0.8\times10^{-3}$ dB/m

Solution:

$$\alpha_{dB} = \frac{10}{L} \log_{10} \frac{Pi}{Po}$$

$$= \frac{10}{3\times10^4 \log\frac{7}{P_o}}$$

$\log (7/P_0) = 2.4;$

$$P_0 = \left(\frac{7}{e^{2.4}}\right) = \mathbf{0.63dBm}$$

6. **What are the types of material absorption losses in silica glass fibers? [DEC 2016]**
   The types of material absorption losses in silica fiber are:
   -Absorption by atomic defects in the glass composition
   -Extrinsic absorption by impurity atoms in the glass material
   Intrinsic absorption by the basic constituent atoms in the glass material
7. **Compare Rayleigh scattering and Mie scattering.**

S.No	Rayleigh Scattering	Mie Scattering

1	Caused due to refractive index variation in the core glass.	Caused by fiber imperfections such as irregularities in the core –cladding interface, core- cladding refractive index difference along the fiber length, diameter fluctuations, strains and bubbles.
2.	When the inhomegenetics size is smaller than the wavelength of light Rayleigh scattering occurs.	When the in homegenetics size is greater than the Wavelength of light, Mie scattering occurs
3	Scattering occurs both is forward and backward direction.	Scattering is mainly in the forward direction.
4.	Rayleigh scattering can be reduced by minimizing the compositional fluctuations by using best manufacturer methods.	Mie scattering can be reduced by Removing imperfections due to the glass manufacturing process. Carefully controlled extrusion and coating of the fiber Increasing the fiber guidance by increasing the relative refractive index difference.

8. Compare Linear scattering and Non- Linear scattering.

S.No	Linear Scattering	Non-Linear Scattering
1.	Linear scatterings are observed only at low optical power densities below the threshold power levels.	Non-Linear scattering are only observed at high optical power densities above the threshold power levels in long single mode fibers.
2.	There are two types are Linear Scattering namely, Rayleigh Scattering Mie Scattering	There are two types of Non-Linear scattering namely, Stimulated Brillouin Scattering (SBS) Stimulated Raman Scattering (SRS)
3.	The Incident light frequency and scattered light frequency is the same. There is no frequency shift during scattering.	The Incident light frequency and scattered light frequency are different. There is a frequency shift during scattering.

9. Compare SRS and SBS.

S.No	SRS	SBS
1.	SRS can occur both in forward and backward direction.	It is mainly backward process.
2.	The threshold power level of SRS is three times higher than SBS threshold in a particular fiber.	The SBS threshold power level is less.
3.	The scattering process produces high frequency optical phonon.	The scattering process produces acoustic phonon as well as a scattered photon.

10. What is meant by intrinsic absorption in optical fibers?

The absorption caused by the interaction of one or more of the major components of the glass is known as intrinsic absorption.

11. What is meant by extrinsic absorption in optical fibers?

The absorption caused by the impurities within the glass is known as extrinsic absorption.

12. Differentiate linear scattering from nonlinear scattering.

- Linear scattering mechanisms transfers linearly some or all of the optical power contained within one propagating mode to a different mode.
- Non-linear scattering causes the optical power from one mode to be transferred in either the forward or backward direction to the same or other modes at different frequencies.

13. What are the types of linear scattering losses? [MAY 2016]

Linear scattering is of two types. They are:

- Rayleigh scattering
- Mie scattering

14.What are the types of nonlinear scattering losses?

Non-linear scattering is of two types. They are

- Stimulated Brillouin Scattering (SBS)
- Stimulated Raman Scattering (SRS)

15. What is meant by Fresnel Reflection? (N/D 2011)

When the two joined fiber ends are smooth and perpendicular to the axes, and the two fiber axes are perfectly aligned, small proportion of the light may be reflected back into the transmitting fiber causing attenuation at joint. This is known as Fresnel reflection.

16. What is meant by linear scattering?

Linear scattering mechanisms transfers linearly some or all of the optical power contained within one propagating mode to a different mode.

17. What are the factors that cause Rayleigh scattering in optical fibers? (M/J 2012)

The inhomogeneties of a random nature occurring on a small scale compared with the wavelength of the light in optical fiber causes Rayleigh scattering. These inhomogeneities manifest themselves as refractive index fluctuations and arise from density and compositional variations that are frozen into the glass lattice on cooling.

18. What are the factors that cause Mie scattering in optical fibers?

The factors that cause Mie scattering in optical fibers are:

- Fiber imperfections such as irregularities in the core – cladding interface
- Core – cladding refractive index differences along the fiber length, diameter fluctuations

19. What are the ways to reduce macro bending losses? (N/D 2009) (N/D 2010)

The ways to reduce macro bending losses are

- Designing fibers with large relative refractive index differences
- Operating at the shortest wavelength possible.

20. What is meant by dispersion in optical fiber? (A/M 2008)

Different spectral components of the optical pulse travel at slightly different group velocities and cause pulse broadening within the fiber. This phenomenon is referred as dispersion.

21. What are the different types of dispersion? (N/D 2008)

There are two types of dispersion. They are

- Intramodal Dispersion:
    - Material Dispersion
    - Waveguide Dispersion
- Intermodal Dispersion:
    - Multimode step index
    - Multimode graded index

22. What is meant by intermodal dispersion? (A/M 2010 A/M 2008)

Pulse broadening due to propagation delay differences between modes within a multimode fiber is known as intermodal dispersion.

23. Define – Group Velocity Dispersion (GVD) (A/M 2011), (N/D 2010)

Intra-modal dispersion is pulse spreading that occurs within a single mode. The spreading arises from the finite spectral emission width of an optical source. This phenomenon is known as Group Velocity Dispersion (GVD).

24. What is meant by modal noise? (A/M 2011)

The speckle patterns are observed in multimode fiber as fluctuations which have characteristic times longer than the resolution time of the detector. This is known as modal or speckle noise.

25. What is meant by chromatic dispersion? (N/D2011)

The dispersion due to the variation of the refractive index of the core material as a function of wavelength is known chromatic dispersion. This causes a wavelength dependence of the group velocity of any given mode. Pulse spreading occurs even when different wavelengths follow the same path.

26. What is meant by polarization mode dispersion? (N/D 2007) [Apr 2018]

Polarization refers to the electric - field orientation of a light signal, which can vary significantly along the length of the fiber.

27. Distinguish between dispersion shifted and dispersion flattened fibers. (N/D 2007)

Reduction in the fiber core diameter with an increase in the relative or fractional index difference to create dispersion is known a dispersion shifted fiber. Fibers which relax the spectral requirements for optical sources and allow flexible wavelength division multiplexing are known as dispersion flattened fibers.

28. What are the two types of fiber joints? The two types of fiber joints are:

(i) Fiber splices: These are semi permanent or permanent joints.
(ii) Demountable fiber connectors or simple connectors: These are removable joints.

29. What is meant by fiber splicing?

A permanent joint formed between two individual optical fibers in the field or factory is known as fiber splice.

30. What are the techniques used in splicing?

Generally used splicing techniques are:

- Fusion splice
- V-groove mecha/ nical splice
- Elastic tube splice

31. List the types of mechanical misalignments that occur between two joined fibers.

There are three types of mechanical misalignments:

- Lateral/radial/axial misalignment
- Longitudinal misalignment
- Angular misalignment

32. What are the causes of absorption?

- Absorption by atomic defects in glass composition.
- Extrinsic absorption by impurity atoms in the glass materials.
- Intrinsic absorption by basic constituent atoms.

33. What is polarization mode dispersion?

The difference in propagation times between the two orthogonal polarization modes will result pulse spreading. This is called as polarization mode dispersion. (PMD)

34. Define signal attenuation.

If P(0) is the optical power in a fiber at the origin (at Z = 0), then the power P(Z) at a distance z further down the fiber is

$P(z) = P(0)\, e^{-\alpha_{p} z}$.

The above equation can be rewritten as

$\alpha_p = (1 / z)\ \{ P(0) / P(z)\}$. Where α_p is the fiber attenuation coefficient given in units of km^{-1}

35. What are bending losses? Name any two types,

Micro bend losses

Macro bend losses

36. What is meant by Polarization of light?

The polarization of light describes by a specifying the orientation of the waves electric field at a point in space over one period of the oscillation. When light travels in free space, it propagates as a transverse wave, i.e. the polarization is perpendicular to the wave"s direction of travel.

37. What is fiber Bi - refrigence?

Fiber bi-refrigence is the optical property of a material having a refractive index that depends on the polarization and propagation direction of light. These optically anisotropic materials are said to be bi-refringence. The bi-refringence is often quantified by the maximum difference in the refractive index within the material.

38. Define Beat length?

Beat length is defined as the period of interference effects in a bi- refringence medium. When two waves with different linear polarization states propagate in a bi-refringence medium, their phases will evolve differently. It is assumed that the polarization of each wave is along the principle directions of the medium (x – axis (or) y – axis), so that this polarization will be preserved during propagation. This means that the phase relation between both waves is restored after integer multiples called the polarization beat length.

39. Define PMF (Polarization Mode Fiber)?

PMF is an optical fiber in which the polarization of linearly polarized light waves launched into the fiber is maintained during propagation, with less or no cross-coupling of optical power between the polarization modes. Such fiber is used in special application where processing the polarization is essential.

40. What are Dispersion Flattened Fibers (DFF)?

DFF is a type of glass optical fiber that provides low pulse Dispersion over a broad portion of the light spectrum and as a result can operate at 1300 nm and 1550 nm wavelength simultaneously.

41. What are Dispersion Shifted Fibers (DSF)?

DSF is a type of optical fiber made to optimize both low dispersion and low attenuation. DSF is a type of single mode optical fiber with a core-clad index profile tailored to shift the zero-dispersion wavelength from the natural 1300 nm in silica-glass fibers to the minimum loss at 1550 nm.

42. What is meant by Fresnel reflection in Fiber cable?

Fresnel reflection at the air-glass interfaces at the entrance and exit of an optical fiber.

43. List out the advantages of elastic tube splicing?

The advantages of elastic tube splicing are,

a) This type of splicing allows accurate and automatic alignment of axes of the two fibers to be joined.

b) In this method the fibers to be splices do not have to be equal in diameter.

44. List out the advantages of V-groove splicing?

a) There is no thermal stress.

b) No change in refraction index of the two fibers. c)

45. What are bending losses? Name any two types. (Apr-May 2015)

(i) Micro bending losses - The light power is dissipated through the micro bends because if the respective coupling of energy between guided modes and leaky modes.

(ii) Macro bending losses - Macrobending losses occur when fibres are physically bent beyond the point at which the critical angle is exceeded.

46. What are the types of fiber losses which are given per unit distance?(Nov-Dec 2014)

(i)Absorption

(ii) Scattering

(iii)Bending Loss

47. List the factors that cause intrinsic joint losses in a fiber. (N0v-Dec 2014)

(i) Different core and / or cladding diameters

(ii) Different numerical apertures and / or relative refractive index differences.

(iii) Different refractive indexprofiles.

(iv) Fiber faults.

48. Define dispersion in multimode fibers. What is its effect? (Nov-Dec 2013) (R)

In multimode fiber many modes are propagating along the fiber at a time. Different modes are taking different ray path and they reach at different time at the output end of the fiber. So a time delay is experienced between modes. This is called intermodal delay and pulse broadening occurs due to intermodal delay is called intermodal dispersion

Effect:

1. It restricts bandwidth of the optical fibercable.
2. The intermodal dispersion causes the light rays to spread out through the fiber.
3. It accounts for a significant loss occurring in thefiber.

49. What are the two reasons for Chromatic Dispersion? (Nov-Dec 2012)

- Dispersive Properties of the waveguide material – **Material Dispersion**
- Guidance effects within the fiber structure– **Waveguide Dispersion**

50. What are the most important non-linear effects of optical fibre communication? (Nov-Dec 2012)

Non linear effects of Scattering are:

- Stimulated Brillouin Scattering (SBS)
- Stimulated Raman Scattering (SRS)

51. A fiber has an attenuation of 0.5dB/Km at 1500nm. If 0.5mW of optical power is initially launched into the fiber estimate the power level after 25km.

$$P_{out}\ (dBm) = P_{in}(dBm) - \alpha\left(\frac{dB}{Km}\right) \times l$$

$$\log_{10}\frac{P_{in}(dBm)}{1mW}$$

$$P_{in}(dBm) = 10\log_{10}\frac{(0.5 \times 10^{-3})}{(1 \times 10^{-3})}$$

$-$

$$P_{out}\ (dBm) = - = 10 - (0.5 \times 25)$$

$$P_{out}\ (dBm) = -$$

PART B & C

1. **Discuss about the design optimization of single mode fiber.(Nov-Dec 2016)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 115·
2. **What is waveguide dispersion? Derive and expression for time delay produced due to waveguide dispersion.(Nov-Dec 2016,APR/MAY 2019)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 109·
3. **With necessary diagrams, explain the causes and types of fiber attenuation loss. (Nov-Dec 2015)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 94·
4. **With diagram, derive the expression for intra modal dispersion. (Nov-Dec 2015)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 109·
5. **What are the loss or signal attenuation mechanism in a fibre? Explain.(Apr-May 2015, NOV/DEC 2018)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 94·
6. **Discuss the pulse broadening in graded index fiber (April 2005,Nov 08)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 105
7. **Derive the expression for pulse broadening due to material dispersion.**
   Refer Book: Optical fiber Communications - Gerd Kaiser -Pg. No. 108
8. **What is meant by waveguide dispersion ? Derive the expression for the same (Nov 2006)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 109
9. **Explain the attenuation mechanisms in Optical fibers. (Dec 2007)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 94
10. **Explain bending losses and type of dispersion (Nov 2010)**
    Refer Book: Optical fiber Communications - Gerd Kaiser -Pg. No. 108
11. **Describe the linear and non-linear scattering losses in optical fibers (Nov 2012)**
    Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 94
12. **Discuss the attenuation encountered in optical fiber communication due to:**
    1. Bending 2. Scattering 3. Absorption.
    Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 94
13. **Explain the attenuation and losses in fiber. (May 2014) [DEC2016]**
    Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 94
14. **With diagram, explain intra and inter modal dispersion. (May 2014, AAPR/MAY2019)**
    Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 115
15. **Explain signal distortion in single mode fibers.**
    Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 115·

UNIT-III

SOURCES AND DETECTORS

1. **What is meant by heterojunction? List out the advantages of heterojunction.(A/M 2011) (N/D 2007)**
A heterojunction is an interface between two adjoining single crystal semiconductors with different bandgap energies. Devices that are fabricated with heterojunction are said to have hetrostructure.
Advantages of heterojunction are:
    - Carrier and optical confinement
    - High output power
    - High coherence and stability

2. **Distinguish between direct and indirect band gap materials. (N/D2010), (N/D 2008)**

Direct bandgap materials	Indirect bandgap material
The electron and hole have the same momentum value	The conduction band minimum and the valence band maximum energy level occur at different values of momentum.
Direct transition is possible from valenc band to conduction band	Direct transition is not possible from valence band to conduction band

3. **Why is silicon not used to fabricate LED or Laser diode? (N/D2011, 2018)[DEC2016]**
Silicon is not used to fabricate LED or Laser diode because
    - It is an indirect bandgap semiconductor
    - It has Eg level of 1.1eV, the radiated emission corresponds to infrared but not the visible light.
4. **What are the advantages of LED?(M/J2012)**
The advantages of LED are:
    - Less expensive
    - Less complex
    - Long life time
    - Used for short distance communication
5. **When an LED has 2V applied to its terminals, it draws 100mA and produces 2mW of optical power. Determine conversion efficiency of the LED from electrical to optical power. (N/D2008)**
Given Data: $V_{in} = 2$ V, $I_{in} = 100\times10^{-3}$ A, $P_{out} = 2\times10^{-3}$
Formula: LED conversion efficiency = $\frac{P_{out}}{P_{in}}$

Solution:
$$P_{in} = V_{in} \times I_{in} = 2 \times 100\times10^{-3}$$
$$\text{Conversion Efficiency} = \frac{2\times10^{-3}}{2\times100\times10^{-3}} = \mathbf{0.01}$$
6. **What are the advantages and disadvantages of LED?**
Advantages:
    - Small size and light weight;
    - High Speed;
    - Low operating temperature;
    - Longer life;
    - No complex driver capacity required.

    Disadvantages:
    - Quantum efficiency is low;
    - Damages due to over voltage and over current;

- Temperature dependent.

7. What are the three requirements of Laser action? [DEC2016]

The three requirements of Laser action are

- Absorption
- Spontaneous emission
- Stimulated emission

8. What is the principle of operation of LASER? (N/D2008)

The principle of operation of LASER is population inversion, the most photons incident on the system. The population of the upper energy level is greater than lower energy level i.e. $N_2 > N_1$. This condition is known as population inversion.

9. Write the three modes of the cavity of LASER diode. (N/D2009)

The three modes of the cavity of LASER are:

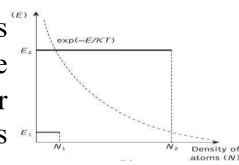
- Longitudinal modes, related to the length L of the cavity
- Lateral Modes lie in the plane of the P-N junction. These modes depend upon the side wall preparation and width of the cavity.
- Transverse modes are associated with the Electro Magnetic Field and beam profile in the direction perpendicular to the plane of the PN junction. These modes determine the radiation pattern of the LASER.

10. What is a DFB Laser? Differentiate DFB LASER from other types of LASER.(N/D2009)

In DFB Laser, the lasing action is obtained by periodic variations of refractive index, which are incorporated into multilayer structure along the length of the diode. DFB LASER does not require optical feedback unlike the other LASERs.

11. What is population inversion? (A/M 2008)

Under thermal equilibrium, the lower energy level E_1 of the two level atomic system contains more atoms than upper energy level E_2.To achieve optical amplification it is necessary to create non-equilibrium distributions of atoms such that population of the upper energy level is greater than lower energy level i.e. $N_2 > N_1$ as shown in the figure. This condition is known as population inversion.



12.Compare LED and ILD sources.[Apr 2017] (A/M 2008)

Sl.No	LED	ILD
1.	Incoherent	Coherent
2.	For multimode fibers only	For multi and single mode fibers
3.	Large beam divergence due to spontaneous emission	Low beam divergence due to stimulated emission

13. Write the three key processes of laser action.(A/M 2008)

The three key processes of laser actions are:

- The atomic system must have population inversion. This means the number of atoms in the excited state should be more than that of ground state
- There should be photons with proper energy to start the stimulated emission
- There should be an arrangement for multiple reflections to increase the intensity of LASER beam

14. What are the advantages of Quantum Well Lasers?(N/D2009)

The advantages of Quantum Well Lasers are:

- High threshold current density
- High modulation speed
- High line width of the device

15. Define – Internal Quantum Efficiency[NOV /DEC 2018]

Internal Quantum Efficiency is defined as the ratio of radiative recombination rate to the total recombination rate.

$$\eta_{in} = \frac{R_r}{R_r + R_{nr}}$$

where R_r is radiative recombination rate, R_{nr} is the non-radiative recombination rate.

16. Define – External Quantum Efficiency

The external quantum efficiency is defined as the ratio of photons emitted from LED to the number of photons generated internally.

17. Define – Quantum efficiency of a photo detector(A/M2008,10) (M/J2009)(N/D2011)

Quantum efficiency is defined as the number of the electron-hole carrier pairs generated per incident photon of energy *hv* is given bynumber of electron−hole pairs generated
number of incident photons

$$\eta = \frac{I_P/q}{P_o/h\nu}$$

where I_p is the photon current
q is the charge of the electron
P_o is the optical output power
h is the Planck's constant
ν is the frequency of the optical signal

18. An LED has radiative and nonradiative recombination times of 30 and 100 ns respectively. Determine the internal quantum efficiency. (N/D 2007) (N/D 2010)

Given data: $\tau = 30\times 10^{-9} sec$, $\tau_{nr} = 100\times 10^{-9} sec$

Formula: $\tau = \frac{\tau_r \times \tau_{nr}}{\tau_r + \tau_{nr}} = \frac{30\times10^{-9}\times100\times10^{-9}}{130\times10^{-9}} = 23.1ns$

Solution: $\eta_{int} = \frac{\tau}{\tau_r} = \frac{23.1\ ns}{30ns} = 0.77 = 77\%$

19. Calculate the external differential quantum efficiency of a laser diode operating at 1.33µm.The slope of the straight line portion of the emitted optical power P versus drive current I is given by 15 mW/mA. (N/D2011)

Given data: $\lambda = 1.33\times10^{-6}$

$\frac{q}{Eg} = 0.8065\,\lambda = 0.8065\times1.33\times10^{-6}$ $M = (q)/Eg \times \frac{dP}{dI} = 0.8065\times1.33\times10^{-6}\times 15\times10^{-3}$

$\frac{dP}{dI} = 15\times10^{-3}$ $= \mathbf{16.089\%}$

20. What are the necessary features of a photo detector? (N/D2007)

The necessary features of a photo detector are:

- High Quantum efficiency
- Low rise time or fast response
- Low dark current

21. Define – Responsivity of a photodetector (N/D2008, 2018),(N/D 2010)

Responsitivity is defined as the ratio of output photo current to the incident optical power.

$R = \frac{I_p}{P_o} = \frac{\eta q}{h\nu}$

where, R=Responsivity.

I_p=Output photo current P_o=Incident optical power

22. Compare the performance of APD with PIN diode. (N/D2008)

APD	PIN
No internal gain	Internal gain is high
Thermal current noise dominates photo detector noise current	Photo detector noise current dominates thermal noise current
Low responsivity	High responsivity
Low dark current	High dark current
Suitable for high intensity application	Suitable for low intensity application

Required low reverse bias voltage	Required high reverse bias voltage

23. List out the operating wavelengths and responsivities of Si, Ge, and InGaAs photodiodes. (N/D2009)

The Operating Wavelengths and Responsivities of Si, Ge, and InGaAs photodiodes are:

Silicon (Si) :

- Operating wavelength range λ = 400 - 1100 nm
- Responsivity R = 0.4-0.6

Germanium (Ge) :

- Operating wavelength range λ = 800 - 1650 nm
- Responsivity R = 0.4 - 0.5

Indium Gallium Arsenide (InGaAs):

- Operating wavelength range λ = 1100 - 1700 nm
- Responsivity R = 0.75 - 0.95

24. List the benefits and drawbacks of avalanche photodiodes.

Benefits of APD are:

- Carrier multiplication takes place.
- Sharp threshold

Drawbacks of APD are:

- High biasing voltage.
- Noisy

25. Photons of energy 1.53×10^{-19} J are incident on a photodiode that has the responsivity of 0.65Amps/W. If the optical power level is 10μW, find the photo current generated.(M/J 2012)

Given data : $E = 1.53\times10^{-19}$ J, R = 0.65Amps/W, $P_0 = 10\times10^{-6}$ W

Formula : $I_p = R\times P_0$

Solution : $I_p = 0.65\times 10\times10^{-6}$ = **6.5 μA**

26. GaAs has band gap energy of 1.43ev at 300k. Determine the wavelength above which an intrinsic photo detector fabricated from this material will cease to operate.(A/M 2008)

Given data: Eg(eV) = 1.43ev

Formula: λ(μm) = 1.24/Eg(eV)

Solution: λ(μm) =1.24/1.43

λ(μm) =**0.86 μm**.

27. Define – Photocurrent

The high electric field present in the depletion region causes the carriers to separate and be collected across the reverse- biased junction. This gives to a current flow in the external circuit, with one electron flowing for every carrier pair generated. This current flow is known as photocurrent.

28. Define – Impact Ionization

In order for carrier multiplication to take place, the photo-generated carriers must traverse a region where a very high electric field is present. In this high field region, a photo generated electron or hole can gain energy so that it ionizes bound electrons in the valence band upon colliding with them. This current multiplication mechanism is known as impact ionization.

29. Define – Avalanche Effect

The newly created carriers are accelerated by the high electric field, thus gaining enough energy to cause further impact ionization. This phenomenon is called avalanche effect.

30. llustrate the factor that determine the response time of the photodiode.

The resistance and capacitance of the photodiode and the external circuitry give rise to another response time known as RC time constant{\display style \tau =RC}. This combination of R and C integrates the photo response over time and thus lengthens the impulse response of the photodiode. When used in an optical communication system, the response time determines the bandwidth available for signal modulation and thus data transmission.

31. Define dark current?

The photo diode dark current is the current that continues to flow through the bias circuit of the device when no light is incident on the photo diode.

32. Define Johnson or thermal noise?

When current is flowing continuously across the load resistor, heat will be dissipated. This is called thermal noise.

33. What is known as detector response time? (May 2012, NOV/DEC2018)

It is defined as the time taken for the photo detector to respond to an optical input pulse. The response time determines the bandwidth available for signal modulation and data transmission.

34. What are the factors that limit the response time of the photo detectors?

• Transit time of photo carriers within the depletionregion.
• Diffusion time of photo carriers outside the depletion region.
• RC time constant of the photo diode and its associated circuit.

35. What are inherent connection problems when joining fibers?

The inherent connection problems when jointing fibers are,

- Different core and/or cladding diameters.
- Different numerical apertures and/or relative refractive index differences.
- Different refractive index profiles.
- Fiber faults(core elliptically, core concentricity etc

36. Compare PIN and APD?

S.No	PIN	APD
1	No internal gain.	Internal gain.
2	Thermal noise current dominates photo detector noise current.	Photo detector noise current dominates thermal noise current.
3	Low responsivity.	High responsivity.
4	Low dark current.	High dark current.
5	Suitable for high intensity application.	Suitable for low intensity application.
6	Required low reverse bias voltage.	Required high reverse biasvoltage.

37. List out the different types of mechanical misalignments during fiber connection?

The three possible types of misalignment which may occur when joining compatible optical fibers are,

- Longitudinal misalignment
- Lateral misalignment
- Angular misalignment

38. What is fiber splicing?

Fiber splicing is the process of joining two fibers by melting the fiber ends.

39. Compare splices and connectors.

S.No	Splices	Connectors
1	Permanent or semi permanent joints	Temporary joint
2	Splice loss is low	Connector loss is high

40. Define power- bandwidth product.(Apr-May 2015)

High output power and high bandwidth are two important parameters in the design of photo-detector. The Product of photodetector bandwidth and power at which bandwidth ismeasured.

41.Contrast the advantages of PIN diode with APD diode. (Apr-May 2015)

- Low dark current
- It is affected but only thermal noise
- No speed limitation due to capacitance effect

42. What is meant by Mechanical splicing? (May-June 2013)

Mechanical splicing, in which the fibers are held in alignment by some mechanical means, may be achieved by including the use of V-groove into which the butted fibers are placed (or) the use of tubes around the fiber ends.

43. Calculate the Band gap energy for an LED to emit $850nm$? (May- June 2013)

Solution $\lambda = 850nm = 0.85\mu m$

$$E_g = \frac{hc}{\lambda} = \frac{6.625 \times 10^{-34} \times 3 \times 10^8}{0.85 \times 10^{-6}} = 2.33 \times 10^{-19} = 1.45\ eV$$

$$E_g = 1.45\ eV$$

44. Define external quantum efficiency.(Nov-Dec 2016).

The external quantum efficiency is defined as the ratio of the photons emitted from the LED to the number of internally generated photons.

45. Write two difference between a Laser diode and a LED. (Nov-Dec 2013)

S.no	Laser Diode	LED
1.	Coherent radiation Takes place.	In coherent radiation takes place.
2.	Narrow spectral width	Wider Spectral width

46. Why silicon is preferred for fabrication of photo receiver?

- Silica is used for fabrication photo receiver, because it has larger band gap, it generates low noise and it supports multiple channels as it has larger bandwidth.
- Silicon is available plenty in nature.

47. Why are semiconductor based photo detectors preferred to other types of photo detectors?

Semiconductor laser diode generates low noise and they support multiple channels as they have larger bandwidth.

48. What are the requirements of photo detector?

- The photo detector must have high quantum efficiency to generate a large signal power.
- The photo detector and amplifier noises should be kept as low as possible.

49. What is the significance of intrinsic layer in PIN diode.[APR/MAY 2019]

The intrinsic region in the diode is in contrast to a PN junction diode. This region makes the PIN diode an lower rectifier, but it makes it appropriate for fast switches, attenuators, photo detectors and applications of high voltage power electronics.

50. What are the factors that limit the response time of the photo detectors?

- Transit time of photo carriers within the depletion region.
- Diffusion time of photo carriers outside the depletion region.
- RC time constant of the photo diode and its associated circuit.

51. What are inherent connection problems when joining fibers?

The inherent connection problems when jointing fibers are,

- Different core and/or cladding diameters.
- Different numerical apertures and/or relative refractive index differences.
- Different refractive index profiles.
- Fiber faults(core elliptically, core concentricity etc)

PART B & C

1. **Discuss the LASER diode principle, modes and threshold conditions. (Jun 2007)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 163 **(Apr./May 2008)**

2. **a. Derive the threshold condition for lasing. [DEC2016]**
   b. Explain in detail the fabry perot resonator cavity Laser diode.
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 163 **(Apr./May 2008)**

3. **a. Explain the various lensing schemes. (Nov 2004,Dec 05,07,April 09, Apr 2017. Apr 2018)**
   b. Explain the various splicing techniques.
4. **Discuss about modulation of LED & Quantum LASER (Nov 2010)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 152
5. **With neat diagram explain the working of surface emitting LED (Nov 2011, 2018, may 2012, Apr 2017, 2019)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 152

6. **Explain the structure of silicon ADP**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 249

7. **Explain any two injection laser structure with neat diagram (May 2012)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 163 **(Apr./May 2008)**

8. **Derive laser diode rate equations. (16 marks) [APR/MAY 2019] (Nov 2012)[DEC2016]**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 163 **(Apr./May 2008, Apr 2018)**

9. **(i) Explain the working of n hetero structure LED. (Nov2013, NOV 2018)**
   (ii) Define internal quantum efficiency of a LED. Deduce the expression for the same.
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 152

10. **Explain expanded beam connectors with neat diagram (Nov 2011)**
    Refer Book: Optical fiber Communications –John M.Senior - Pg. No. 238-244.

11. **Write brief note on fiber alignment and joint loss (May 2012)**
    Refer Book: Optical fiber Communications –John M.Senior - Pg. No. 227-234.

12. **Describe about connectors, splices and couplers. (Nov-Dec 2015)**
    Refer Book: Optical fiber Communications –John M.Senior - Pg. No. 238-244.

13. **A Photodiode is constructed of GaAs which has a band gap energy of 1.43eV at 300K. Find the long wavelength cut-off. (Apr-May 2015)**
    Refer Book: Optical fiber Communications –John M.Senior - Pg. No. 238-244.

14. **What do you understand by optical-wave confinement and current confinement in LASER diode? Explain with suitable structures. (Nov-Dec 2013)**
    Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 163

15. **Discuss about optical detection noise. (Nov-Dec 2015)**
    Refer Book: Optical fiber Communications –John M.Senior - Pg. No. 238-244.

16. **Explain gain guided and Index guided laser diodes.**
    Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 163

UNIT-IV

FIBER OPTIC RECEIVER AND MEASUREMENTS

1. **What is bit rate?**

   The transmitted signal is two level binary data stream consisting of either 0 or 1 in a time slot of duration T. this time slot is referred to a bit period.

2. **What are the error sources of receiver? (M / J 2013)**

   The error sources of receiver are

   - Thermal noise
   - Dark current noise
   - Quantum noise

3. **A digital fiber optic link operating at 1310 nm, requires a maximum BER of 10^{-8}. Calculate the required average photons per pulse. (N / D 2013)**

   The probability error $P_r(o) = e^{-N} = 10^{-8}$

   Solving for $N = 8 \log_e 10 = 18.42$

   An average of 18 photons per pulse is required for this BER.

4. **Define: Probability of error**.

   Probability of error means that a transmitted' l' is misinterpreted as a '0' or transmitted '0' is misinterpreted as a '1' by the receiver.

5. **Define – Quantum Limit (M/J2012), (N/D2007)9DEC2016)**

   The minimum received power level required to maintain a specific Bit – Error - Rate (BER) of an optical receiver is known as the quantum limit.

6. **What is meant by (1/f) noise corner frequency? (N/D2009)**

   The (1/f) noise corner frequency is defined as the frequency at which (1/f) noise, which dominates the FET noise at low frequencies and has (1/f) power spectrum.

7. **Why silicon is preferred to make fiber optical receivers? (N/D2010), (A/M2011)**

   Silicon is preferred to make fiber optical receivers because

   It has high sensitivity over the 0.8–0.9 μm wavelength band with adequate speed

   It provides negligible shunt conductance, low dark current and long-term stability

8. **Define – Modal noise and Mode Partition Noise.(A/M2011)(M/J2009)(A/M2010)**

   Disturbances along the fibre such as vibrations, discontinuities, connectors, splices and source/detector coupling may cause fluctuations in the speckle patterns. It is known as modal noise.

   Phenomenon that occurs in multimode semiconductor lasers when the modes are not well stabilized is known as mode partition noise.

9. **Mention the error sources in fiber optical receiver. (N/D2011)**

   There are three main error sources in fiber optical receiver. They are:

   - Thermal noise
   - Dark current noise
   - Quantum noise

10. **Define – Bit Error Rate(DEC2016)**

    Bit Error Rate (BER) is defined as the ratio of the number of errors occurred over a certain time interval't' to the number of pulses transmitted during this interval.

11. **How does dark current arise?**

    When there is no optical power incident on the photo detector a small reverse leakage current flows from the device terminals known as dark current. Dark current contributes to the total system noise and gives random fluctuations about the average particle flow of the photocurrent

12. **What is Inter Symbol Interference?**

Each pulse broadens and overlaps with its neighbors, eventually becoming indistinguishable at the receiver input. This effect is known as Inter Symbol Interference.

13. **Define – Extinction ratio**

The extinction ratio is usually defined as the ratio of the optical energy emitted in the '0' bit period to that emitted during the '1' bit period.

14. **What are the requirements of an optical receiver?(Nov. / Dec. 2006)**
    - It should have fast response;
    - High sensitivity;
    - Tolerable SNR;
    - Should reproduce the signal without any distortion.

15. **Define – Minimum Detectable Optical Power**
It is defined as the optical power necessary to produce a photocurrent of the same magnitude as the root mean square of the total current.

16. **What are the noise effects on system performance?**
The main penalties are modal noise, wavelength chirp, spectral broadening, mode-partition noise.

17. **Why the attenuation limit curve slopes towards to the right?**
As the minimum optical power required at the receiver for a given BER becomes higher for increasing data rates, the attenuation limit curve slopes downward to the right.

18. **What do you mean thermal noise?**
Thermal noise is due to the random motion of electrons in a conductor. Thermal noise arising from the detector load resistor and from the amplifier electronics tend to dominate in applications with low signal to noise ratio.

19. **What is meant by excess noise factor?**
The ratio of the actual noise generated in an avalanche photodiode to the noise that would exist if all carrier pairs were multiplied by exactly m is called the excess noise factor. (F).

20. **What are the system requirements?**
The key system requirements are as follows
    - The desired or possible transmission distance
    - The data rate or channel bandwidth
    - Bit error rate (BER)

21. **Give the two analyses that are used to ensure system performance.**
The two analyses that are used to ensure system performance are
    - Link power budget analysis
    - Rise time budget analysis.

22. **What are the requirements of preamplifier?**
It should have low noise level, high bandwidth, high dynamic range, and high sensitivity to avoid non linearity and high gain.

23. **What are the types of pre - amplifiers?**
The types of pre-amplifier are
    - Low- impedance preamplifier
    - High – impedance preamplifier

Transimpedance preamplifier

24. **List the advantages of preamplifiers.**
The advantages of pre amplifiers are
    - Low noise level
    - High Bandwidth
    - High dynamic range

- High Sensitivity
- High gain

25. What are the standard fiber measurement techniques?

The standard fiber measurement techniques are

- Fiber attenuation measurement
- Fiber dispersion measurement
- Fiber refractive index profile measurement
- Fiber cutoff wavelength measurement
- Fiber numerical aperture measurement
- Fiber diameter measurement

26. Define – Bend Attenuation

A peak in the wavelength region where the radiation losses resulting from the small loop are much higher than the fundamental mode is known as bend attenuation.

27. **What is the technique used for measuring the total fiber attenuation?**

Total fiber attenuation per unit length can be determined using cut-back method. Taking a set of optical output power measurements over the required spectrum using a long length of fiber usually at least a kilometre is known as cut back technique. The fiber is then cut back to a point 2 meters from the input end and maintaining the same launch conditions, another set of power output measurements are taken.

Relationship for the optical attenuation per unit length α_{db} for the fiber may be obtained from,

$$\alpha_{db} = \frac{10}{(L_1 - L_2)\log_{10}\frac{P_{02}}{P_{01}}}$$

where,

L_1, L_2 - original and cut-back fiber length respectively

P_{02}, P_{01} -output optical powers at a specific wavelength from the original and cut back fiber lengths.

28. What are the factors that produce dispersion in optical fibers?

The factors that produce dispersion in optical fibers are:

- Propagation delay difference between the different spectral components of the transmitted signal.
- Variation in group velocity with wavelength

29. What are the methods used to measure fiber dispersion?

The methods used to measure fiber dispersion are:

- Time domain measurement
- Frequency domain measurement

30. What are the methods used to measure fiber refractive index profile? (M/J2012)

The methods used to measure fiber refractive index profile are

- Interferometric method
- Near infra scanning method
- Refracted near field method

31. List the process associated with fiber optic receiver section.

Although the photo-detector is the major element in the fibre optic receiver, the other elements to the whole unit. Once the light has been received by the fibre optic receiver and converted into electronic pulses, the signals are processed by the electronics in the receiver. Typically these will include various forms of amplification including a limiting amplifier. These serve to generate a suitable square wave that can then be processed in any logic circuitry that may be required.

32. What is Mode Coupling and what are its causes?

It is another type of pulse distortion which is common in optical links.

The pulse distortion will be increased less rapidly after a certain initial length of fiber, due to this mode coupling and differential mode losses occur.

33. Define Quantum limit (Q). (May-June 2013)

The minimum received power level required for a specific BER of digital system is known as Quantum limit.

34. List out the methods used to measure fiber refractive index profile.

1. Inter-ferometric method
2. Near field scanning method
3. End field scanning method

35. What are the error sources in fiber optic receiver? (May-June 2013, Nov-Dec 2012)

The error sources in fiber optic receiver are

- Shot Noise
- DarkCurrent
  Bulk Dark Current SurfaceDarkCurrent
- Thermal Noise.
- Amplifier noise

36. What are the different techniques for determining attenuation in optical fiber?

The different techniques for determining attenuation are

i) Cut-back ii) Insertion-loss

37. Write the expression to measure attenuation using cut back method.

$$d \quad \frac{10}{L_1 \quad L} \log_{10} \frac{V_1}{V_2}$$

Where

38. List any two advantages of trans-impedance amplifiers.(Apr-May 2015)

(i) Reduces thermal noise

(ii) Provide wide bandwidth

39. State the significance of maintaining the fiber outer diameter constant.(Nov-Dec 2014)

It is essential during the fiber manufacturing process (at the drawing stage) that the fiber outer dian (cladding diameter) is maintained constant to within 1%. Any diameter variations may cause excessive radi losses and make accurate fiber – fiber connection difficult.

40. Mention few fiber diameter measurement techniques. (Nov-Dec 2015)

There are two very broad classifications of diameter measurements techniques

(i) Contacting or destructive methods

(ii) Non-contacting and nondestructive methods

41. What is dark current?(Nov-Dec 2012)

The photo diode dark current is the current that continues to flow through the bias circuit of the device when no light is incident on the photo diode.

42. A digital fiber optic link operating at 1310 nm, requires a maximum BER of 10-8. Calculate the required average photons per pulse. (Nov- Dec 2013)

Solution:

Given

Probability error $(_r)P0 = \quad N \quad 10 \quad 8$

L_1 = original fiber length

L_2 = Cut-back fiber lengthV1, V2are the output voltages

$N \quad 8\log_e 10 \quad 18.42 \quad 18$

An average of 18 photons per pulse ie required for this BER.

43. A trignometrical measurement is performed in order to determine the numerical aperture of a step index fiber. The screen is positioned 10.0cm from the fiber end face. When illuminated from a wide angled visible source the measurement output pattern size is6.2 cm. Calculate the Numerical Aperture of the fiber.

NA = A / (A^2 +4D^2) = 6.2 / (38.44 + 400) = 0.30

44. In a fiber optic system operating at 1.3 µm, the transmitter power = -3 dB m. Fiber cable loss = 0. 2 dB/km. Total connector loss at the transmitter and receiver = - 2dB. PINreceiver sensitivity when operating at 400 Mbps = - 44 dB m. Safety margin = 6 dB. Calculate the maximum transmission distance without repeaters (i) when there is no dispersion equalization penalty and (ii) when there is a dispersion equalization penalty o f1.5 dB.

(i) P Tr- P Rr= a fL + a c+ P SM= - 3 dB - (- 44 dB)

=0.2 x L + 2 + 641-8=0.2L

L= 33/0.2 = 165 km

(ii) P Tr- P Rr= a fL + a c+ P SM+ D L

41 =0.2xL+2+6+1.5

L = 31.5/0.2 = 157.5 km

45. State detector response time

This is the measure of the photodiode response speed to a stepped light input signal. It is the time required for the photodiode to increase its output from 10% to 90% of final output level. is the rise timeof the device.

46. Give the 2 analysis that are used to ensure system performance?

The 2 analysis that are used to ensure system performance are: • link power budget analysis • rise time budget analysis

47. Explain briefly about link power budget analysis?

In the optical power loss model for a pt-to-pt link, the optical power rxed at the photo detector depends on the amount of light coupled into the fiber & losses occurring in the fiber at the connectors & splices. The link loss budget is derived from the sequential loss contribution of each element in the link. Loss=10 log (Pout) (Pin) The total optical power loss is, PT = PS - PR

48. **Give the range of system margin in link power budget?** The system margin is usually (6-8) dB. A positive system margin ensures proper operation of the circuit. A negative value indicates that insufficient power will reach the detector to achieve the required bit error rate, BER.

49. The specifications of the light sources are converted to equivalent rise time in rise time budget. Why? A rise time budget is a convenient method to determine the dispersion limitation of an optical link. This is particularly useful for digital systems. For this purpose, the specifications of the light sources (both the fiber & the photo detector) are converted to equivalent rise time. The overall system rise time is given in terms of the light source rise time, fiber dispersion time & the photo detector rise time.

50. **What are the system components of system rise time?** The 4 basic system components that contribute to the system rise time are: • transmitter (source) rise time • receiver rise time • material dispersion time of the fiber • modal dispersion time of the fiber link All these 4 basic elements may significantly limit system speed.

51. Why the attenuation limit curve slopes downwards to the right? As the minimum optical power required at the rxer for a given BER becomes higher for increasing data rates, the attenuation limit curve slopes downward to the right.

PART B & C

1. **Draw and explain the high impedence of high impedence pre-amplifier designed based on BJT and FET (8)**
   b) Write a brief note on trans impedence amplifier. [8] (Nov/Dec 2008, 2018)
   Refer Book: Optical fiber Communications - John M.Senior - Pg. No . 377.

2. **Explain the operation of preamplifier built using FET (Nov 2011)**
   Refer Book: Optical fiber Communications - John M.Senior - Pg. No . 377.

3. **Explain measurement technique used in the case of fiber diameter, fiber cut off length, refractive index profile, Numerical aperture (Nov 2011, 2018)**
   Refer Book: Optical fiber Communications - John M.Senior - Pg. No . 779 -781.

4. **Draw and explain the operation of high impedance FET and BJT preamplifiers(May 2012)**
   Refer Book: Optical fiber Communications - John M.Senior - Pg. No . 377.

5. **Explain a) Attenuation measurement using cut back technique**
   b)Frequency domain measurement of fiber dispersion (May 2012) (DEC2016)
   Refer Book: Optical fiber Communications - John M.Senior - Pg. No . 782 -783.

6. **Considering the probability distributions for received logic 0 and 1 signal pulses.**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 282**(Nov. / Dec. 2007)**

7. **Derive the expressions for BER and error function. (Nov 2012)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 282**(Nov. / Dec. 2007)**

8. **Explain the types of preamplifiers used in a receiver.**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 282**(Nov. / Dec. 2007)**

9. **Define the terms- Quantum limit and probability of Error with respect to a receiver with typical values. (Nov 2013, 2018)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 282**(Nov. / Dec. 2007)**

10. **With suitable diagram, explain optical receiver operation and its performance.(May 2014, May 2015)**
    Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 279

11. **Describe the dispersion and numerical aperture measurements of fiber. (May 2014)**
    Refer Book: Optical fiber Communications - John M.Senior - Pg. No . 779 -781.

12. **With schematic diagram, explain the blocks and their functions of an optical receiver. (Apr-May 2015, Nov-Dec 2014, APR/MAY 2019)**
    Refer Book: Optical fiber Communications - John M.Senior - Pg. No . 779 -781.

13. **A digital fibre optic link operationg at 850nm requires a maximum BER of 10^{-9}. Find the quantum limit in terms of the quantum efficiency of the detector and the energy of the incident photon. (Apr-May 2015)**
    Refer Book: Optical fiber Communications - John M.Senior - Pg. No . 779 -781.

14. **What are the performance measures of a digital receiver? Derive an expression for bit error rate of a digital receiver. (Nov-Dec 2016,Nov-Dec 2015, 2018)**
    Refer Book: Optical fiber Communications - John M.Senior - Pg. No . 779 -781.

15. **Draw the block diagram of OTDR. Explain the measurements of any two fiber optic measurements with this. (Nov-Dec 2014)**
    Refer Book: Optical fiber Communications - John M.Senior - Pg. No . 779 -781.

UNIT-V OPTICAL NETWORKS

1. **Define power penalty [NOV/DEC 2018]**
   The power penalty may become significant if the semiconductor laser is biased above the threshold. For lasers biased below threshold, the extinction ratio is typically 0.05 and the power penalty is less than 0.4 dB. Timing Jitter In a digital system the signal is generally sampled at the center of the pulse.
2. **Distinguish between fundamental and higher order solitons.[APR/MAY 2019]**
   A fundamental soliton is an optical pulse which can propagate in a dispersive medium (e.g. an optical fiber) with a constant shape of the temporal intensity profile, i.e., without any temporal broadening as is usually caused by dispersion.
   A higher-order soliton is a soliton pulse the energy of which is higher than that of a fundamental soliton by a factor which is the square of an integer number
3. **Mention the drawbacks of Broadcast and select networks for wide area networkapplications.[Apr 2018]**
   The drawbacks of broadcast and select networks for wide area network applications are:
   More wavelengths are needed as the number of nodes in the network grows
   Without the use of optical booster amplifiers splitting losses occurs
4. **What are the three topologies used for fiber optical network? (N/D 2011)**
   The three topologies used for fiber optical network are:
   Bus
   Ring
   Star
5. **Calculate the number of independent signals that can be sent on a single fiber in the 1525-1565 nm bands. Assume the spectral spacing as per ITU-T recommendation G.692. (A/M 2011)**
   Given data: Mean frequency spacing as per ITU-T is 0.8 nm
   Wavelength = 1565 nm -1525 nm = 40 nm
   Solution:
   Number of independent channel = (40 nm/0.8 nm) = 50 Channels
6. **What is meant by power penalty?**
   When nonlinear effects contribute to signal impairment, an additional amount of power will be needed at the receiver to maintain the same BER. This additional power(dB) is known as the power penalty.
7. **Define – Network**
   Network is defined as to establish connections between these stations; one interconnects them by transmission paths to form a network.
8. **What is meant by topology?**
   The topology is the logical manner in which nodes are linked together by information transmission channels to form a network.
9. **What are the drawbacks of broadcast and select networks for wide area network applications? (M/J 2012)**
   The drawbacks of broadcast and select networks for wide area network applications are:
   More wavelengths are needed as the number of nodes in the network grows
   Without the use of optical booster amplifiers splitting losses occurs
10. **Define – WDM (A/M2011)**
   In fiber-optic communications, wavelength-division multiplexing (WDM) is a technology which multiplexes a number of optical carrier signals onto a single optical fiber by using different wavelengths

(i.e. colors) of laser light. This technique enables bidirectional communications over one strand of fiber, as well as multiplication of capacity.

11. **What are the advantages of WDM? (N/D2007)**

The advantages of WDM are

- Various optical channels can support different transmission formats
- Increase in the capacity of optical fiber compared to point-to-point link

12. What is the purpose of rise-time budget analysis? (A/M2008)

Rise-time budget ensures that the link is able to operate for a given data rate at specified BER. All the components in the link must operate fast enough to meet the band width or rise time requirements.

13. The specifications of the light sources are converted to equivalent rise time in rise time budget. Why?

A rise time budget is a convenient method to determine the dispersion limitation of an optical link. This is particularly useful for digital systems. For this purpose, the specifications of the light sources (both the fiber and the photo detector) are converted to equivalent rise time. The overall system rise time is given in terms of the light source rise time, fiber dispersion time and the photo detector rise time.

14. What is EDFA?(A/M2008, 2019), (M/J2012)NOV /DEC2018

An erbium-doped fiber amplifier (EDFA) is a device that amplifies an optical fiber signal. A trace impurity in the form of a trivalent erbium ion is inserted into the optical fiber's silica core to alter its optical properties and permit signal amplification.

15. What are the two different types of WDM? (DEC2016)

The two different types of WDM are

a. Unidirectional WDM

b. Bidirectional WDM

16. Define – Crosstalk

Crosstalk is defined as the feed through one of the channel signals into another channel.

17. Give the important features of time-slotted optical TDM network.

The important features of time slotted optical TDM network are

c. To provide backbone to interconnect high speed networks
d. To transfer quickly very large data blocks
e. To switch large aggregations of traffic
f. To provide both high- rate.

18. How the speckle pattern can form?

The speckle patterns are formed by the interference of the modes from a coherent source when the coherence time of the source is greater than the intermodal dispersion time within the fiber.

19. Define – Full- Width Half- Maximum(FWHM)

The FWHM is a pulse defined as the full width at its half-maximum power level.

20. **What are the advantages of using soliton signals through fiber? (M/J2009)**

The advantages of using soliton signals through fiber are, it is very narrow, high-intensity optical pulses that retain their shape through the interaction of balancing pulse dispersion with the nonlinear properties of an optical fiber

21. **What is chirping? (N/D2009)**

The d.c. modulation of a single longitudinal mode semiconductor laser can cause a dynamic shift of the peak wavelength emitted from the device This phenomenon, which results in dynamic line width broadening under the direct modulation of the injection current, is referred to as frequency chirping.

22. What is the best way to minimize chirping?

It is to choose the LASER emission wavelength close to the zero-dispersion of the wavelength of the fiber.

23. What do you mean by bidirectional WDM?

A single WDM which operates as both multiplexing and demultiplexing device is said to be bidirectional WDM.

24. What are the basic performances of the WDM?

The basic performances of WDM are

- ✓ Insertion loss
- ✓ Channel width
- ✓ Cross talk

25. Distinguish between fundamental and higher order soliton. (N/D2007)

The optical pulse that does not change in shape is called fundamental solitons.

The pulses that undergo periodic shape changes are called higher order solitons.

26. What are the two different types of WDM? (MAY 2016)

The two different types of WDM are

g. Unidirectional WDM

h. Bidirectional WDM

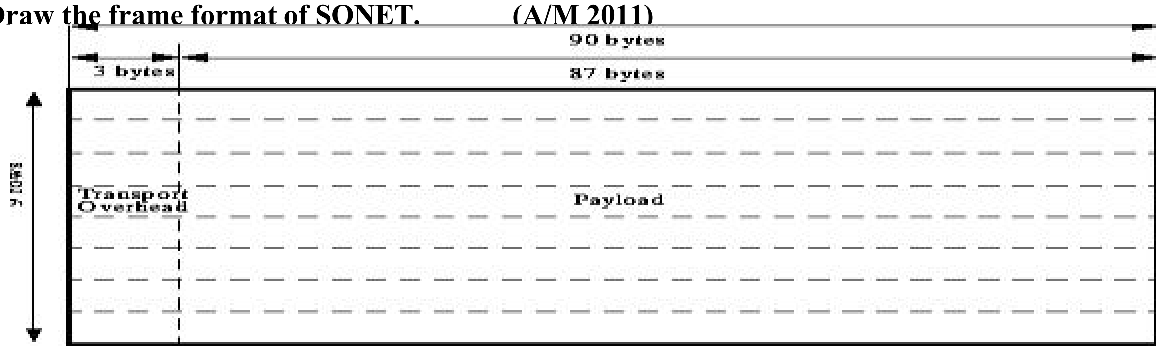
27. What is DWDM?

Dense Wavelength Division Multiplexing (DWDM) is an optical technology used to increased bandwidth over existing fiber-optic bones. It works by combining and transmitting multiple signals simultaneously at different wavelengths on the same fibers.

28. What is SONET/SDH?[Apr 2018]

Synchronous Optical NETworking (SONET) or Synchronous Digital Hierarchy (SDH) is a standardized protocol that transfers multiple digital bit streams over optical fiber using lasers or highly coherent light from light emitting diodes. At low transmission rates data can also be transferred via an electrical interface.

29. Draw the frame format of SONET. (A/M 2011)



30. **What are the drawbacks of broadcast and select network for wavelength multiplexing?**

The problems that arise in broadcast and select networks are:

- More wavelengths are needed as the number of nodes in the network grows.

- Without the width spread use of optical booster amplifiers, due to this splitting loss is high.

31. What is optical CDMA? (Nov-Dec 2015)

Optical CDMA is a multiple access technique in which each user is assigned an unique optical code. When a receiver is placed anywhere on the network with a bar code that matches a transmitter that signal line is decoded and extracted from the network.The codes are orthogonal to each other.

32. Distinguish SONET and SDH. (Nov-Dec 2015)

ONET	DH
t means synchronous optical network developed by ANSI. Basic signaling unit is OC-I (51.84Mbps) ONET uses the term section, line and path.	t means synchronous digital hierarchy developed by ITU Basic signaling unit is STM-1 (155.52 Mbps) DH uses the term path, multiplex section and egenerator section.

33. Name two popular architectures of SONET/SDH network.(Nov-Dec 2016) (R)

The two popular architectures of SONET/SDH networks are:

- o UPSR - Unidirectional Path Switched Ring, two-fiber.
- o BLSR – Bidirectional Line Switched Ring, two-fiber or four-fiber.

34. Obtain the transmission bit rate of the basic SONET frame in Mbps.(Nov-Dec 2013) (E)

STS-1 frame rate = (810 bytes/frame)*(8000 frames/sec)
= 51.840 Mbps.

35. Illustrate inter-channel cross talk that occurs in a WDM system.(Nov- Dec 2013) (A)

Inter-channel crosstalk arises when an interfacing signal comes from a neighboring channel that operates at a different wavelength. This nominally occurs when a wavelength selecting device imperfectly rejects or isolates the signals from other near-by wavelength channels.

36. What is a broadcast and select network?(May-June 2013) (R)

In broadcast and select networks, a node sends its transmission to the star coupler on the available wavelength using a laser which produces an optical information stream. The information stream from multiple sources is optically combined by the star and the signal and the signal power of each stream is equally spilt and forwarded to all the nodes on their receiver fiber.

37. What is SONET?(Apr-May 2015) (R)

SONET means synchronous optical network which is developed by ANSI, standardized protocol that transfer multiple digital bit stream synchronously over optical fiber using laser.

38. What were the problems associated with PDH networks?(Nov-Dec 2012) (AZ)

1. PDH- Plesiochronous Digital Hierarchy
2. It is difficult to "pick out" (drop) a low bit rate stream out of a high bit rate stream it is completely demultiplexing stream.
3. Expensive and compromises network reliability.

39. Enumerate the various SONET/SDH layers. ?(Nov-Dec 2012)

The various SONET/SDH layers are,

- Photonic layer
- Section layer
- Line layer
- Path layer.

40. What is DWDM?

Dense Wavelength Division Multiplexing (DWDM) is an optical technology used to increased bandwidth over existing fiber-optic bones. It works by combining and transmitting multiple signals simultaneously at different wavelengths on the same fibers.

41.What are solitons? (N/D2010) (DEC2016)

Solitons are nonlinear optical pulses that have the potential to support very high optical transmission rates of many terabits per second over long distances.

42. Give the important features of time-slotted optical TDM network.

The important features of time slotted optical TDM network are

- ✓ To provide backbone to interconnect high speed networks
- ✓ To transfer quickly very large data blocks
- ✓ To switch large aggregations of traffic
- ✓ To provide both high- rate.

43. How the speckle pattern can form?

The speckle patterns are formed by the interference of the modes from a coherent source when the coherence time of the source is greater than the intermodal dispersion time within the fiber.

44.What do you mean by bidirectional WDM?

A single WDM which operates as both multiplexing and demultiplexing device is said to be bidirectional WDM.

45. Define – Full- Width Half- Maximum(FWHM)

The FWHM is a pulse defined as the full width at its half-maximum power level.

46. What are the types of broadcast and select network?

The types of broadcast and select network are

- ✓ Single – hop networks
- ✓ Multi – hop networks

47. What is meant by cross- phase modulation (XPM)?

Cross- phase modulation, which converts power fluctuations in particular wavelength channel to phase fluctuations in the copropating channels.

48. Define self-healing rings.

The SONET/SDH rings are called **self-healing rings,** since the traffic flowing along a certain path can automatically be switched to an alternate path.

49. Mention the architectures for SONET/SDH networks.

- ✓ Two fiber unidirectional path switched ring.
- ✓ Two or four fiber bidirectional path switched ring.

50. Define single –hop network.

Single –hop network refers to networks where information transmitted in the form of light reaches its destination without being converted to an electrical form at any intermediate point.

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PART B & C

1. **With neat diagram, explain the elements of SONET infrastructure. (16) (May 2007) (MAY 2016)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. NO.472

2. **Explain the principle and operation of Erbium doped fiber amplifiers with neat diagrams. (10) (Jan 2010)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 514- 516.

3. **Describe the principle and performance of DT-WDMA protocol. (8)**
   Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 477- 482

4. Explain the architecture of SONET and discuss the nonlinear effects on network performance (Nov 2011)

Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. NO.472

5. Explain the principle of solitons and discuss the soliton parameters with necessary expressions (May 2012)

Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 506.

6. Write short notes on optical CDMA,WDM and EDFA performance (May 2012)

Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 426.

7. Describe the non-linear effects on network performance in detail.(8) (Nov 2012, 2018) [DEC 2016] MAY 2019

Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 514- 516.

8. Explain the basics of optical CDMA systems. (8) (Nov 2012)

Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 514- 516.

9. (i) What is a four fiber BLSR ring in a SONET? Explain the reconfiguration of the same during node or fiber failure

(ii) What is broadcast and select multi hop network? Explain. (Nov 2013)

Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. NO.4 72

10. (i) Explain the following requirements for the design of an optically amplified WDM link: 1) Link band width

2) Optical power requirements for a specific BER.

Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 477- 482

(ii) Write a note on solitons. (Nov 2013)

11. Expalin SONET layers and frame structure with diagram (May 2014) [DEC 2016,2018]

Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. NO.4 72

12. Discuss in detail about the effect of noise on system performance.(Nov-Dec 2016)

13. Discuss the performance improvement of WDM and EDFA systems.(Nov- Dec 2015,Apr-May 2015, 2019, Nov-Dec 2014, NOV/DEC2018)

Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 426.

14. Discuss the non-linear effects on optical network performance.(Apr-May 2015, 2019, Nov-Dec 2012)

Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 514- 516.

15. Explain i)Optical CDMA ii)Optical Wavelength Routing Network.(Nov-Dec 2012)

Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 514- 516.

16. Discuss about Ultra High Capacity Networks. (Apr-May 2015,Nov-Dec 2014)

Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 514- 516.

B.E B.Tech. DEGREE EXAMINATION, APRIL / MAY 2019.
Seventh Semester
Electronics and Communication Engineering

EC6702- OPTICAL COMMUNICATION AND NETWORKS

PART A – (10x2 = 20 marks)

1. **Why do we prefer step index single mode fiber for long distance communication?**
Step index single mode fiber has (1) low attenuation due to smaller core diameter, (2) Higher bandwidth, (3)Low dispersion.
2. **What is the necessity of cladding for an optical fiber?**
a) To provide proper light guidance inside the core b) To avoid leakage of light from the fiber c) To avoid mechanical strength for the fiber d) To protect the core from scratches and other mechanical damages
3. **Give the measure of information capacity in optical wave guide.**
It is usually specified by bandwidth distance product in MHz.For a step index fiber the various distortion effects tend to limit the bandwidth distance product to 20MHz.
4. **Why silicon is not used to fabricate LED or laser diode?**
   a. It is an indirect bandgap semiconductor
   b. It has Eg level of 1.1eV; the radiated emission corresponds to infrared but not the visible light.
5. **A fiber has attenuation of 0.5 db/km.at 1500nm. If 0.5mwf 0.5mw of optical power is initially launched into the fiber, estimate the power level after 25 km.**

$$P_{out}\,(dBm) = P_{in}(dBm) - \alpha\left(\frac{dB}{Km}\right) \times l$$

$$\log_{10}\frac{P_{in}(dBm)}{1mW}$$

$$P_{in}(dBm) = 10 \quad \log_{10}\frac{(0.5 \times 10^{-3})}{(1 \times 10^{-3})}$$

$$-$$

$$P_{out}\,(dBm) = \equiv 10 \quad -(0.5 \times 25)$$

$$P_{out}\,(dBm) = -$$

6. **A GaAs laser operating at 850nm has a 500µm length and a refractive index of n = 3.7. what are the frequency spacing and the wavelength spacing?**

$$\Delta v = \frac{c}{2\,L\,n}$$

$$\Delta \lambda = \frac{\lambda^2}{2\,L\,n}$$

7. **State the significance of maintaining the fiber outer diameter constant.**
It is essential to maintain the fiber outer diameter constant. Any diameter variation may cause excessive radiation losses and make accurate fiber to fiber connection difficult.
8. **What is the significance of intrinsic layer in PIN diode.**
The intrinsic region in the diode is in contrast to a PN junction diode. This region makes the PIN diode an lower rectifier, but it makes it appropriate for fast switches, attenuators, photo detectors and applications of high voltage power electronics.
9. **Distinguish between fundamental and higher order solutions.**
A *fundamental* soliton is an optical pulse which can propagate in a dispersive medium (e.g. an optical fiber) with a constant shape of the temporal intensity profile, i.e., without any temporal

broadening as is usually caused by dispersion.

A *higher-order* soliton is a soliton pulse the energy of which is higher than that of a fundamental soliton by a factor which is the square of an integer number

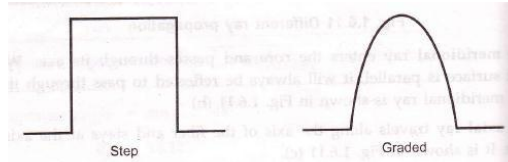


Fig. 1.6.12 Index profiles

10. What is EDFA?

EDFA means Erbium Doped Fiber Amplifier which is used to amplify the multiple lightwave signals completely in the optical domain. It is a 10 to 30 m length of silica optical fiber that has been lightly doped with the rare earth element, Erbium and inserted in the optical fiber link. Here the photons are used to directly raise electrons into excited state. This process is called optical pumping.

PART B – (5x13 = 65 marks)

11. Draw the explain the refractive index profile and ray transmission in multimode step index and single mode step index fibers.

Fiber Profiles

- A fiber is characterized by its profile and by its core and cladding diameters.
- One way of classifying the fiber cables is according to the index profile at fiber. The **index profile** is a graphical representation of value of refractive index across the core diameter.

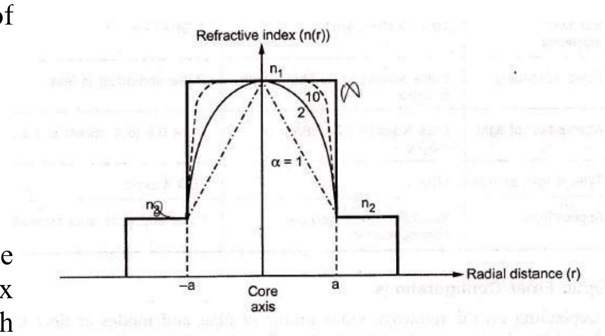


Fig. 1.6.15 Possible fiber refractive index profiles for different values of α

- There are two basic types of index profiles.

i) Step index fiber. ii) Graded index

Step Index (SI) Fiber

- The step index (SI) fiber is a cylindrical waveguide core with central or inner core has a uniform refractive index of n_1 and the core is surrounded by outer cladding with uniform refractive index of n_2. The cladding refractive index (n_2) is less than the core refractive index (n_1). But there is an abrupt change in the refractive index at the core cladding interface. Refractive index profile of step indexed optical fiber is shown in Fig.

The propagation of light wave within the core of step index fiber takes the path of meridional ray i.e. ray follows a zig-zag path of straight line segments.

The core typically has diameter of 50-80 μm and the cladding has a diameter of 125 μm.

- The refractive index profile is defined as –

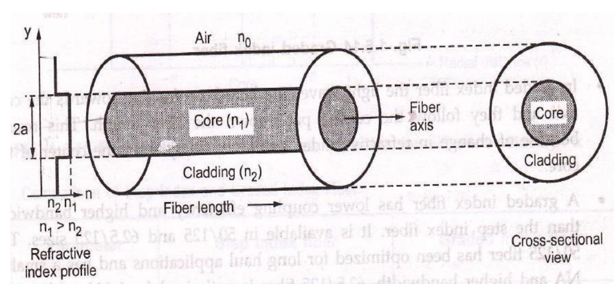


Fig. 1.6.13 Step index fiber

$$n(r) = \begin{cases} n_1 & \text{when } r < a \text{ (core)} \\ n_2 & \text{when } r \geq a \text{ (cladding)} \end{cases}$$

Graded Index (GRIN) Fiber

- The graded index fiber has a core made from many layers of glass.
- In the **graded index (GRIN)** fiber the refractive index is not uniform within the core, it is highest at the center and decreases smoothly and continuously with distance towards the cladding. The refractive index profile across the core takes the parabolic nature. Fig.

In graded index fiber the light waves are bent by refraction towards the core axis and they follow the curved path down the fiber length. This results because of change in refractive index as moved away from the center of the core.

- A graded index fiber has lower coupling efficiency and higher bandwidth than the step index fiber. It is available in 50/125 and 62.5/125 sizes. The 50/125 fiber has been optimized for long haul applications and has a smaller NA and higher bandwidth. 62.5/125 fiber is optimized for LAN applications which is costing 25% more than the 50/125 fiber cable.

- The refractive index variation in the core is giver by relationship

$$n(r) = \begin{cases} n_1\left(1 - 2\Delta\left(\frac{r}{a}\right)^{\alpha}\right) & \text{when } r < a \ (core) \\ n_1(1-2\Delta)^{\frac{1}{2}} \approx n_2 & when\ r \geq a \ (\text{cladding}) \end{cases}$$

where,

r = Radial distance from fiber axis a = Core radius

n_1 = Refractive index of core

n_2 = Refractive index of cladding α = Shape of index profile.

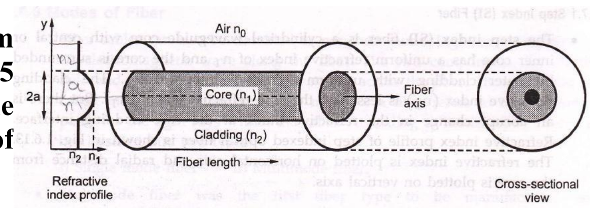


Fig. 1.6.14 Graded index fiber

a(ii)Consider a multimode step index fiber with a 62.5μm core diameter and a core cladding index difference of 1.5 percent. If the core refractive index is 1.480, estimate the normalized frequency of the fiber and the total number of modes supported in the fiber at a wavelength of 850nm

Solution : Given : MM step index fiber, 2 a = 80 μm

Core radians a = 40 μm

Relative index difference, Δ = 1.5% = 0.015

Wavelength, λ = 0.85μm

Core refractive index, n_1 = 1.48

Normalized frequency, V = ?

Number of modes, M = ?

Numerical aperture

$$\boxed{NA = n_1(2\Delta)^{1/2}}$$

$= 1.48\ (2 \times 0.015)^{1/2}$

= 0.2563

Normalized frequency is given by,

$$\boxed{V = \frac{2\pi a}{\lambda} NA}$$

$$V = \frac{2\pi \times 40}{0.85} \times 0.2563$$

V = 75.78 **Ans.**

Number of modes is given by,

$$M = \frac{V^2}{2}$$

$$M = \frac{(75.78)^2}{2} = \mathbf{2871.50}$$

OR

b)(i)Explain in detail linearly polarized modes in optical fibers and their relationship to V number.

(ii)Consider a fiber with a 25μm core radius, a core index n1= 1.48 and Δ = 0.01.

1) if =1320nm, what is the value of V number and how many modes propagate in the fiber?

a = 3.3 μm

$\Delta = 1\,\% = 0.01 \qquad n_1 = 1.5 \qquad \lambda = 1.3\ \mu m = 1.3 \times 10^{-6} m$

$$V = 2.4\left(1 + \frac{2}{\alpha}\right)^{\frac{1}{2}} \qquad V = 2.4\sqrt{2}$$

$$a = \frac{V\lambda}{2\pi\, n_1 (2\Delta)^{\frac{1}{2}}} \qquad a = \frac{24\sqrt{2} \times 1.3 \times 10^{-6}}{2\pi \times 1.5 \times (0.02)^{\frac{1}{2}}}$$

2) what is the % of optical power that flows in the cladding?

3) if the core cladding difference is reduced to Δ = 0.003, how many modes does the fiber have and what fraction of the optical power flows in the cladding?

12 a)(i)How does wave dispersion affect the performance of Transmission in optical fibre explain in detail.

Waveguide Dispersion

- Waveguide dispersion is caused by the difference in the index of refraction between the core and cladding, resulting in a 'drag' effect between the core and cladding portions of the power.
- Waveguide dispersion is significant only in fibers carrying fewer than 5-10 modes. Since multimode optical fibers carry hundreds of modes, they will not have observable waveguide dispersion.
- The group delay (τwg) arising due to waveguide dispersion.

$$(\tau_{wg}) = \frac{L}{c}\left[n_2 + n_2\,\Delta\,\frac{d\,(kb)}{dk}\right] \qquad \ldots$$

(2.6.5)

Where, b = Normalized propagation constant

k = 2π / λ (group velocity)

Normalized frequency V,

$$V = ka(n_1^2 - n_2^2)^{\frac{1}{2}}$$

$$V = k\,a\,n_2\sqrt{2\Delta}\ \text{(For small } \Delta\text{)}$$

$$\tau_{wg} = \frac{L}{c}\left[n_2 + n_2\,\Delta\,\frac{d\,(V_b)}{dV}\right]$$

The second term $\frac{d(V_b)}{dV}$ is waveguide dispersion and is mode dependent term..

- As frequency is a function of wavelength, the group velocity of the energy varies with frequency. The produces additional losses (waveguide dispersion). The propagation constant (b) varies with wavelength, the causes of which are independent of material dispersion.

(ii)Manufactures data sheet list the material dispersion Dmatof GeO2 doped fibre to be 110 ps at a wavelength of 860 NM find The RMS pulse broadening per kilometre due to the material dispersion if the optical sources is a GaA11As LED That has a spectral width of 40 NM 8 and output wavelength of 860 NM

$$\propto_{intermodal} = \frac{LN_1\Delta}{2c} \cdot \frac{\propto}{\propto + 1}\left(\frac{\propto + 2}{3\propto + 2}\right)^{1/2} x$$

$$\sigma^2_{intramodal} = \left(\frac{\sigma\lambda}{\lambda}\right)^2 \left\langle\left(\lambda \frac{d\tau g}{d\lambda}\right)^2\right\rangle$$

OR

b)(i) Discuss about the intermodal dispersion that occurs in a multimode graded index fibre

The inter-modal dispersion is due to difference in velocity of different modes inside a fiber. Obviously, the inter-modal dispersion takes place in a multi-mode fiber. It has been shown earlier that the optical rays launched at different angles give different modal fields. The inter-modal dispersion can therefore be approximately calculated using the ray model. The inter-modal dispersion is approximately given as The unit of inter modal-dispersion is ps/Km. The magnitude of inter-modal dispersion is much larger compared to the chromatic dispersion. Therefore the chromatic dispersion is neglected while calculating the dispersion in a multi-mode fiber.

(ii)Continuous 12 kilometre long Optical Fibre link as a loss of 1.5 TB per kilometre propose a proper solution to find the minimum optical power that must be launched into the fibre to maintain optical power level of 0.3 microwatt at the receiving end

Solution : Given data : z = 12 km

α = 1.5 dB/km

P(0) = 0.3 μW

i) Attenuation in optical fiber is given by,

$$\alpha = 10 \text{ x } \frac{1}{z} \log\left(\frac{P(0)}{P(z)}\right)$$

$$1.5 = 10 \text{ x } \frac{1}{12} \log\left(\frac{0.3\ \mu W}{P(z)}\right)$$

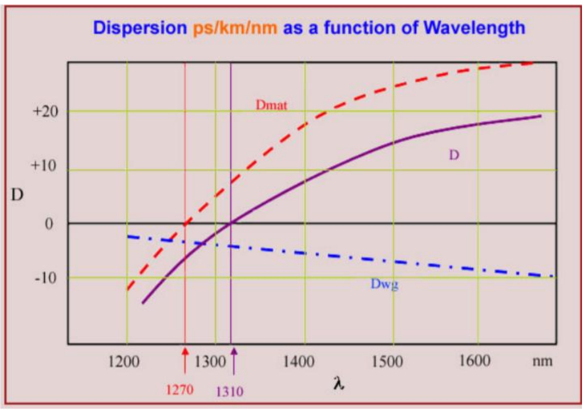
$$\log\left(\frac{0.3\ \mu W}{P(z)}\right) = \frac{1.5}{0.833}$$

= 1.80

$$\left(\frac{0.3\ \mu W}{P(z)}\right) = 10^{1.8}$$

$$P(z) = \left(\frac{0.3\ \mu W}{10^{1.8}}\right) = \frac{0.3}{63.0}$$

$$P(z) = 4.76 \text{ x } 10^{-9} W$$



Optical power output = **4.76 x 10^{-9} W**

ii) Input power = ? P(0)

When α = 2.5 dB/km

$$\boxed{\alpha = 10 \text{ x } \frac{1}{z} \log\left(\frac{P(0)}{P(z)}\right)}$$

$$2.5 = 10 \ x \ \frac{1}{z} \log\left(\frac{P(0)}{4.76 \times 10^{-9}}\right)$$

$$\log\left(\frac{P(0)}{4.76 \times 10^{-9}}\right) = \frac{2.5}{0.833} = 3$$

$$\frac{P(0)}{4.76 \times 10^{-9}} = 10^3 = 1000$$

P(0) = 4.76 μW

Input power= **4.76 μW**

13a)(i)With diagram explain surface and edge emitting LED structures.

<u>LED configurations</u>

At present there are two main types of LED used in optical fiber links –

1. Surface emitting LED.
2. Edge emitting LED.

Both devices used a DH structure to constrain the carriers and the light to an active layer.

Surface Emitting LEDs

- ✓ In surface emitting LEDs the plane of active light emitting region is oriented perpendicularly to the axis of the fiber.
- ✓ A DH diode is grown on an N-type substrate at the top of the diode.
- ✓ A circular well is etched through the substrate of the device. A fiber is then connected to accept the emitted light.
- ✓ At the back of device is a gold heat sink. The current flows through the p-type material and forms the small circular active region resulting in the intense beam of light.
- ✓ Diameter of circular active area = 50 μm Thickness of circular active area = 2.5 μm Current density = 2000 A/cm^2 half-power Emission pattern = Isotropic, 120^o beamwidth.
- ✓ The isotropic emission pattern from surface emitting LED is of Lambartian pattern. In Lambartian pattern, the emitting surface is uniformly bright, but its projected area diminishes as cos θ, where θ is the angle between the viewing direction and the normal to the surface. The beam intensity is maximum along the normal.
- ✓ The power is reduced to 50% of its peak when $\theta = 60^o$, therefore the total half-power beamwidth is 120^o. The radiation pattern decides the coupling efficiency of LED.

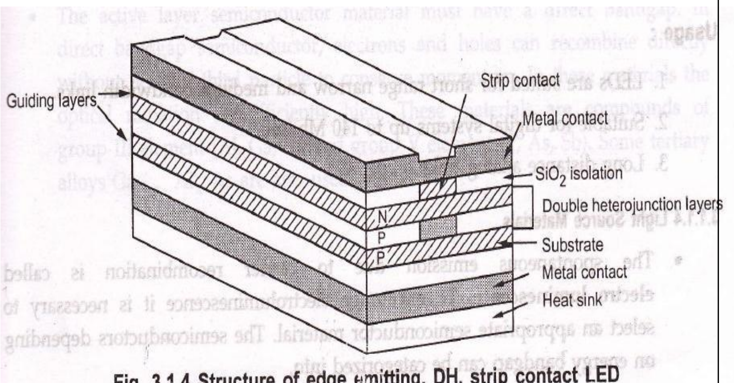


Fig. 3.1.4 Structure of edge emitting, DH, strip contact LED

Edge Emitting LEDS (ELEDs)

- ✓ In order to reduce the losses caused by absorption in the active layer and to make the beam more directional, the light is collected from the edge of the LED. Such a device is known as **edge emitting** LED or ELED.
- ✓ It consists of an active junction region which is the source of incoherent light and two guiding layers.
- ✓ The refractive index of guiding layers is lower than active region but higher than outer surrounding material. Thus a waveguide channel is form and optical radiation is directed into the fiber.
- ✓ Edge emitter's emission pattern is more concentrated (directional) providing improved coupling efficiency. The beam is Lambartian in the plane parallel to the junction but diverges more slowly in the plane perpendicular to the junction.

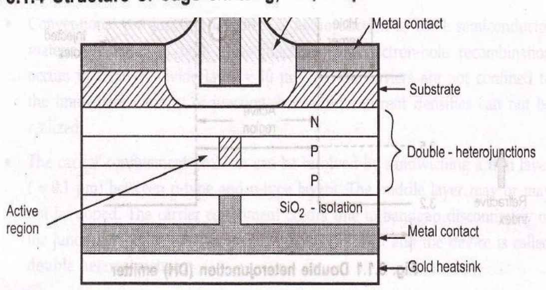
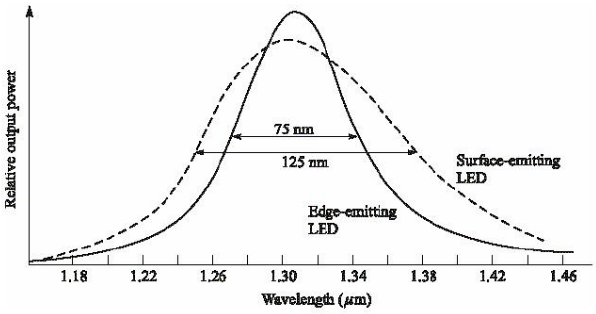


Fig. 3.1.2 Cross-section through a typical surface emitting LED

- ✓ In this plane, the beam divergence is limited. In the parallel plane, there is no beam confinement and the radiation is Lambartian. To maximize the useful output power, a reflector may be placed at the end of the diode opposite the emitting edge.

LED Spectral Width



Edge emitting LED's have slightly narrow line width

Features of ELED:

1. Linear relationship between optical output and current.
2. Spectral width is 25 to 400 nm for λ = 0.8 – 0.9 µm.
3. Modulation bandwidth is much large.
4. Not affected by catastrophic gradation mechanisms hence are more reliable.
5. ELEDs have better coupling efficiency than surface emitter.
6. ELEDs are temperature sensitive.

Usage :

1. LEDs are suited for short range narrow and medium bandwidth links.
2. Suitable for digital systems up to 140 Mb/sec.
3. Long distance analog links.

(ii)A double heterojunction InGaAsP LED emitting at a peak wavelength of 1310 NM radiative and nonradiative radiative recombination times of 30and 100 NS respectively. The drive current is 40 microampere. find the

1. **Bulk recombination time**
2. **internal Quantum efficiency**
3. **and internal power level**

i) Bulk Recombination Life time (τ) :

$$\frac{1}{\tau} = \frac{1}{\tau_r} + \frac{1}{\tau_{nr}}$$

$$\frac{1}{\tau} = \frac{1}{30} + \frac{1}{100}$$

4. **internal Quantum efficiency**

$$\eta_{int} = \frac{\tau}{\tau_r}$$

$$\eta_{int} = \frac{23.07}{30}$$

$$\eta_{int} = \mathbf{0.769}$$

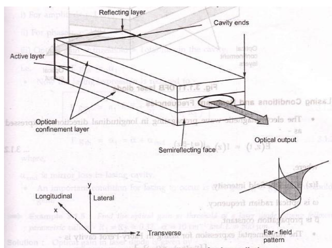


Fig. 3.1.10 Fabry-Perot resonator for laser diode

Internal pwer level (Pint) :

$$P_{int} = \eta_{int} \cdot \frac{hc\,I}{q\lambda}$$

$$P_{int} = 0.769 \times \frac{(6.625 \times 10^{-34})(3 \times 10^{8}) \times 0.04}{(1.602 \times 10^{-19})(0.87 \times 10^{-6})}$$

$$P_{int} = \mathbf{2.913\ mW}$$

(b)Draw and explain the structure of fabry Perot resonator cavity for a laser diode derive laser diode rate equation

Lasers are oscillators operating at frequency. The oscillator is formed by a resonant cavity providing a selective feedback. The cavity is normally a Fabry-Perot resonator i.e. two parallel plane mirrors separated by distance L,

Light propagating along the axis of the interferometer is reflected by the mirrors back to the amplifying medium providing optical gain. The dimensions of cavity are 25-500 μm longitudinal 5-15 μm lateral and 0.1-0.2 μm transverse. Fig. 3.1.10 shows Fabry-Perot resonator cavity for a laser diode.

The two heterojunctions provide carrier and optical confinement in a direction normal to the junction. The current at which lasing starts is the threshold current. Above this current the output power increases sharply.

Lasing conditions and resonant Frequencies

- The electromagnetic wave propagating in longitudinal direction is expressed as –

$$E(z, t) = I(z)\, e^{j(\omega t - \beta z)}$$

where,

I(z) is optical field intensity.
Ω is optical radian frequency.
β is propagation constant.

- The fundamental expression for lasing in Fabry-Perot cavity is –

$$I(z) = I(0)e^{[\{\Gamma g(h v) - \alpha(h v)\} z]} \quad \ldots 3.1.24$$

where,

Γ is optical field confinement factor or the fraction of optical power in the active layer. α is effective absorption coefficient of material.

g is gain coefficient.
h v is photon energy.

z is distance traverses along the lasing cavity.

- Lasing (light amplification) occurs when gain of modes exceeds above optical loss during one round trip through the cavity i.e.z = 2L. If R_1 and R_2 are the mirror reflectivities of the two ends of laser diode. Now the expression for lasing expressing is modified as,

$$I(2L) = I(0)e^{[2L\{\Gamma g(h v) - \alpha(h v)\}]} \quad \ldots 3.1.25$$

The condition of lasing threshold is given as –

i) For amplitude : I (2L) = I (0)

ii) For phase : $e^{-j2\beta L} = 1$

iii) Optical gain at threshold = Total loss in the cavity.

i.e. $\Gamma g_{th} = \alpha_t$

- Now the lasing expression is reduced to –

$$\Gamma g_{th} = a_t = \alpha + \frac{1}{2L} \ln\left(\frac{1}{R_1 R_2}\right) \quad \ldots 3.1.26$$

$$\Gamma g_{th} = \alpha_t = \alpha + \alpha_{end}$$

where,

A_{end} is mirror loss in lasing cavity.

- An important condition for lasing to occur is that gain, g ≥ g th i.e. threshold gain.

14 a)Develop the schematics of pin photodiode and APD and also explain in detail

PIN Photodiode

- PIN diode consists of an intrinsic semiconductor sandwiched between two heavily doped p-type and n-type semiconductors as shown in Fig.
- Sufficient reverse voltage is applied so as to keep intrinsic region free from carries, so its resistance is high, most of diode voltage appears across it, and the electrical forces are strong within it. The incident photons give up their energy and excite an electron from valance to conduction band. Thus a free electron hole pair is generated, these are calledas **photocarriers**. These carriers are collected across the reverse biased junction resulting in rise in current in external circuit called **photocurrent**.
- In the absence of light, PIN photodiodes behave electrically just like an ordinary rectifier diode. If forward biased, they conduct large amount of current.
- PIN detectors can be operated in two modes : **Photovoltaic** and **photoconductive**. In photovoltaic mode, no bias is applied to the detector. In this case the detector works very slow, and output is approximately logarithmic to the input light level. Real world fiber optic receivers never use the photovoltaic mode.
- In photoconductive mode, the detector is reverse biased. The output in this case is a current that is very linear with the input light power.
- The intrinsic region some what improves the sensitivity of the device. It does not provide internal gain. The combination of different semiconductors operating at different wavelengths allows the selection of material capable of responding to the desired operating wavelength.

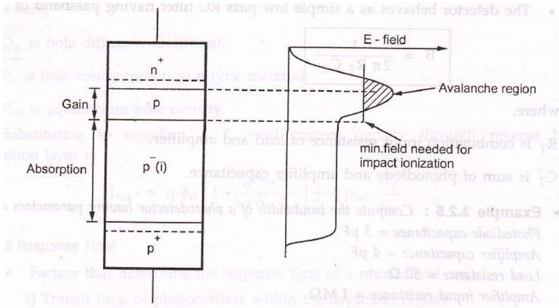


Fig. 3.2.5 APD schematic and variation of E-field across diode

Avalanche Photodiode (APD)

- When a p-n junction diode is applied with high reverse bias breakdown can occur by two separate mechanisms direct ionization of the lattice atoms, zener breakdown and high velocity carriers impact ionization of the lattice atoms called avalanche breakdown. APDs uses the avalanche breakdown phenomena for its operation. The APD has its internal gain which increases its responsivity.
- Fig. 3.2.5 shows the schematic structure of an APD. By virtue of the doping concentration and physical construction of the n+ p junction, the electric filed is high enough to cause impact ionization. Under normal operating bias, the I-layer (the p^- region) is completely depleted. This is known as reach through condition, hence APDs are also known as reach through APD or RAPDs.
- Similar to PIN photodiode, light absorption in APDs is most efficient in I-layer. In this region, the E-field separates the carriers and the electrons drift into the avalanche region where carrier multiplication occurs. If the APD is biased close to breakdown, it will result in reverse leakage current. Thus APDs are usually biased just below breakdown, with the bias voltage being tightly controlled

b)A given Silicon Avalanche photodiode has a Quantum efficiency of 65% at a wavelength of 900 NM suppose 0.5 microwatts of optical power producers multiplied photo current of 10 micro amperes what is the multiplication factor m.

APD multiplication factor (*M*), an instructive expression is given by the formula

$$M = \frac{1}{1 - \int_0^L \alpha(x)\,dx},$$

where *L* is the space-charge boundary

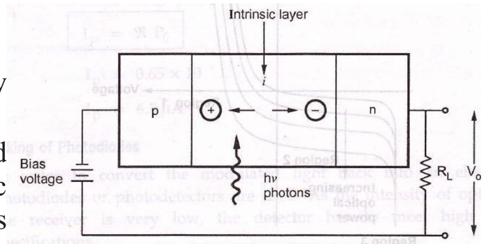


Fig. 3.2.2 PIN photodiode

for electrons, and is the multiplication coefficient for electrons (and holes). This coefficient has a strong dependence on the applied electric field strength, temperature, and doping profile. Since APD gain varies strongly with the applied reverse bias and temperature, it is necessary to control the reverse voltage to keep a stable gain. Avalanche photodiodes therefore are more sensitive compared to other semiconductor photodiodes.

15) a)Explain in brief the blocks and their function of an optical receiver with schematic diagrams.

Optical Receiver Design

- An optical receiver system converts optical energy into electrical signal, amplify the signal and process it. Therefore the important blocks of optical receiver are
  - ✓ Photo detector / Front-end
  - ✓ Amplifier / Liner channel
  - ✓ Signal processing circuitry / Data recovery.

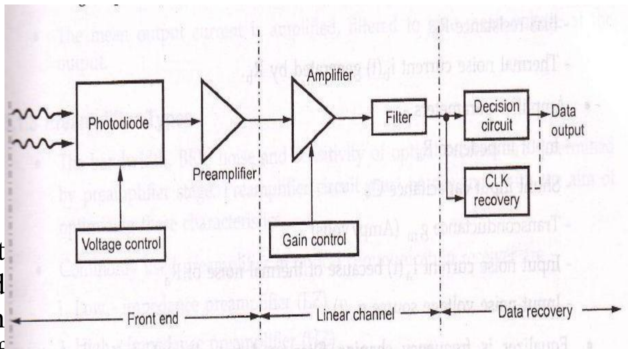


Fig. 5.1.1 Optical receiver

Noise generated in receiver must be controlled precisely as it decides the lowest signal level that can be detected and processed. Hence noise consideration is an important factor in receiver design. Another important performance criteria of optical receiver is average error probability.

Receiver Configuration

- Configuration of typical optical receiver is shown in Fig.

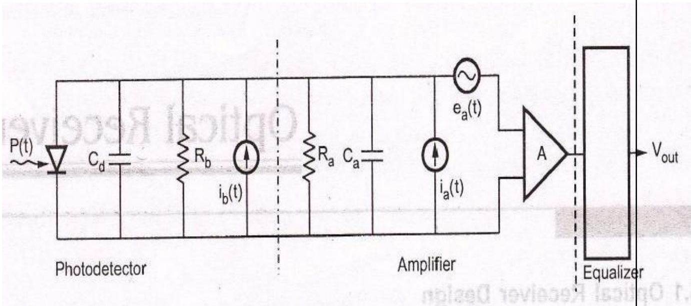


Fig. 5.1.2 Optical receiver configuration

Photo detector parameters –

- ✓ PIN or APD type
- ✓ Gain M = 1
- ✓ Quantum efficiency η
- ✓ Capacitance Cd
- ✓ Dias resistance Rb
- ✓ Thermal noise current ib (t) generated by Rb.

- Amplifier parameters –
  - ✓ Input impendence Ra
  - ✓ Shunt input capacitance Co
  - ✓ Transconductance gm (Amp/volts)
  - ✓ Input noise current ia (t) because of thermal noise of Ra
  - ✓ Input noise voltage source ea (t)
- Equalizer is frequency shaping filter used to mollify the effects of signal distortion and ISI.

Expression for Mean Output Current from Photodiode Assumptions :

1. All noise sources are Gaussian in statistics.
2. All nose sources are flat in spectrum.
3. All noise sources are uncorrelated (statistically independent).

- Binary digital pulse train incident on photodector is fiven by –

$$P(t) = \sum_{n=-\infty}^{\infty} b_n h_p(t - nT_b) \qquad \ldots \quad (5.1.1)$$

Where,
P(t) is received optical power.
b is bit period.
bn is amplitude parameter representing nth message bit.
hp (t) is received pulse shape.

- At time t, the mean output current due to pulse train P(t) is –

$$\langle i\,(t)\rangle = \frac{\eta q}{h\nu} M\,P(t) \qquad \ldots (5.1.2)$$

Where, M is gain of photodectector $\frac{\eta q}{h\nu}$ is responsivity of photodiode $(\Re_0)$

- Neglecting dark current, the mean output current is given as –

$$\langle i(t)\rangle = \Re_0\; M \sum_{n=-\infty}^{\infty} b_n h_p(t - nT_b) \qquad \ldots (5.1.3)$$

- Then mean output current is amplified, filtered to give mean voltage at the output.

b) Define and explain the principle of WDM networks

WDM (Wavelength Division Multiplexing) corresponds to the scheme in which multiple optical carriers at different wavelengths (produced by LASER) are modulated by using independent electrical bit streams (which may themselves use TDM and FDM techniques in the electrical domain) and are then transmitted over the same fiber.

• The optical signal at the receiver is demultiplexed into separate channels by using an optical technique.

• The main system feature of WDM are as follows:

1. Capacity
2. Transparency
3. Wavelength routing
4. Wavelength switching

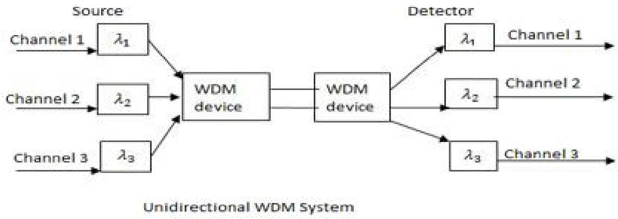


Figure 4.12: Unidirectional WDM System

• There are two types of WDM

i. Unidirectional

ii. Bidirectional

• In unidirectional WDM system Single Carrier wavelengths are fed into single fibers at one end and then separate them into their corresponding detectors at other end.

• The insertion loss, channel width and cross talk are the three basic parameters which are used to decide the performance of a WDM system.

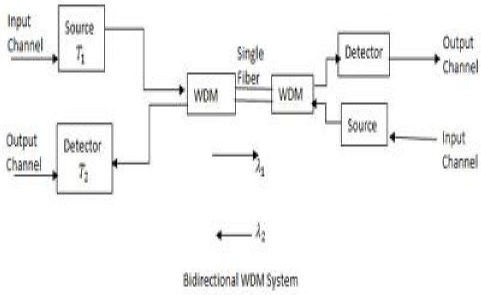


Figure 4.13: Bidirectional WDM

System

• The bidirectional WDM technique enables bidirectional communications over one strand of fibre, as well as multiplication of capacity.

• WDM systems are divided in different wavelength patterns conventional or coarse and dense WDM.

• Conventional WDM systems provide up to 8 channels in the 3rd transmission window (C-band) of silica fibres around 1550nm. Dense WDM uses the same transmission window but with denser channel spacing.

Advantages of WDM:

Wavelength division multiplexing has several advantages over the other presented approaches to increase the capacity of a link:

• Works with existing single mode communication fibre

• Works with low speed equipment

• Is transparent: Doesn't depend on the protocol that has to be transmitted.

• Is scalable: Instead of switching to a new technology, a new channel can easily be added to existing channels. Companies only have to pay for the bandwidth they actually need.

• It is easy for network providers to add additional capacity in a few days if customers need it. This gives companies using WDM an economical advantage. Parts of a fibre can be leased to a customer who then gets fast network access without having to share the connection with others. The telecommunication company on the other hand still has an independent part of the fibre available for other customers

PART C – (1x15 = 15 marks)

16 a)Present the design procedure of Sonet Network and suggest a Framework in detail.

- SONET (Synchronous Optical Network) is an optical transmission interface originally proposed by Bellcore and Standardized by ANSI
- Important characteristics, similarities and differences between SONET and SDH:

1. SONET is a synchronous network.
2. SDH is also a synchronous network with optical interfaces.
3. SONET is a set of standard interfaces on an optical synchronous network of elements that conform to these interfaces.
4. SONET interfaces defines all layers, from physical to the application layer.
5. SDH is a set of standard interfaces in a network of elements that conform to these interfaces.
6. Like SONET, SDH interfaces define all layers, from physical to the application layer.

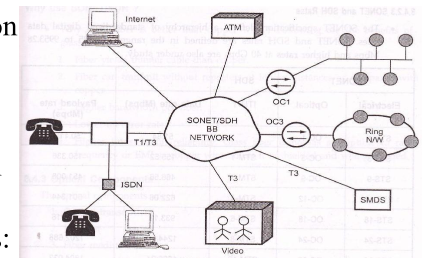


Fig. 8.4.1 SONET/SDH services

- The SONET standard addresses the following specific issues:

1. Establishes a standard multiplexing format using any

number of 51.84Mbps signals as building blocks.

2. Establishes an optical signal standard for interconnecting equipment from different suppliers.
3. Establishes extensive operations, administration and maintenance capabilities as part of the standard.
4. Defines a synchronous multiplexing format for carrying lower level digital signals.

Broadband Networks

- Fig. 8.4.1 shows SONET/SDH network services. (Refer Fig. 8.4.1 on next page).
- Voice, video data, internet and data from LAN'S, MAN'S, and MAN'S will be transported over a SONET or a SDH network.
- The SONET network is also able to transport asynchronous transfer mode (ATM) payloads. These systems, called broadband can manage a very large aggregate bandwidth or traffic.

OR

b)State and discuss on the no linear effects on an optical network

Non-Linear Effects

- Non-linear phenomena in optical fiber affects the overall performance of the optical fiber networks. Some important non-linear effects are –

1.Group velocity dispersion (GVD).

2.Non-uniform gain for different wavelength.

3.Polarization mode dispersion (PMD).

4.Reflections from splices and connectors.

5.Non-linear inelastic scattering processes.

6.Variation in refractive index in fiber.

- The non-linear effects contribute to signal impairements and introduces BER.

B.E B.Tech. DEGREE EXAMINATION, NOV / DEC 2018.
Seventh Semester
Electronics and Communication Engineering

EC6702- OPTICAL COMMUNICATION AND NETWORKS

PART A – (10x2 = 20 marks)

1. **Distinguish between meridional rays from skew Rays.**
   A **skew ray** is a **ray** that travels in a non planar zig zag path and never crosses the axis of an optical fibre!
   A **meridional ray** is a **ray** that passes through the axis of an optical fiber.
2. **Manufacturing engineer wants to to make an optical fibre that has core intex of 1.40 and cladding intex of 1.47 8 what should be the core size for single mode operation 1550 nm**

$$V = \frac{2\pi a}{\lambda} NA$$

3. **What is polarization mode dispersion?**
   The difference in propagation times between the two orthogonal polarization modes will result pulse spreading. This is called as polarization mode dispersion. (PMD)
4. **Distinguish between intra model and inter modal dispersion**
   Intramodal dispersion:
   Pulse broadening within a single mode is called as intramodal dispersion or chromatic dispersion
   Intermodal dispersion:
   • Dispersion caused by multipath propagation of light energy is referred to as intermodal dispersion.
5. **Why is silicon not used to fabricate led or laser diode?**
   Silicon is not used to fabricate LED or Laser diode because
   - It is an indirect bandgap semiconductor
   - It has Eg level of 1.1eV, the radiated emission corresponds to infrared but not the visible light.
6. **What is internal quantum efficiency?**
   Internal Quantum Efficiency is defined as the ratio of radiative recombination rate to the total recombination rate.

$$\eta_{in} = \frac{R_r}{R_r + R_{nr}}$$

   where R_r is radiative recombination rate, R_{nr} is the non-radiative recombination rate.
7. **Define responsivity**
   Responsitivity is defined as the ratio of output photo current to the incident optical power.
   $R = \frac{I_p}{P_o}$ $P_o = \frac{\eta q}{h\nu}$
   where, R=Responsivity.
   I_p=Output photo current P_o=Incident optical power
8. **State detector response time**
   This is the measure of the photodiode response speed to a stepped light input signal. It is the time required for the photodiode to increase its output from 10% to 90% of final output level. is the rise timeof the device.
9. **Define power penalty**
   The power penalty may become significant if the semiconductor laser is biased above the threshold. For lasers biased below threshold, the extinction ratio is typically 0.05 and the power penalty is less than 0.4 dB. Timing Jitter In a digital system the signal is generally sampled at the center of the pulse.
10. **What is EDFA.**
   An erbium-doped fiber amplifier (EDFA) is a device that amplifies an optical fiber signal. A trace impurity in the form of a trivalent erbium ion is inserted into the optical fiber's silica core to alter its optical properties and permit signal amplification.

PART B – (5x13 = 65 marks)

11. **a)1)Draw a neat diagram and explain the rate theory begin the optical fiber communication with a**

special mention about the total internal reflection summer acceptance angle and numerical aperture.
Total Internal Refleciton (TIR)

- When the incident angle is increased beyond the critical angle, the light ray does not pass through the interface into the other medium. This gives the effect of mirror exist at the interface with no possibility of light escaping outside the medium. In this condition angle of reflection (2) is equal to angle of incidence (1). This action is called as **Total Internal Reflection (TIR)** of the beam. It is TIR that leads to the propagation of waves within fiber-cable medium. TIR can be observed only in materials in which the velocity of light is less than in air.

- The two conditions necessary for TIR to occur are :

1. The refractive index of first medium must be greater than the refractive index of second one.
2. The angle of incidence must be greater than (or equal to) the critical angle.

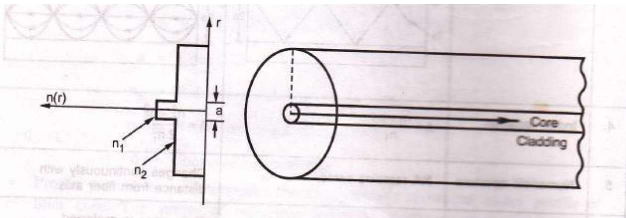


Fig. 1.6.16 The refractive index profile and ray transmission in single mode step index fiber

$$NA = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

Numerical aperture (NA) = sin $\phi_{0(max)}$

For air $n_0 = 1$

$$NA = \sqrt{n_1^2 - n_2^2}$$

Hence acceptance angle = $\sin^{-1}$ NA

(ii)Consider a multimode fiber that has a core refractive index of 1.48 and a core cladding index difference 2% find the numerical aperture the acceptance angle and the critical angle of the fiber

$$NA = \sqrt{n_{core}^2 - n_{cladding}^2}$$

Acceptance angle - $sin^{-1} \sqrt{n_{core}^2 - n_{cladding}^2} = sin^{-1}$ NA

b) Explain about step index and graded index fiber with index profile diagrams.
Optic Fiber Configurations

- Depending on the refractive index profile of fiber and modes of fiber there exist three types of optical fiber configurations. These optic-fiber configurations are -

i) Single mode step index fiber.
ii) Multimode step index fiber.
iii) Multimode graded index fiber.

Single mode Step index Fiber

- In single mode step index fiber has a central core that is sufficiently small so that there is essentially only one path for light ray through the cable. The light ray is propagated in the fiber through reflection. Typical core sizes are 2 to 15 μm. Single mode fiber is also known as fundamental or monomode fiber.Fig. 1.6.16 shows single mode fiber.

  Single mode fiber will permit only one mode to propagate and does not suffer from mode delay differences. These are primarily developed for the 1300 nm window but they can be also be used effectively with time division multiplex (TDM) and wavelength division multiplex (WDM) systems operating in 1550 nm wavelength region.

- The core fiber of a single mode fiber is very narrow compared to the wavelength of light being used. Therefore, only a single path exists through the cable core through which light can travel. Usually, 20 percent of the light in a single mode cable actually travels down the cladding and the effective diameter of the cable is a blend of single mode core and degree to which the cladding carries light. This is referred to as the 'mode field diameter', which is larger than physical diameter of the core depending on the refractive indices of the core and cladding.

The disadvantage of this type of cable is that because of extremely small size interconnection of cables and interfacing with source is difficult. Another disadvantage of single mode fibers is that as the refractive index of glass decreases with optical wavelength, the light velocity will also be wavelength dependent. Thus the light from an optical transmitter will have definite spectral width.

Multimode step Index Fiber

Multimode step index fiber is more widely used type. It is easy to manufacture. Its core diameter is 50 to 1000 μm i.e. large aperture and allows more light to enter the cable. The light rays are propagated down the core in zig-zag manner. There are many many paths that a light ray may follow during the propagation.

The light ray is propagated using the principle of total internal reflection (TIR). Since the core index of refraction is higher than the cladding index of refraction, the light enters at less than critical angle is guided along the fiber.

Light rays passing through the fiber are continuously reflected off the glass cladding towards the centre of the core at different angles and lengths, limiting overall bandwidth.

The disadvantage of multimode step index fibers is that the different optical lengths caused by various angles at which light is propagated relative to the core, causes the transmission bandwidth to be fairly small. Because of these limitations, multimode step index fiber is typically only used in applications requiring distances of less than 1 km.

Multimode Graded Index Fiber

The core size of multimode graded index fiber cable is varying from 50 to 100 μm range. The light ray is propagated through the refraction. The light ray enters the fiber at many different angles. As the light propagates across the core toward the center it is intersecting a less dense to more dense medium. Therefore the light rays are being constantly being refracted and ray is bending continuously. This cable is mostly used for long distance communication.

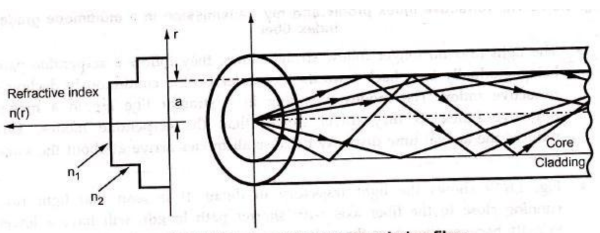


Fig. 1.6.17 TIR in multimode step index fiber

Fig 1.6.18 shows multimode graded index fiber.

The light rays no longer follow straight lines, they follow a serpentine path being gradually bent back towards the center by the continuously declining refractive index. The modes travelling in a straight line are in a higher refractive index so they travel slower than the serpentine modes. This reduces the arrival time disparity because all modes arrive at about the same time.

12. A graded index fiber has a core the parabolic refractive index profile which has a diameter of 50 micrometre numerical aperture of 0.2 estimate the total number of guided modes propagating in the fiber when it is operating at a wavelength of 1 micrometre.

$$V = \frac{2\pi a}{\lambda} NA$$

$$M = \frac{V^2}{2}$$

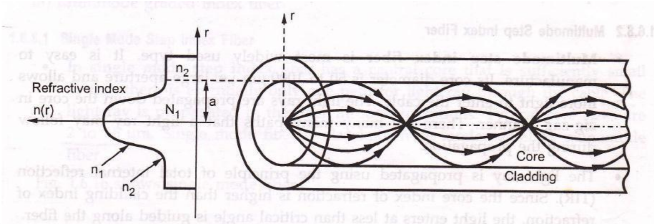
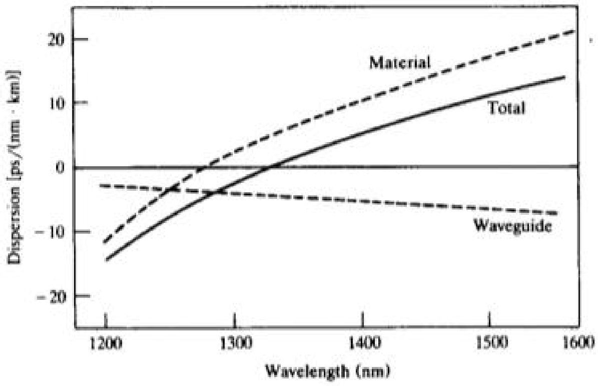


Fig. 1.6.18 The refractive index profile and ray transmission in a multimode graded index fiber

13. Prove that delay difference between the axial Ray and extreme Meridional ray is



$$\sigma_{mod} = T_{max} - T_{min} = \frac{n_1 \Delta L}{c}$$

a)ii)A 6 kilometre optical link consists of multimode step index fiber with a Core or a of 1.5 relative refractive index difference of 1 percentage estimate

- **Delay difference between the slowest and the fastest modes at the fiber**
- **RMS pulse broadening due to intermodal dispersion on the link**
- **Maximum bit rate that may be obtained without substantial errors on the link assuming only inter model dispersion**

b)i)Describe the attenuation mechanism in optical fiber

Attenuation

- Attenuation is a measure of decay of signal strength or loss of light power that occurs as light pulses propagate through the length of thefiber.
- In optical fibers the attenuation is mainly caused by two physical factors absorption and scattering losses. Absorption is because of fiber material and scattering due to structural imperfection within the fiber. Nearly 90 % of total attenuation is caused by Rayleigh scattering only. Micro bending of optical fiber also contributes to the attenuation ofsignal.
- The rate at which light is absorbed is dependent on the wavelength of the light and the characteristics of particular glass. Glass is a silicon compound, by adding different additional chemicals to the basic silicon dioxide the optical properties of the glass can be changed.
- The Rayleigh scattering is wavelength dependent and reduces rapidly as the wavelength of the incident radiationincreases.
- The attenuation of fiber is governed by the materials from which it is fabricated, the manufacturing process and the refractive index profile chosen. Attenuation loss is measured indB/km.

Attenuation Units

As attenuation leads to a loss of power along the fiber, the output power is significantly less than the couples power. Let the couples optical power is p(0) i.e. at origin (z =0).

Then the power at distance z is given by,

$$P(z) = P(0)e^{-\alpha_p z}$$

where, αp is fiber attenuation constant (per km).

$$\alpha_p = \frac{1}{z} l\ n\left[\frac{P(0)}{P(z)}\right]$$

Absorption

$$\alpha_{dB/km} = 10.\frac{1}{z}\log\left[\frac{P(0)}{P(z)}\right]$$

$$\alpha_{dB/km} = 4.343\ \ \alpha_p \ \text{ per km}$$

Absorption loss is related to the material composition and fabrication process of fiber. Absorption loss results in dissipation of some optical power as heat in the fiber cable. Although glass fibers are extremely pure, some impurities still remain as residue after purification. The amount of absorption by these impurities depends on their concentration and light wavelength.

- Absorption is caused by three different mechanisms.

1) Absorption by atomic defects in glass composition.

2) Extrinsic absorption by impurity atoms in glass matts.
3) Intrinsic absorption by basic constituent atom of fiber.

Absorption by Atomic Defects

Atomic defects are imperfections in the atomic structure of the fiber materials such as missing molecules, high density clusters of atom groups. These absorption losses are negligible compared with intrinsic and extrinsiclosses.

Extrinsic Absorption

Extrinsic absorption occurs due to electronic transitions between the energy level and because of charge transitions from one ion to another. A major source of attenuation is from transition of metal impurity ions such as iron, chromium, cobalt and copper. These losses can be upto 1 to 10 dB/km. The effect of metallic impurities can be reduced by glass refiningtechniques.

Another major extrinsic loss is caused by absorption due to **OH (Hydroxil)** ions impurities dissolved in glass. Vibrations occur at wavelengths between 2.7 and 4.2 µm. The absorption peaks occurs at 1400, 950 and 750 nm. These are first, second and third overtonesrespectively.

Intrinsic Absorption

Intrinsic absorption occurs when material is in absolutely pure state, no density variation and inhomogenities. Thus intrinsic absorption sets the fundamental lower limit on absorption for any particularmaterial.

Intrinsic absorption results from electronic absorption bands in UV region and from atomic vibration bands in the near infraredregion.

The electronic absorption bands are associated with the band gaps of amorphous glass materials. Absorption occurs when a photon interacts with an electron in the valene band and excites it to a higher energy level. UV absorption decays exponentially with increasing wavelength(λ).

ii)A continuous 40 km long Optical Fiber link has share loss of 0.4 GB per kilometre

1. **What is the minimum optical power level that must be launched into the fibre to maintain optical power level of 2.0mW the receiving end**
2. **What is the required input power if the fibre as a loss of 0.6db/ kilometer**

Solution : Given data : z = 12 km

α = 1.5 dB/km

P(0) = 0.3 µW

iii) Attenuation in optical fiber is given by,

$$\alpha = 10 \text{ x } \frac{1}{z} \log\left(\frac{P(0)}{P(z)}\right)$$

$$1.5 = 10 \text{ x } \frac{1}{12} \log\left(\frac{0.3\ \mu W}{P(z)}\right)$$

= 1.80

$$\log\left(\frac{0.3\ \mu W}{P(z)}\right) = \frac{1.5}{0.833}$$

$$\boxed{\alpha = 10 \text{ x } \frac{1}{z} \log\left(\frac{P(0)}{P(z)}\right)}$$

i) Input power = ? P(0)

When α = 2.5 dB/km

$$\boxed{\alpha = 10 \text{ x } \frac{1}{z} \log\left(\frac{P(0)}{P(z)}\right)}$$

$$2.5 = 10 \text{ x } \frac{1}{z}\log\left(\frac{P(0)}{4.76 \text{ x } 10^{-9}}\right)$$

$$\log\left(\frac{P(0)}{4.76 \text{ x } 10^{-9}}\right) = \frac{2.5}{0.833} = 3$$

$$\frac{P(0)}{4.76 \text{ x } 10^{-9}} = 10^3 = 1000$$

P(0) = 4.76 μW

Input power= **4.76 μW**

13a)(i)What are the characteristics required for an optical source with the help of a neat diagram describe the operation of surface emitting LED.

- It must emit the required wavelengths 1.3 μm and 1.55 μ m.
- To avoid dispersion, the spectral width of the source should be very small ~ 1 nm).
- It should be possible to modulate the source at high speeds (> Gb/s)
- It should have compact size and be possible to design in the integrated fo rm.

Surface Emitting LEDs

- ✓ In surface emitting LEDs the plane of active light emitting region is oriented perpendicularly to the axis of the fiber.
- ✓ A DH diode is grown on an N-type substrate at the top of the diode.
- ✓ A circular well is etched through the substrate of the device. A fiber is then connected to accept the emitted light.
- ✓ At the back of device is a gold heat sink. The current flows through the p-type material and forms the small circular active region resulting in the intense beam of light.
- ✓ Diameter of circular active area = 50 μm Thickness of circular active area = 2.5 μm Current density = 2000 A/cm^2 half-power Emission pattern = Isotropic, 120^O beamwidth.
- ✓ The isotropic emission pattern from surface emitting LED is of Lambartian pattern. In Lambartian pattern, the emitting surface is uniformly bright, but its projected area diminishes as cos θ, where θ is the angle between the viewing direction and the normal to the surface. The beam intensity is maximum along the normal.
- ✓ The power is reduced to 50% of its peak when θ = 60^O, therefore the total half-power beamwidth is 120^O. The radiation pattern decides the coupling efficiency of LED.

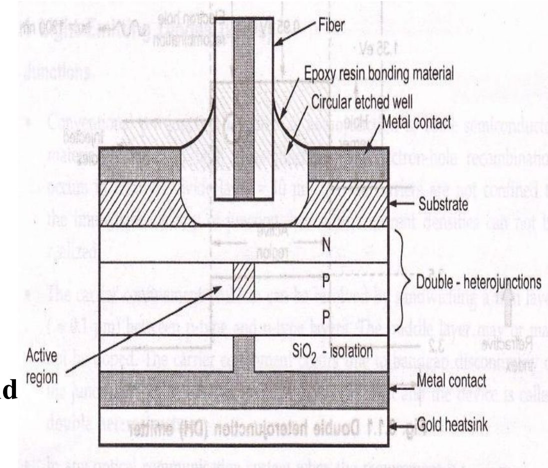


Fig. 3.1.2 Cross-section through a typical surface emitting LED

13a)ii)**A double heterojunction InGaAsP LED emitting at a peak wavelength of 1310 NM radiative and nonradiative radiative recombination times of 25 and 90 NS respectively the drive current is 35 microampere**

b)1)Find the internal Quantum efficiency and the internal power level

2) If the refractive index of light source material is n = 3.5 find the power emitted from the device

$$\eta_{int} = \frac{\tau}{\tau_r}$$

$$P_{int} = \eta_{int} \cdot \frac{hc\, I}{q\lambda}$$

$$\frac{1}{\tau} = \frac{1}{\tau_r} + \frac{1}{\tau_{nr}}$$

OR

b)i)Describe the term external Quantum efficiency relating to laser

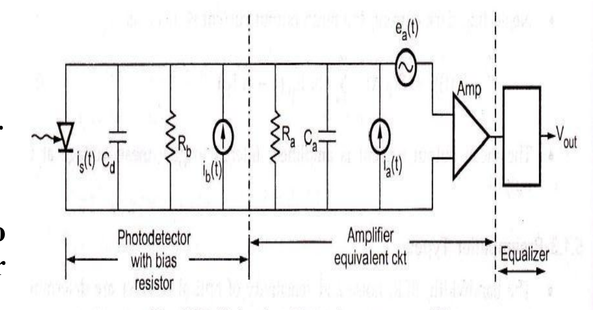


Fig. 5.1.3 High - input impedance preamplifier

ii)A GaAs Optical source with refractive index of 3.6 is coupled to end silica fibre that has a refractive index of 1.48 what is the power lost between the source and the fibre

14 a)i)Explain in detail about the front end optical amplifiers
Preamplifier Types

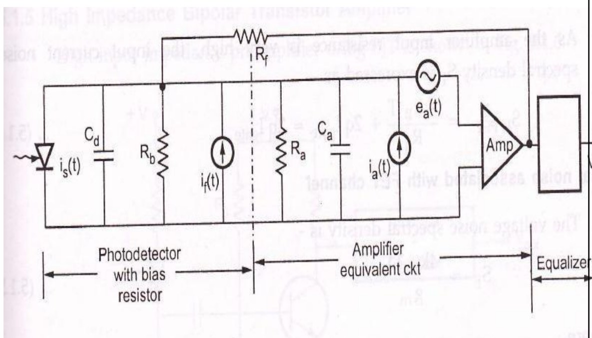


Fig. 5.1.4 Transimpedance preamplifier equivalent circuit

- The bandwidth, BER, noise and sensitivity of optical receiver are determined by preamplifier stage. Preamplifier circuit must be designed with the aim of optimizing these characteristics.

Commonly used preamplifier in optical communication receiver are –

1. Low – impedance preamplifier (LZ), High – impedance preamplifier (HZ), Transimpedance preamplifier (TZ)

1. Low – impedance preamplifier (LZ)

- In low-impedance preamplifier, the photodiode is configured in low – impedance amplifier. The bias resister R_b is used to match the amplifier impedance. R_b along with the input capacitance of amplifier decides the bandwidth of amplifier.

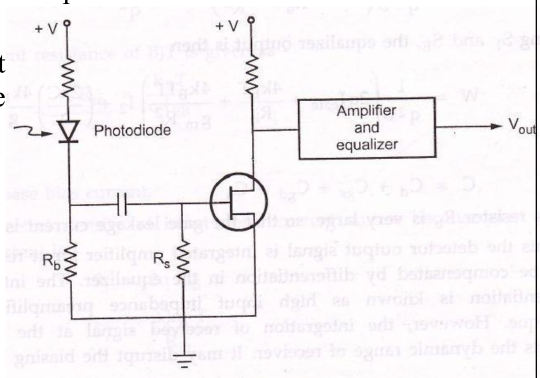


Fig. 5.1.5 High input impedance preamplifier using FET

- Low – impedance preamplifier can operate over a wide bandwidth but they have poor receiver sensitivity. Therefore the low – impedance amplifier are used where sensitivity is of not prime concern.

2. High – impedance preamplifier (HZ)

- In high – impedance preamplifier the objective is to minimize the noise from all sources. This can be achieved by –

Reducing input capacitance by selecting proper devices.
Selecting detectors with low dark currents.
Minimizing thermal noise of baising resistors.
Using high impedance amplifier with large R_b.

- The high impedance amplifier uses FET or a BJT. As the high impedance circuit has large RC time constant, the bandwidth is reduced.

High-input impedance preamplifier are most sensitive and finds application in long – wavelength, long haul routes. The high sensitivity is due to the use of a high input resistance (typically > 1 MΩ), which results in exceptionally low thermal noise. The combination of high resistance and receiver input capacitance, results in very low BW, typically < 30 kHz, and this causes integration of the received signal. A differentiating, equalizing or compensation network at the receiver output corrects for this integration.

Transimpedance preamplifier (TZ)

The drawbacks of ghigh input impedance are eliminated in transimpedance preamplifier. A negative feedback is introduced by a feedback resistor R_f to increase the bandwidth of open loop preamplifier with an equivalent thermal nose current i_f (t) shunting the input.

e_a (t) = Equivalent series voltage noise source i_a(t) = Equivalent shunt current noise.

$R_{in} = R_a \parallel C_a$.

R_f = Feedback resistor.

i_f (t) = Equivalent thermal noise current.

Although the resulting receiver is often not as sensitive as the integrating front end design, this type of preamplifier does not exhibit a high dynamic range and is usually cheaper to produce.

High Impedance FET Amplifier

- Basic noise sources in the circuit are –

- Thermal noise associated with FET channel.
- Thermal noise from load.
- Thermal noise from feedback resistor.
- Shot noise due to gate – leakage current (I_{gate})
- FET 1/f noise.

- As the amplifier input resistance is very high, the input current noise spectral density S1 is expressed as –

$$S_{I,FET} = \frac{4 k_B T}{R_a} + 2_q I_{gate} \approx 2_q I_{gate} \pi \qquad \dots (5.1.4)$$

Thermal noise associated with F

High Impedance Bipolar Transistor Amplifier

- Input resistance of BJT is given as –

$$R_{in} = \frac{k_B T}{q I_{BB}} \qquad \dots (5.1.7)$$

Where, I_{BB} is base bias current.

- Spectral density of input noise current source because shot noise of base current is –

$$S_I = 2qI_{BB}$$

$$S_I = \frac{2k_B T}{R_{in}} \qquad \dots (5.1.8)$$

- Spectral height of noise voltage source is given as –

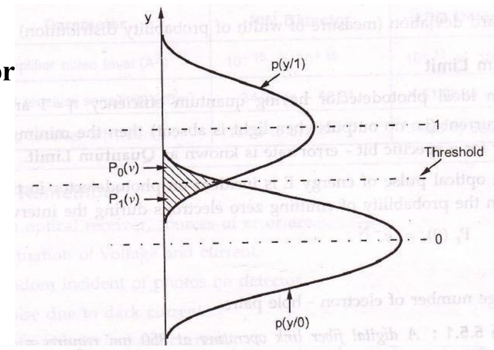
$$S_E = \frac{2k_B T}{g_m} \qquad \dots (5.1.9)$$

Where, gm is transconductance.

$$g_m = \frac{qI_c}{k_B T} = \frac{\beta}{R_{in}}$$

ii)Estimate the terms Quantum limit and the probability of error with respect to receiver with typical values

Probability of Error



Bit error rate (BER) is defined as the ratio of number of errors occurring over a time interval to the number of pulses transmitted during the interval.

$$BER = \frac{N_e}{N_t} \qquad \dots (5.5.1)$$

$$BER = \frac{N_e}{Bt} \qquad \dots (5.5.2)$$

Where,

Ne is number of errors occurring during the interval. Nt is number of pulses transmitted during the interval.

B is bit rate or pulse transmission rate. $\left(\frac{1}{T_b}\right)$

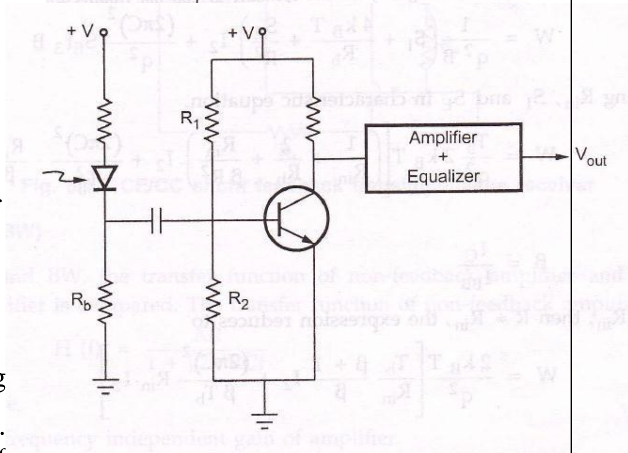


Fig. 5.1.6 High input impedance preamplifier using BJT

- BER for optical fiber communication system is ranging between 10^{-9} to 10^{-12}. BER of receiver depends on S/N ratio. To compute the BER at receiver probability distribution of output signal is considered.
- Condiitonal PDF : P(y/x) is the probability that the output voltage is y when x was transmitted. The functions p (y/1) and p (y/0) are conditional PDF as shown in Fig. 5.5.1.

$$P_1(v) = \int_{-\infty}^{v} p(y/1)\, dy$$

- The probability distributions are given as –

It is the probability that output voltage is less than threshold when logic '1' is sent.

$$P_0(v) = \int_{v}^{\infty} p(y/1)\, dy$$

It is the probability that output voltage exceeds threshold voltage when a logic '0' is sent.

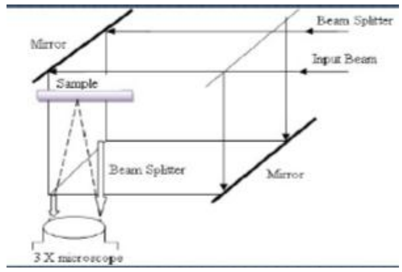
The error probability is expressed as

$$P_e = aP_1(v) + b\, P_0\, (v) \quad \dots (5.5.3)$$

Where,

a and b are probabilities that either 1 or 0 occurs.

$$P_e = \frac{1}{2}\left[1 - \text{efr}\left(\frac{V}{2\sqrt{2}\sigma}\right)\right] \quad \dots (5.5.4)$$



Where,

V is the pulse amplitude.

σ is standard deviation (measure of width of probability distribution)

Quantum Limit

- For an ideal photodetector having quantum efficiency η = 1 and has zero dark current (i.e. no output when light is absent) then the minimum received power for a specific bit – error rate is known as Quantum Limit.
- Let an optical pulse of energy E is incident on photoetector in time interval τ. Then the probability of emitting zero electrons during the interval is

$$P_e\ (0) = e^{-N} \quad \dots (5.5.5)$$

Where,

XXXX is average number of electron – hole pairs.

14b)Demonstrate the following in detail

i. Fibre refractive index profile measurement

<u>REFRACTIVE INDEX MEASUREMENT:</u>

- ✓ The refractive index profile of the fiber core plays an important role in characterizing different other properties of optical fibers.
- ✓ Therefore it is essential that fiber manufacturers produce accurate profile fibers and thus it is essential to measure refractive index accurately:
- ✓ Different techniques for measurement:
  - Interferometric method
  - Near field scanning method
  - Refractive near field

INTERFEROMETRIC METHOD:

- ✓ This method involves use of interference microscopes.
- ✓ Technique usually involves the preparation of this slice of fiber (slab) which has both ends accurately polished.
- ✓ The slab is often immersed in an index matching fluid and the assemble is examined with an interference microscope.

Two methods are used:

- Transmitted light interferometer
- Reflected light interferometer

- ✓ In both the methods, light from a microscope travels normal to the prepared fiber slice faces and difference in refractive index results in different optical bandwidth.
- ✓ When faces of incident light is compared with phase of emerging light, a field of parallel inference fringes is observed.

- ✓ The fringe displacement for the points with in the fiber core are then measured using parallel fringes in fiber cladding as a reference.
- ✓ Refractive index between two points can be measured from frings shift q, (no of fringe displacement)

Near Field scanning Method

✓ This method utilize the close resemblance that exist between near field intensity distribution and refractive index profile for a fiber with all guided modes equally illuminated.

✓ When a diffused lambertian source is used to excite all the guided modes, then PD(r) / PD(0) can be expressed as a function of refractive indices.

$$\frac{PD(r)}{PD(0)} = C(r,z)\left[\frac{n1^2\,(r) - n2^2}{n1^2(0) - n2^2}\right]$$

✓ Where n1(r) and n1(0) are refractive index at distance r from core and at core resp.

✓ n2 is cladding refractive index.

✓ C(r,z) is correction factor, is a compensation for any leaky mode present in short test fiber.

Refracted Near Field on Method

✓ This method is complimentry to transmitted near field techniques, but has the advantage that it does not require leaky mode correction factor or equal mode execution.

✓ It provides refractive index difference directly without any external calibration.

ii) **Fibre Cutoff Wavelength Measurement**

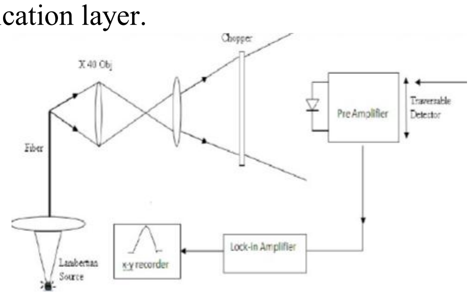
15 a) Explain Sonet layer and its frame structure with diagram

- SONET (Synchronous Optical Network) is an optical transmission interface originally proposed by Bellcore and Standardized by ANSI
- Important characteristics, similarities and differences between SONET and SDH:

1. SONET is a synchronous network.
2. SDH is also a synchronous network with optical interfaces.
3. SONET is a set of standard interfaces on an optical synchronous network of elements that conform to these interfaces.
4. SONET interfaces defines all layers, from physical to the application layer.
5. SDH is a set of standard interfaces in a network of elements that conform to these interfaces.
6. Like SONET, SDH interfaces define all layers, from physical to the application layer.

- The SONET standard addresses the following specific issues:

5. Establishes a standard multiplexing format using any number of 51.84Mbps signals as building blocks.
6. Establishes an optical signal standard for interconnecting equipment from different suppliers.
7. Establishes extensive operations, administration and maintenance capabilities as part of the standard.
8. Defines a synchronous multiplexing format for carrying lower level digital signals.



Broadband Networks

- Fig. 8.4.1 shows SONET/SDH network services. (Refer Fig. 8.4.1 on next page).
- Voice, video data, internet and data from LAN'S, MAN'S, and MAN'S will be transported over a SONET or a SDH network.
- The SONET network is also able to transport asynchronous transfer mode (ATM) payloads. These systems, called broadband can manage a very large aggregate bandwidth or traffic.

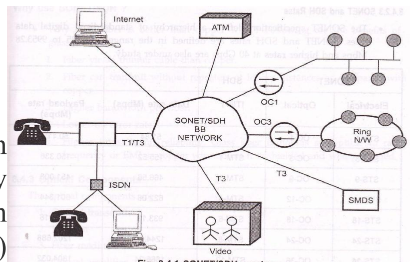


Fig. 8.4.1 SONET/SDH services

OR

b) i)Define and explain the principle of WDM networks

WDM (Wavelength Division Multiplexing) corresponds to the scheme in which multiple optical carriers at different wavelengths (produced by LASER) are modulated by using independent electrical bit streams (which may themselves use TDM and FDM techniques in the electrical domain) and are then transmitted over the same fiber.

• The optical signal at the receiver is demultiplexed into separate channels by using an optical technique.
• The main system feature of WDM are as follows:

5. Capacity
6. Transparency
7. Wavelength routing
8. Wavelength switching

• There are two types of WDM
i. Unidirectional
ii. Bidirectional
• In unidirectional WDM system Single Carrier wavelengths are fed into single fibers at one end and then separate them into their corresponding detectors at other end.

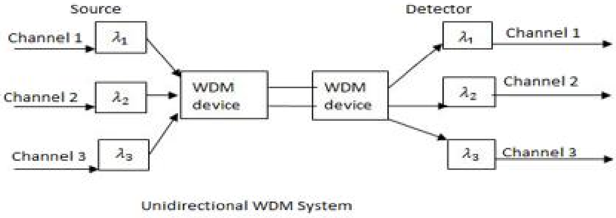


Figure 4.12: Unidirectional WDM System

• The insertion loss, channel width and cross talk are the three basic parameters which are used to decide the performance of a WDM system.
System
• The bidirectional WDM technique enables bidirectional communications over one strand of fibre, as well as multiplication of capacity.
• WDM systems are divided in different wavelength patterns conventional or coarse and dense WDM.
• Conventional WDM systems provide up to 8 channels in the 3rd transmission window (C-band) of silica fibres around 1550nm. Dense WDM uses the same transmission window but with denser channel spacing.

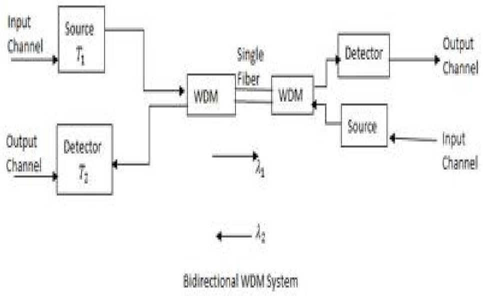


Figure 4.13: Bidirectional WDM

Advantages of WDM:
Wavelength division multiplexing has several advantages over the other presented approaches to increase the capacity of a link:
• Works with existing single mode communication fibre
• Works with low speed equipment
• Is transparent: Doesn't depend on the protocol that has to be transmitted.
• Is scalable: Instead of switching to a new technology, a new channel can easily be added to existing channels. Companies only have to pay for the bandwidth they actually need.
• It is easy for network providers to add additional capacity in a few days if customers need it. This gives companies using WDM an economical advantage. Parts of a fibre can be leased to a customer who then gets fast network access without having to share the connection with others. The telecommunication company on the other hand still has an independent part of the fibre available for other customers

ii) State the nonlinear effects on optical networks performance

- Non-linear phenomena in optical fiber affects the overall performance of the optical fiber networks. Some important non-linear effects are –

1. Group velocity dispersion (GVD).
2. Non-uniform gain for different wavelength.
3. Polarization mode dispersion (PMD).
4. Reflections from splices and connectors.
5. Non-linear inelastic scattering processes.
6. Variation in refractive index in fiber.

- The non-linear effects contribute to signal impairements and introduces BER.

PART C – (1x15 = 15 marks)

a) (i)When a current pulse supplied to a laser diode the injected carrier density n and within the recombination region of width 'd' changes with time according to the relationship

ii)Assume the average carrier lifetime in the recombination region when the injected carrier density and near the threshold current density J that is in the steady state we have

OR

b) With the schematic diagram, explain the blocks and their functions of the major elements of an optical fiber transmission link.

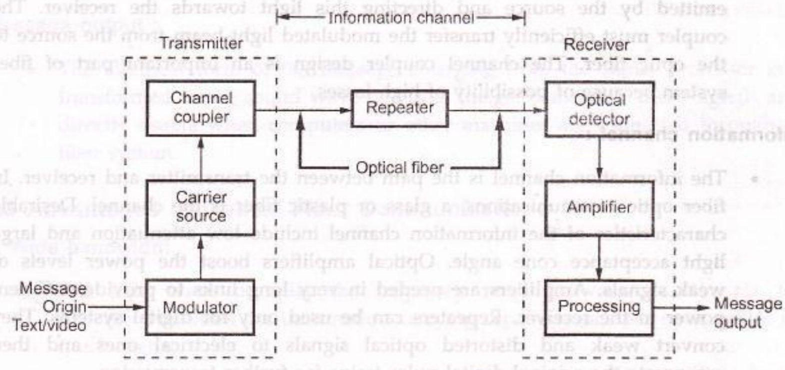


Fig. 1.2.1 Block diagram of OFC systems

General Optical Fiber Communication System

- Basic block diagram of optical fiber communication system consists of following important blocks.

1. Transmitter
2. Information channel
3. Receiver.

Fig. 1.2.1 shows block diagram of OFC system.

Message origin :

- Generally message origin is from a transducer that converts a non-electrical message into an electrical signal. Common examples include microphones for converting sound waves into currents and video (TV) cameras for converting images into current. For data transfer between computers, the message is already in electrical form.

Modulator :

- The modulator has two main functions.

1) It converts the electrical message into the proper format.
2) It impresses this signal onto the wave generated by the carrier source.

Two distinct categories of modulation are used i.e. analog modulation and digital modulation.

Carrier source :

- Carrier source generates the wave on which the information is transmitted. This wave is called the carrier. For fiber optic system, a laser diode (LD) or a light emitting diode (LED) is used. They can be called as optic oscillators, they provide stable, single frequency waves with sufficient power for long distance propagation.

Channel coupler :

- Coupler feeds the power into the information channel. For an atmospheric optic system, the channel coupler is a lens used for collimating the light emitted by the source and directing this light towards the receiver. The coupler must efficiently transfer the modulated light beam from the source to the optic fiber. The channel coupler design is an important part of fiber system because of possibility of high losses.

Information channel :

- The information channel is the path between the transmitter and receiver. In fiber optic communications, a glass or plastic fiber is the channel. Desirable characteristics of the information channel include low attenuation and large light acceptance cone angle. Optical amplifiers boost the power levels of weak signals. Amplifiers are needed in very long links to provide sufficient power to the receiver. Repeaters can be used only for digital systems. They convert weak and distorted optical signals to electrical ones and then regenerate the original disgital pulse trains for further transmission.
- Another important property of the information channel is the propagation time of the waes travelling along it. A signal propagating along a fiber normally contains a range of optic frequencies and divides its power along several ray paths. This results in a distortion of the propagating signal. In a digital system, this distortion appears as a spreading and deforming of the pulses. The spreading is so great that adjacent pulses begin to overlap and become unrecognizable as separate bits of information.

Optical detector :

- The information being transmitted is detector. In the fiber system the optic wave is converted into an electric current by a photodetector. The current developed by the detector is proportional to the power in the incident optic wave. Detector output current contains the transmitted information. This detector output is then filtered to remove the constant bias and thn amplified.

- The important properties of photodetectors are small size, economy, long life, low power consumption, high sensitivity to optic signals and fast response to quick variations in the optic power.

Signal processing :

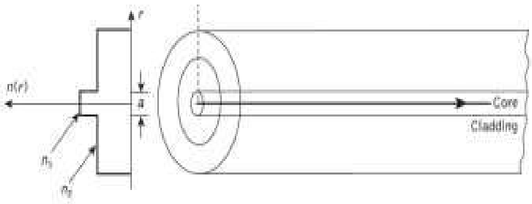
- Signal processing includes filtering, amplification. Proper filtering maximizes the ratio of signal to unwanted power. For a digital system decision circuit is an additional block. The bit error rate (BER) should be very small for quality communications.

Message output :

- The electrical form of the message emerging from the signal processor are transformed into a soud wave or visual image. Sometimes these signals are directly usable when computers or other machines are connected through a fiber system.

B.E B.Tech. DEGREE EXAMINATION, April / May 2018.
Seventh Semester
Electronics and Communication Engineering
EC6702- OPTICAL COMMUNICATION AND NETWORKS
(Regulation 2013)
PART A – (10x2 = 20 marks)

1. **Sketch the cross sectional view of transverse electric field vectors for the four lowest order modes in a step index fiber.**



2. State the reasons to opt for optical fiber communication.

- **Broad bandwidth**: A single optical fiber can carry over 3,000,000 full-duplex voice calls or 90,000 TV channels.
- **Immunity to electromagnetic interference:** Light transmission through optical fibers is unaffected by otherelectromagnetic radiation nearby. The optical fiber is electrically non-conductive, so it does not act as an antenna to pick up electromagnetic signals. Information traveling inside the optical fiber is immune to electromagnetic interference, evenelectromagnetic pulses generated by nuclear devices.
- **Low attenuation loss over long distances:** Attenuation loss can be as low as 0.2 dB/km in optical fiber cables, allowing transmission over long distances without the need for repeaters.
- **Electrical insulator:** Optical fibers do not conduct electricity, preventing problems with ground loops and conduction oflightning. Optical fibers can be strung on poles alongside high voltage power cables.
- **Material cost and theft prevention:** Conventional cable systems use large amounts of copper. Global copper prices experienced a boom in the 2000s, and copper has been a target of metal theft.
- **Security of information passed down the cable:** Copper can be tapped with very little chance of detection.

3. What is elastic and inelastic scattering? Give examples.

Purely elastic scattering means all the pre-collision kinetic energy of the colliding objects goes into kinetic energy of the post-collision objects. A collision between two hard things, like billiard balls, is a good example of a collision that’s *mostly* elastic.

Inelastic scattering means that at least *some* of the pre-collision kinetic energy ends up somewhere else, besides post-collision kinetic energy. For example, the pre-collision kinetic energy can be used to cause an internal state change in one of the colliding objects.

4. **Define polarization mode dispersion and write the expression for it.**

Polarization refers to the electric - field orientation of a light signal, which can vary significantly along the length of the fiber.

5. Illustrate the factor that determine the response time of the photodiode.

The resistance and capacitance of the photodiode and the external circuitry give rise to another response time known as RC time constant{\displaystyle \tau =RC}. This combination of R and C integrates the photoresponse over time and thus lengthens the impulse response of the photodiode. When used in an optical communication system, the response time determines the bandwidth available for signal modulation and thus data transmission.

6. An LED has radiative and non-radiative recombination times of 30ns and 100ns respectively. Determine the internal quantum efficiency.

Given data: $\tau = 30\times 10^{-9} sec$, $\tau_{nr} = 100\times 10^{-9} sec$

Formula: $\tau = \frac{\tau_r \times \tau_{nr}}{\tau_r + \tau_{nr}} = \frac{30\times10^{-9}\times100\times10^{-9}}{130\times10^{-9}} = 23.1ns$

Solution: $\eta_{int} = \frac{\tau}{\tau_r} = \frac{23.1\ ns}{30ns} = 0.77 = 77\%$

7. **List the process associated with fiber optic receiver section.**
   Although the photo-detector is the major element in the fibre optic receiver, the other elements to the whole unit. Once the light has been received by the fibre optic receiver and converted into electronic pulses, the signals are processed by the electronics in the receiver. Typically these will include various forms of amplification including a limiting amplifier. These serve to generate a suitable square wave that can then be processed in any logic circuitry that may be required.
   Once in a suitable digital format the received signal may undergo further signal processing in the form of a clock recovery, etc. This will undertaken before the data from the fibre optic receiver is passed on.
8. **Define quantum limit.**
   The minimum received power level required to maintain a specific Bit – Error - Rate (BER) of an optical receiver is known as the quantum limit.
9. **Mention the drawbacks of Broadcast and select networks for wide area network applications.**
   The drawbacks of broadcast and select networks for wide area network applications are:
   More wavelengths are needed as the number of nodes in the network grows
   Without the use of optical booster amplifiers splitting losses occurs
10. **Write a short note on soliton.**
   Solitons are nonlinear optical pulses that have the potential to support very high optical transmission rates of many terabits per second over long distances.

PART B - (5 x 16 - 80 marks)

11.(a)1) A silica optical fiber with core diameter large enough to be considered by a range theory analysis has a core refractive index of 1.5 and cladding refractive index of 1.47 . determine

a. The critical angle at the core -cladding interface
b. The numerical aperture for the fiber
c. The acceptance angle in air for the fiber

Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. NO.45

2) Discuss briefly about the structure of graded index fiber

Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. NO.41

(Or)

(b)1)A graded index fibre with parabolic refractive index profile core fractive index of the core axis of 1.5 and relative index difference of 1%. estimate the maximum possible core diameter which allows single mode operation a wavelength of 1.3 micrometer

(2) With the neat block diagram , explain the fundamental blocks of Optical Fiber communication.

Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. NO.8

12) a) ¡)Explain in detail about the scattering and bending losses that occur in optical fiber with relevant diagrams and expressions

Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. NO.95

¡¡) When the mean optical power launched into a 8 kilometre length of fibre is 120 microwatts the mean optical power at the fiber output is 3 micro watts. Determine

a)The oral signal attenuation or loss in decibels through the fibre assuming there are no connectors or splices

b) The signal attenuation per kilometer for the fiber

c)The overall signal attenuation for a in kilometre optical link using the same fibre with splices at 1 km interval each giving an attenuation of 1 dB

d) The numerical input /output power ratio in (c).

Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. NO.91

(Or)

b) ¡) Discuss material and waveguide dispersion mechanisms with necessary mathematical expressions.

Refer Book: Optical fiber Communications – John Senior - Pg. NO.105

¡¡) Multimode graded index fibre exhibits total pulse broadening of 0.1 microseconds over a distance of 15 km. Estimate

a)the maximum possible bandwidth on the link assuming no inter- symbol interference

b) the pulse dispersion per unit length

c) the bandwidth length product for the fiber

13) a) ¡) A planar LED is fabricated from gallium arsenide which has a refractive index of 3.6

a) Calculate the optical power emitted into air as a percentage of the internal optical power for the device when the transmission factor at the Crystal air interference is 0. 68

b)When the optical power generated internally is 50 percentage of the power supply determine the external power efficiency.

Refer Book: Optical fiber Communications – John Senior - Pg. NO.398

¡¡) Illustrate the different lensing schemes available to improve the power coupling efficiency

(Or)

b)¡) Give a brief account on the resonant frequencies of laser diodes

Refer Book: Optical fiber Communications – John Senior - Pg. NO.294

¡¡) Explain about the various fiber splicing techniques with necessary diagrams

14)a)¡) Measurements are made using calorimeter and Thermocouple experimental arrangement initially high absorption fiber is utilised to obtain a plot of (on the logarithmic scale against it is found from the plot that reading of after 10 and 100 seconds or 0. 525 and 0. 021 microvolts respectively full stop that is fiber is then inserted in the calorimeter and gives a maximum temperature rise of 4.3 * 10 $^{-4}$C with a constant measured optical 5 power of 98 milliwatts at a wavelength of 0. 75 micrometre thermal capacity per kilometre of silica capillary and the fluid is calculated to be 1. 64 10 power 4 joules degree Celsius determine the absorption loss in DB kilometre at the wavelength of point 75 0.75 micrometre for the fibre Under test

¡¡)with a typical experimental arrangement brief the measurement process of diameter of the fiber.

(Or)

b) ¡) Discuss the different structures of receiver in the optical fiber communication with neat diagram.

Refer Book: Optical fiber Communications – John Senior - Pg. NO.524.

¡¡) A He-Ne laser operating at a wavelength of 0. 63micrometre with solar cell cube to measure the scattering loss in the multimode fiber sample with a constant optical output power the reading from the solar cell cube Wars 6. 14 nV. the optical power measurement at the cube without scattering was 15 3.38 microvolts the length of the fibre in the cube was 2.92 cm determine the Loss due to scattering in DB kilometre for the fibre at the wavelength of 0.63 micrometre

¡¡¡) A trigonometrical measurements is performed in order to determine the numerical of astep index fibre the screen is position 10 cm from the fibre end face when illuminated from a wide angle visible source then the measure output pattern size is 6. 2cm calculate the approximate numerical aperture of the fiber.

15) a) ¡)what is optical power budgeting?. determine the optical power budget for the below system and hence determine its viability.

Refer Book: Optical fiber Communications – John Senior - Pg. NO.731

Components are chosen for a digital Optical Fibre link of overall length 7 km and operating at 20 micro bits using a RZ code it is decided that an LED emitting at 0.85 micrometre with graded index fibre to a p-i- n photodiode is suitable choice for the system components giving no dispersion- equalization penalty an LED which is capable of launching and average of 100 microwatts of optical power including the connector loss into a graded index fibre of 15 micro metre core diameter is chosen.the proposed fibre cable has and attenuation of 2.6 DB kilometre and request splicing every kilometre with and loss of 0.5 DB per splice.there is also have connector loss at the receiver of 1.5 GB the receiver mean incident Optical power of -41dBm in order to give the necessary BER of 10 power minus 10 and it is predicted that a safety margin of 6db will be required.

¡¡)Discuss about the concept of routing and the wavelength assignment in the wavelength routed networks. Refer Book: Optical fiber Communications – John Senior - Pg. NO.992

(Or)

b)¡) Briefly explain the layers of the SONET.
Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 506.
¡¡)Describe in detail the non-linear effects on the performance of the network
Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 514- 516.

B.E B.Tech. DEGREE EXAMINATION, Nov / Dec 2017.
Seventh Semester
Electronics and Communication Engineering
EC6702- OPTICAL COMMUNICATION AND NETWORKS
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PART A – (10x2 = 20 marks)

1. **Why partial reflection does not the propagation of light?**
   Partial reflection of light in the quantum picture of photons is explained a certain probability for whole photons to be reflected as opposed to be transmitted. There is no partial reflection of a single photon. This probability corresponds to the intensity reflection coefficient of the corresponding electromagnetic wave.
2. **A graded index optical fiber has a core with a parabolic index profile which has a diameter of 50um. The fiber has a numerical aperture of 0.2. Calculate the total number of guided models in the fiber when it is operating at a wavelength of 1um.**

3. **Define attenuation.**

Attenuation coefficient is defined as the ratio of the input optical power P_i launched into the to the output

$$\propto_{dB} = \frac{10}{L} \, log_{10}^{\frac{P_i}{P_o}}$$

optical power P_o from the fiber.

where $\propto_{dB}$ is the attenuation coefficient in decibels per kilometer.

4. **A manufacturer's data sheet lists the material dispersion Dmat = 110ps/nm at a wavelength of 860nm. Find the rms pulse broadening per km due to material dispersion if the optical source has a spectral width = 40nm at b an output wavelength of 860nm.**

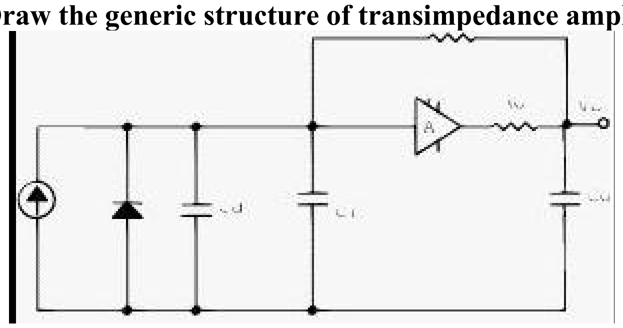
5. **Write the laser diode rate equation.**

$$\frac{dN}{dt} = \frac{J}{q} - BN^2 - \frac{N}{2\tau_0} - v_{gr}\Gamma\ell(N - N_{tr})S$$

$$\frac{dS}{dt} = \beta BN^2 - \frac{S}{\tau_{ph}} + v_{gr}\Gamma\ell(N - N_{tr})S$$

$$P_1 = v_{gr} SW \ln \frac{1}{\sqrt{R_1}}$$

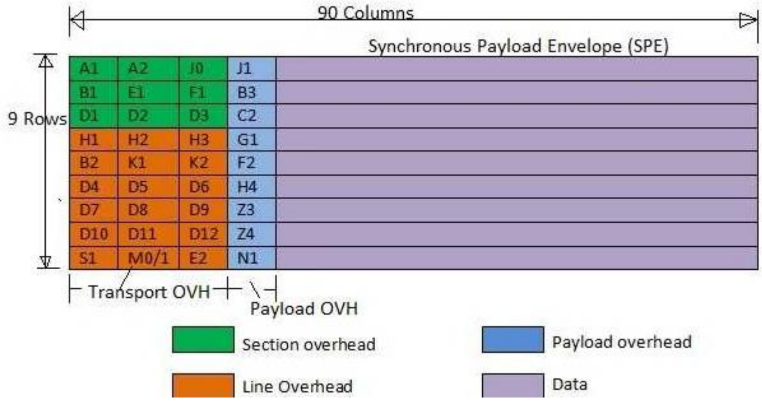
6. **Give some possible lensing schemes to improve optical source to fiber coupling efficiency.**
   1. Rounded – end fiber. 2. Spherical – surfaced LED and Spherical-ended fiber. 3. Taper ended fiber. 4. Non imaging microsphere. 5. Cylindrical lens. 6. Imaging sphere.
7. **Draw the generic structure of transimpedance amplifier.**



8. **Define receiver sensitivity.**

Receiver Sensitivity is the minimum average received optical power Pmin required to achieve a fixed BER.

9. **Draw the basic structure of STS-1 SONET frame.**



10. **Mention any 2 nonlinear effects present in optical fiber.**

Stimulated Scattering • Stimulated Brillouin Scattering (SBS) • Stimulated Raman Scattering (SRS) – Self Phase Modulation (SPM) • Optical Solitons for long distance communications – Cross phase modulation effects. • Four wave mixing (FWM)

11. **a) Explain phase shift with total internal reflection and evanescent field. (16)**

(Or)

b) Discuss whether TEM waves exist in an optical fiber. If not type of mode will propagate in a practical optical fiber. (16)

12. **a) In detail, explain linear scattering losses (16)**

(Or)

b) A multimode step index fiber has a numerical aperture of 0.3 and a core refractive index of 1.45. the material dispersion for the fiber is 250 ps $nm^{-1}km^{-1}$ which makes material dispersion the totally domination chromatic dispersion mechanism. Estimate (a) the total rms pulse broadening per km when the fiber is used with an LED source of rms spectral width 50nm and (b) the corresponding bandwidth-length product of the fiber. (16)

13. a) With steps, derive the internal quantum efficiency of LED. (16)

b) With a neat diagram, explain the structure of LASER diode and its radiation pattern. (16)

14. a) Explain the dispersion measurements methods in optical fiber. (16)

b) Discuss on the numerical aperture measurements of optical fiber. (16)

15. a) Explain SONET/ SDH Networks. (16)

b) Write a note on optical switching methods. (16)

B.E B.Tech. DEGREE EXAMINATION, Apr/May 2017.
Seventh Semester
Electronics and Communication Engineering
EC6702- OPTICAL COMMUNICATION AND NETWORKS
(Regulation 2013)
PART A – (10x2 = 20 marks)

1. **What are the advantages of optical fiber?**
   Faster speed with less attenuation, less impervious to electromagnetic interference (EMI), smaller size and greater information carrying capacity.
2. **A multimode silica fiber has a core refractive index n1=1.48 and cladding refractive index n2= 1.46. Find the numerical aperture fiber.**
   Numerical Aperture (N.A) = $(n_1^2 - n_2^2)^{1/2}$=$(1.48^2 - 1.46^2)^{1/2}$ =0.24
3. **What is intra modal dispersion.**
   Pulse broadening within a single mode is called as intramodal dispersion or chromatic dispersion
4. **Define group delay.**
   The observable delay experiences by the optical signal waveform & energy, when traveling a length of l along the fiber is commonly referred to as group delay.
   $$\tau_g = \frac{l}{V_g} = l\frac{d\beta}{d\omega}$$
5. **What is minimum detectable optical power?**
   The sensitivity of a photodetector in an optical fiber communication system is described in terms of the minimum detectable optical power. This is the optical power necessary to produce a photocurrent of the same magnitude as the root mean square (rms) of the total noise current or a signal-to-noise ratio of 1.
6. **Compare the optical sources : LASER and LED.**

S.No.	LED	Laser diode
1	The output obtained is incoherent	The output obtained is coherent
2	Less expensive and less complex	More expensive and more complex.
3	Long lifetime	Short lifetime.
4	Output power less	Output power more
5	Less temperature dependant	More temperature dependant

7. **What are the methods employed for measuring attenuation in optical fiber.**
   1. Insertion loss method 2. Cut-back method 3. Optical Time-Domain Reflectometry (OTDR)
8. **Define bit error rate.**
   Bit Error Rate (BER) is defined as the ratio of the number of errors occurred over a certain time interval'‘t’ to the number of pulses transmitted during this interval.
9. **What is an optical layer?**
   The introduction of second-generation optical networks adds yet another layer to the protocol hierarchy – the so-called optical layer. The optical layer is a *server* layer that provides services to other *client* layers. This optical layer provides lightpaths to a variety of client layers,
10. **What are the key parameters required for analyzing the optical link?**
    The desired transmission distance
    Bit error rate
    Data rate or bandwidth

B.E B.Tech. DEGREE EXAMINATION, November / December 2016.
Seventh Semester
Electronics and Communication Engineering
EC6702- OPTICAL COMMUNICATION AND NETWORKS
(Regulation 2013)
PART A – (10x2 = 20 marks)

1. Define Numerical Aperture.
Numerical aperture defines the light cathering capacity of the fiber.
Numerical Aperture = NA = $(n1^2 - n2^2)$

2. What are the conditions for light to be propagation inside a fiber?
The light signal must be totally internally reflected within the core. The incident angle must be greater than critical incident angle.

3. What are the causes of absorption?
- Absorption by atomic defects in glass composition.
- Extrinsic absorption by impurity atoms in the glass materials.
- Intrinsic absorption by basic constituent atoms.

4. What is polarization mode dispersion?
The difference in propagation times between the two orthogonal polarization modes will result pulse spreading. This is called as polarization mode dispersion. (PMD)

5. What are mechanisms behind lasing actions?
The three requirements of Laser action are
✓ Absorption
✓ Spontaneous emission
✓ Stimulated emission

6. Define external quantum efficiency.
The external quantum efficiency is defined as the number of photons emitted per radiative electron-hole pair recombination above threshold.

7. Define BER.
The transmitted signal is two level binary data stream consisting of either 0 or 1 in a time slot of duration T. this time slot is referred to a bit period.

8. What is cut back method?
Cut back method is a destructive method of determining attenuation which involves the measuring the optical power transmitted power through a long and a short length of fiber using identical input coupling.

9. How do you ensure that the required system performance is met or not?
1. Link power budget
2. System rise time budget analysis

10. Name two popular architectures of SONET/SDH network.
1. Two fiber, unidirectional path switched ring
2. Two fiber or four fiber, bidirectional, line switched ring

PART B - (5 x 16 - 80 marks)

11.(a) (i) Compare the structure and characteristics of step index and graded indx fiber (12)
Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. NO.37

(ii) A graded index fiber with a core with a parabolic refractive index profile (ά=2) and diameter of 50μm. The fiber has numerical aperture of 0.2. Estimate the number of the guided modes propagating in the fiber when the transmitted light has a wavelength 1μm.(4)

OR

(b) (i) Consider a fiber with 25μm core radius, core index n1=1.48 and Δ = 0.01. if λ = 1320nm. What value of V and how many modes propagate in the fiber. What percent of optical power flows in the cladding? If the core cladding difference is reduced to Δ = 0.003, how many modes does the fiber support and what fraction of the optical power flows in the cladding?(8)

(ii) Explain the functional blocks of an optical communication link with neat block diagram.(8)
Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. NO.37

12. (a) Discuss about the design optimization of single mode fiber (16)

OR

(b) What is waveguide dispersion? Derive an expression for time delay produced due to waveguide dispersion (16)
Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 109

13. (a) (i) A double heterojunction LED emitting at a peak wavelength of 1301 nm has radiative and non- radiative recombination time of 45ns and 95ns respectively.the drive current is 35mA. Determine internal efficiency and internal power level. If the refractive index of the light source material is n = 3.5 find the power emitted from the device. (6)

(ii) What is fiber splicing?. Discuss about fusion splicing and mechanical splicing. (10)
Refer Book: Optical fiber Communications –John M.Senior - Pg. No. 227-234.

OR

(b) Explain the working principle of laser diode and derive its rate equation. (16)
Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No. 163

14.(a) Explain the different methods employed in measuring the attenuation in optical fiber with neat block diagram. (16)
Refer Book: Optical fiber Communications - John M.Senior - Pg. No . 782 -783.

OR

(b) What are the performance measures of a digital receiver? Derive an expression for bit error rate of a digital receiver. (16)
Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 279

15. (a) (i) Draw the generic configuration of SONET and explain the functions of add drop multiplexers in SONET. (8)
Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. NO.4 72

(ii) A 90 Mb/s NRZ data transmission system that sends two DS3 channels uses a GaAlAs laser diode that has a spectral width of 1nm. The rise time if the laser transmitter output is 2ns. The transmission distance is 7km over a graded index fiber that has 800 MHz. km bandwidth-distance product. If the receiver bandwidth is 90MHz and mode mixing factor q=0.7, what is the system rise time? What is the rise time if there is no mode mixing?(use 0.07 ns/(nm-km))

OR

(b) Discuss in detail about the effort of noise on system performance.
Refer Book: Optical fiber Communications - Gerd Kaiser - Pg. No . 252