Subject Name: Optical Communications

Prepared by (Faculty (s) Name): Mr. Ch. Mani Kumar, Assistant Professor, ECE

Year and Sem, Department: IV Year- II Sem, ECE

Unit-I: Overview of Optical Fiber Communication

Important points / Definitions: (Minimum 15 to 20 points covering complete topics in that unit)

1. Optical fiber communication systems are used in telecommunication networks and many other more localized communication application areas. An optical fiber communication system is similar in basic concept to any type of communication system.
2. The optical fiber communication system consists of information source, electrical transmit, optical source, optical fiber cable, optical detector, electrical receive and destination.
3. Advantages of optical fiber communication system are enormous potential bandwidth, small size and weight, electrical isolation, immunity to interference and crosstalk, signal security, low transmission loss, ruggedness and flexibility, system reliability and ease of maintenance and potential low cost.
4. When the angle of incidence is greater than the critical angle the light is reflected back into the originating dielectric medium this is called as total internal reflection. If the ray has an angle of incidence$(\emptyset)$ at the interference which is greater than the critical angle$(\emptyset_c)$ is reflected at the same angle i.e. angle of incidence$(\emptyset)$ to the same dielectric medium.
5. Acceptance angle(θ_a) is the maximum angle to the fiber axis at which the light enter into the fiber, in order to propagate by total internal reflection with in the fiber core. The rays to be transmitted with in the fiber core, by total internal reflection, they must be incident on the fiber core within an acceptance cone defined by the conical half angle(θ_a).
6. Numerical aperture of the fiber is used to obtain a relation ship between the acceptance angle(θ_a) and the refractive indices of the three media involved, they are core, cladding and

air. If the refractive indices of air is n_0, the fiber core is n_1 and cladding is n_2, then the numerical aperture(NA) is defined as,

$$NA = n_0 \sin\theta_a = (n_1^2 - n_2^2)^{\frac{1}{2}}$$

7. Skew rays are another category of rays exists in optical fiber cable which is transmitted without passing through fiber axis, these rays follow a helical path through the fiber.
8. An optical fiber is a long cylindrical dielectric waveguide, usually of circular cross-section, transparent to light over the operating wavelength.
9. The individual modes which are propagating in optical fiber will have effect of mixing of energy travelling in one mode to another mode depending on waveguide irregularities such as deviations of the from straightness, variations in the core diameter, irregularities at the core-cladding interface and refractive index variations may change the propagation characteristics of the fiber. This mode conversion i.e. mixing of energy travelling in one mode to another mode is known as mode coupling.
10. The normalized frequency is a dimension less parameter and it is also called as V number, it is value of the fiber. It is relation between three important design variables for the optical fiber. They are the core radius $'a'$, the relative refractive index difference $'\Delta'$ and the operating wavelength $'\lambda'$.

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

$$V = \frac{2\pi}{\lambda} a n_1 (2\Delta)^{\frac{1}{2}}$$

11. The optical fiber having a core of constant refractive index n_1 and cladding of a slightly lower refractive index n_2 is known as step index fiber. Step index fiber is classified in two major types, they are multimode step index fiber and single mode step index fiber. The refractive index profile is defined as

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

12. Graded index fiber have 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.

Where n_1 is refractive index of the fiber core and n_2 is refractive index of the cladding. This index variation is represented as

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

13. Single-mode fibers are used for the transmission of single mode, and the fiber must be designed to allow propagation of only one mode and remaining all other modes are attenuated by leakage or absorption. The advantage of the propagation of a single mode within an optical fiber is that signal dispersion caused by the delay differences, between modes in a multimode fiber is avoided.
14. Cutoff wavelength(λ_c) of mode operation in single-mode fiber is

$$\lambda_c = \frac{2\pi a n_1}{V_c}(2\Delta)^{\frac{1}{2}}$$

Where V_c is the cutoff normalized frequency. λ_c is the wavelength above which a particular optical fiber becomes single-mode fiber.

15. Mode-field diameter(MFD) is an important parameter for characterizing single-mode fiber properties which takes into account the wavelength dependent field penetration into fiber cladding. It is a better measuring parameter of the functional properties of single-mode fiber than the core diameter.
16. Effective refractive index for single-mode fiber referred to as a phase index or normalized phase change coefficient. It is denoted by n_{eff}, it is the ratio of the propagation constant of the fundamental mode to that of the vacuum propagation constant.

$$n_{eff} = \frac{\beta}{k}$$

17. Optical fiber materials must have requirements like, possible to make long, thin, flexible fibers from the material. The material must be transparent at a particular optical wavelength, to guide the light efficiently in optical fiber. Glasses and plastic materials satisfy these requirements.

18. Glass is made by fusing mixtures of metal oxides, sulfides or selenides. Oxide glass materials are optically transparent, mostly used for manufacturing optical fibers. The most common oxide glass material is silica(SiO_2), which has a refractive index 1.458 at 850nm.
19. Doping rare earth elements into passive glass materials like silica, tellurite and halide gives the active glass fiber material having new optical and magnetic properties. These new properties of material is used for amplification, attenuation and phase retardation on the light passing through it.
20. Chalcogenide glasses generally comprise mixture of one or more of the elements like Sulphur(S), Selenium(Se) and Tellurium(Te), together with one or more elements Germanium(Ge), Silicon(Si), Arsenic(As) and Antimony(Sb), are capable of optical transmission in both the mid-infrared and far-infrared regions.
21. Plastic optical fibers are high-speed, high bandwidth graded-index polymer optical fibers(POF). The core of these fibers is made by polymethylmethacrylate or a per fluorinated polymer. Therefore these fibers are called as PMMA POF(polymethylmethacrylate polymer optical fibers) and PF POF(per fluorinated polymer optical fibers).

Short Questions (minimum 10 previous JNTUH Questions)

1. What are the various elements of an optical communication system? Explain each element in brief?
2. Give the block diagram of digital optical communication system and explain the function of each block?
3. Distinguish between optical fiber communication system and conventional communication system?
4. List out the advantages of optical fiber communication?
5. Define an optical fiber? What are the different types of optical fibers?
6. Explain about mode field diameter?
7. Explain about cut-off wavelength of single-mode fibers?
8. Write short notes on numerical aperture?
9. Explain about acceptance angle?
10. What are advantages of plastic optical fibers?

Long Questions (minimum 10 previous JNTUH Questions)

1. Write in detail about ray optics?
2. Define an optical fiber? Explain in detail different types of optical fibers giving neat sketches?
3. Compare fiber structure and numerical aperture in step index fiber and graded index fiber?
4. List the requirements that must be satisfied by materials used to manufacture optical fiber?
5. Write in detail about glass fiber?
6. Write in detail about plastic optical fiber?
7. Write in detail about total internal reflection?
8. Explain about modes and V number of cylindrical fibers?
9. Write in detail about effective refractive index?
10. Explain about ray theory transmission?

Fill in the Blanks / Choose the Best: (Minimum 10 to 15 with Answers)

1. **Acceptance angle** is the maximum angle to the fiber axis at which the light enter into the fiber.
2. **Mode-field diameter(MFD)** is an important parameter for characterizing single-mode fiber properties.
3. When the angle of incidence is greater than the critical angle the light is reflected back into the originating dielectric medium this is called as **total internal reflection**.
4. The optical fiber having a core of constant refractive index n_1 and cladding of a slightly lower refractive index n_2 is known as **step index fiber**.
5. **Graded index fiber** have decreasing core index $n(r)$.
6. Mixing of energy travelling in one mode to another mode is known as **mode coupling**.
7. The normalized frequency is a dimension less parameter and it is also called as **V number**.
8. **Glass** is made by fusing mixtures of metal oxides, sulfides or selenides.
9. **Skew rays** are another category of rays exists in optical fiber cable which is transmitted without passing through fiber axis.
10. Skew rays follow a **helical path** through the fiber.

Unit-II: Signal Distortion in Optical Fibers

Important points / Definitions: **(Minimum 15 to 20 points covering complete topics in that unit)**

1. An optical signal weakens from attenuation mechanisms and increases due to distortion effects as it travels along a fiber. These two factors will cause neighboring pulses to overlap. After certain overlap occurs, the receiver can no longer distinguish the individual adjacent pulses and errors arise when interpreting the received signal. This is called signal distortion in optical fibers.
2. Signal attenuation is also known as fiber loss or signal loss is one of the most important properties of an optical fiber. The basic attenuation mechanism in a fiber are absorption, scattering and radiative losses of the optical energy.
3. Absorption is caused by atomic defects in the glass composition, extrinsic absorption is by impurity atoms in the glass material. Whereas intrinsic absorption is by the basic constituent atoms of the fiber material.
4. Optical fibers that can be used in the E-band are known as “low-water-peak” or “full-spectrum fibers”.
5. Scattering losses in glass material is due to microscopic variations in the material density, from compositional fluctuations and from structural inhomogeneities or defects occurring during fiber manufacture.
6. Radiative losses occur when an optical fiber undergoes a bend of finite radius of curvature. There are two types of bends, they are macroscopic bends, having radii large when compared with fiber diameter and random microscopic bends of the fiber axis, when the fibers are incorporated into cables.
7. The core and cladding have different refractive indices, differ in composition and having different attenuation coefficients, denoted by α_1 and α_2 respectively.
8. Information-carrying capacity of a fiber link can be determined by examining the deformation of short light pulses propagating along the fiber.
9. As signal propagates along the fiber, each spectral component can be assumed to travel independently and to undergo a time delay or group delay per unit length τ_g/L in the direction of the propagation given by

$$\frac{\tau_g}{L} = \frac{1}{V_g} = \frac{1}{c}\frac{d\beta}{dk} = -\frac{\lambda^2}{2\pi c}\frac{d\beta}{d\lambda}$$

Here, L is the distance traveled by the pulse, β is the propagation constant along the fiber axis.

10. Material dispersion is due to the variations of the refractive index of the core material as a function of wavelength. It is also called as chromatic dispersion.
11. Waveguide dispersion arises because the fraction of light power propagating in the cladding travels faster than the light confined to the core, since the index is lower in cladding.
12. A varying birefringence along its length will cause each polarization mode to travel at a slightly different velocity. The resulting difference in propagation times $\Delta\tau_{PMD}$ between the two orthogonal polarization modes will result in pulse spreading. This is called as polarization-mode dispersion(PMD).
13. The differential time delay $\Delta\tau_{PMD}$ between the polarization components during propagation of the pulse over a distance L is

$$\Delta\tau_{PMD} = \left|\frac{L}{v_{gx}} - \frac{L}{v_{gy}}\right|$$

Where v_{gx} and v_{gy} are the group velocities of the two orthogonal polarization modes.

14. Intermodal dispersion is also known as modal delay appears only in multimode fibers. This signal distortion is a result of each mode having a different value of the group velocity at a single frequency.
15. The maximum pulse broadening arising from the modal delay is the difference between the travel time T_{max} of the longest ray congruence paths(the highest-order mode) and the travel time T_{min} of the shortest ray congruence paths(the fundamental mode). This broadening is simply obtained from ray tracing and for a fiber of length L is given by

$$\Delta T = T_{max} - T_{min} = \frac{n_1}{c}\left(\frac{L}{\sin\varphi} - L\right) = \frac{Ln_1^2}{cn_2}\Delta$$

Where $\sin\varphi = \frac{n_1}{n_2}$ and Δ is the index difference.

16. Optical fiber connectors are used from simple single-channel fiber-to-fiber connectors in a benign location to multichannel connectors used in harsh military field environments.
17. Low coupling losses, interchangeability, ease of assembly, low environmental sensitivity, low-cost and reliable construction and ease of connection are some of the principal requirements of a good connector.

18. Connectors are available in designs that screw-on, twist-on, or snap into place. The most commonly used connectors are the twist-on and snap-on design. The basic coupling mechanism used in this connectors belong to either the butt-joint or the expanded-beam classes.
19. There are two types of butt-joint alignment designs used in both multimode and single-mode fiber mechanisms. They are the straight-sleeve and the tapered-sleeve or biconical mechanisms.
20. The amount of power reflected from the connector to connector interface. This is called as connector return loss. This can affect the optical frequency response, the line width and the internal noise of the laser, which results in degradation of system performance.

Short Questions (minimum 10 previous JNTUH Questions)

1. What are the basic attenuation mechanisms in the optical fiber communication?
2. Explain about bending losses?
3. Explain about scattering losses?
4. Explain about absorption losses?
5. Explain about signal distortion in optical fiber?
6. Explain about modal birefringence?
7. Write short notes on pulse broadening?
8. Explain group delay or time delay in fiber optics?
9. Write short notes on fiber optic connectors?
10. Explain about single-mode fiber connectors?

Long Questions (minimum 10 previous JNTUH Questions)

1. Explain in brief on what factors attenuation mechanism depends in the fiber optic communication?
2. Explain in detail about signal distortion and attenuation in optical fiber?
3. Explain about fiber optic connectors and types of connectors in detail?
4. Explain briefly about core and cladding losses in optical fibers?
5. Explain about material dispersion?
6. Explain about wave-guide dispersion?
7. Explain briefly about information capacity determination?

8. Explain in detail about polarization mode dispersion?
9. Explain about intermodal dispersion?
10. What is optical fiber connector? Explain in detail about different fiber connectors?

Fill in the Blanks / Choose the Best: (Minimum 10 to 15 with Answers)

1. Signal attenuation is also known as **fiber loss or signal loss**.
2. Intermodal dispersion is also known as **modal delay**.
3. Intermodal dispersion appears only in **multimode fibers**.
4. **Extrinsic absorption** is by impurity atoms in the glass material.
5. **Intrinsic absorption** is by the basic constituent atoms of the fiber material.
6. Optical fibers that can be used in the E-band are known as **low-water-peak or full-spectrum fibers**.
7. Information-carrying capacity of a fiber link can be determined by examining the deformation of **short light pulses** propagating along the fiber.
8. A varying **birefringence** along its length will cause each polarization mode to travel at a slightly different velocity.
9. Material dispersion is also called as **chromatic dispersion**.
10. **Radiative losses** occur when an optical fiber undergoes a bend of finite radius of curvature.