AR-2139

Modal Answer Sheet

M.Sc. Electronics - III

Fiber optics and optical communication

Section - A

Q.1. (i) a, (ii) a (iii) a (iv) a, (v) a
(vi) a (vii) a (viii) d (ix) b (x) a.

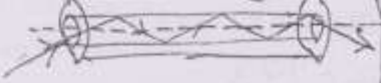
Section - B

Ans 2:- **Characteristics of optical Fiber Comm.**

The main characteristics of optic fiber communication systems are as follows:

(a) Fast and long durable
(b) Reliable (c) wide Band width
(d) Large data carrying capacity
(e) Low noise (f) Cheap communication
(g) Large area coverage etc.

Difference betwn. step index and graded index fiber

Step index	Graded index fiber
1. The core has a uniform and high R.I (n_1) throughout its core	1. The core has varying R.I with a maximum value n_1 at the core axis and decreasing radially towards the core wall
2. The R.I. of clad and air decreases step by step	2. The light rays periodically converge and diverge along the length of the fiber
3. The single mode and multi-mode signals are allowed in this fiber	3. 
4. High signal carrying capacity, large BW of the order of 1 GHz and very less attenuation	(4) $n(r) = n_1\sqrt{1 - [2\Delta(\frac{r}{a})^{\alpha}]}$
5. diagram $N = V^2/2$ 	(5) $N = \frac{V^2}{4}$

(2)

Characteristics of single mode opt-fib

1. only one mode transmitted through single mode opt. fiber
2. The HE_{11} mode which has V number = 0 will be supported by the single mode opt. fib.
3. It has core diameter $\sim 5 \mu m$ and $NA = 0.1$ at $\lambda = 0.8 \mu m$.
4. No degradation of signal takes place during the propagation through single mode fiber
5. It is highly useful for long distance communication such as submarine cables.

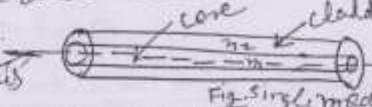


Fig. single mode fib

Ans. 3. The core diameter is $70 \mu m$

therefore core radius $a = \frac{70}{2} = 35 \mu m$.

$\Delta = \frac{n_1 - n_2}{n_1} = 1.5\%$; $n_1 = 1.46$; and $\lambda = 0.85 \mu m$.

(a) $\because \Delta = \frac{n_1 - n_2}{n_1} = \frac{1.5}{100} = 0.015$

therefore $n_1 - n_2 = 0.015 n_1$

$$n_2 = n_1 - 0.015 n_1 = 1.46(1 - 0.015)$$

$$\boxed{n_2 = 1.438} \text{ Ans}$$

(b) V number can be calculated as

$$V = \frac{2\pi a}{\lambda}[n_1^2 - n_2^2]^{1/2} = \frac{2\pi a}{\lambda}[(n_1+n_2)(n_1-n_2)]^{1/2}$$

$$= \frac{2\pi a}{\lambda}(2n_1)^{1/2}(n_1-n_2)^{1/2}$$

[Putting $n_1 + n_2 = 2n_1$]

$$= \frac{2\pi a}{\lambda} n_1 \left[\frac{2(n_1-n_2)}{n_1}\right]^{1/2} = \frac{2\pi a}{\lambda} n_1 (2\Delta)^{1/2}$$

$$2\Delta = \frac{2 \times 1.5}{100} = 0.03$$

$$\therefore (2\Delta)^{1/2} = (0.03)^{1/2} = 0.173$$

$$V = \frac{2\pi \times 35 \times 10^{-6} \times 1.46 \times 0.173}{0.85 \times 10^{-6}} = \boxed{65.3} \text{ Ans.}$$

(C) Total no. of guided modes in the step-index fiber is

$$M = \frac{V^2}{2} = \frac{(65.3)^2}{2} = \boxed{2132 \text{ modes}} \text{ Ans}$$

Ans:4 (i) For step index fiber, the pulse dispersion is given by

$$\Delta\tau = \frac{n_1 L}{c}\Delta$$

$$\Delta = \frac{n_1 - n_2}{n_2} = \frac{1.46 - 1.0}{1.0} = \frac{0.46}{1.0} = 0.46$$

$L = 1\,km$; $c = 3 \times 10^5\, km/sec$

$$\Delta\tau = \frac{1.46 \times 1 \times 0.46}{3 \times 10^5} = \frac{0.6716 \times 10^{-5}}{3}$$

$$= 0.2239 \times 10^{-5} \times 10^{-9}\, ns/km$$

$$\boxed{\Delta\tau = 2239\, ns/km.} \text{ Ans}$$

(ii) Attenuation loss

$$\alpha = \frac{10}{L}\log\left[\frac{P_{in}}{P_{out}}\right]$$

$$3.5\, dB/km = \frac{10}{4\,km}\log\left[\frac{0.35\,mW}{P_{out}}\right]$$

$$\boxed{P_{out} = 19.9 \times 10^{-6}\, W} \text{ Ans}$$

Ans 5:- Signal distortion in optical fiber

The signal distortion in an optical is a consequence of intermodal dispersion and intermodal delay effects. The distortion effects can be explained by examining the behaviour of the group velocities of the guided modes. The group velocity is the speed at which energy in a particular mode traveling along the fiber.

Intermodal dispersion is pulse spreading that occurs within a single mode. It is a result of the group velocity being a function of the wavelength λ and referred to as chromatic dispersion. The signal distortion increases with the spectral width of the optical source.

The main causes of intramodal dispersion are;

1. Material dispersion, which arises from the variation of the refractive index of the core material as a function of λ. This causes a wavelength dependence of the group velocity of any given mode.
2. Waveguide dispersion, which occurs because the modal propagation constant β as a function of (a/λ).

Group Delay:- In case of an optical fiber, as the 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 and is given by

$$\frac{t_g}{L} = \frac{1}{V_g} = \frac{1}{c}\frac{d\beta}{dk} = -\frac{\lambda^2}{2\pi c}\frac{d\beta}{d\lambda} \quad \text{--- (1)}$$

The group velocity $V_g = c\left(\frac{d\beta}{dk}\right)^{-1}$ is the velocity at which the energy in a pulse travels along a fiber.

The signal delay difference τ over a distance L is given by

$$\tau = \frac{dt_g}{d\lambda}\Delta\lambda \quad \text{- - - - (2)}$$

or The pulse spreading can be given as

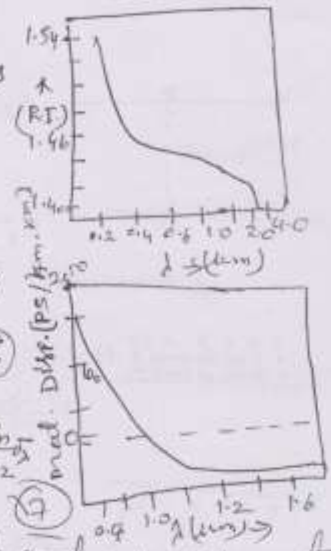
$$\tau_g = \frac{dt_g}{d\lambda}\sigma_\lambda = -\frac{L\sigma_\lambda}{2\pi c}\left(2\lambda\frac{d\beta}{d\lambda} + \lambda^2\frac{d^2\beta}{d\lambda^2}\right) \quad \text{--- (3)}$$

The factor $D = \frac{1}{L}\frac{dt_g}{d\lambda}$ - - - - (4)

is known as the dispersion. It defines the pulse spread as a function of λ and is measured in ns/km/nm. It is a result of material and waveguide dispersion.

Material Dispersion

It occurs because the R.I varies as a nonlinear function of the optical λ. It is an intermodal dispersion effect. The β can be given as $\beta = \frac{2\pi n(\lambda)}{\lambda}$ - (5)



$$t_{mat} = \frac{L}{c}\left(n - \lambda\frac{dn}{d\lambda}\right) \quad \cdots (6)$$

or $$\tau_{mat} = \frac{dt_{mat}}{d\lambda}\sigma_\lambda = -\frac{L}{c}\lambda\frac{d^2n}{d\lambda^2}\sigma_\lambda \quad (7)$$

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Ans 6. Structure, materials and working of Semiconductor Laser Diode

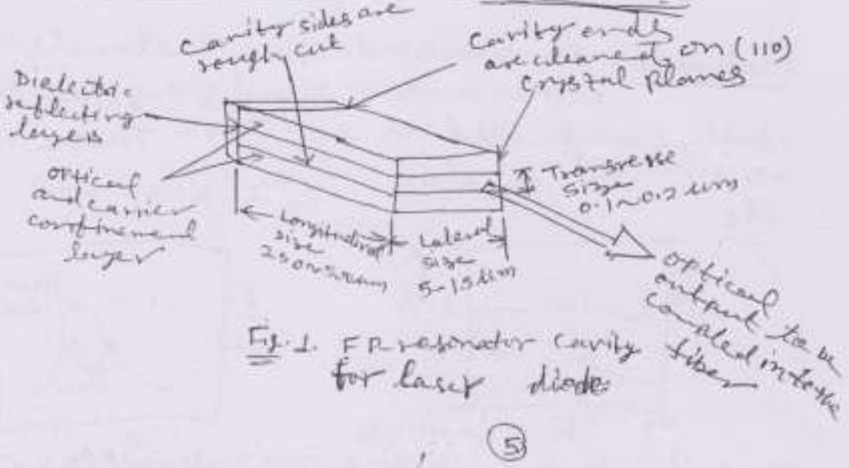
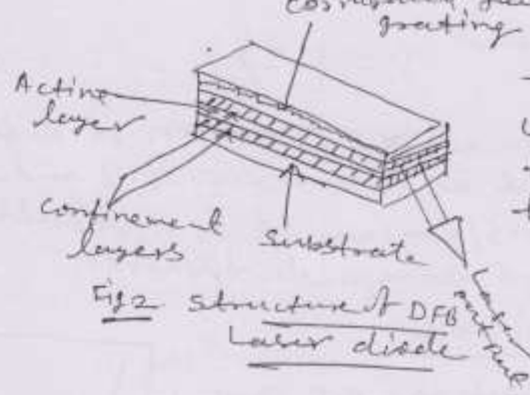
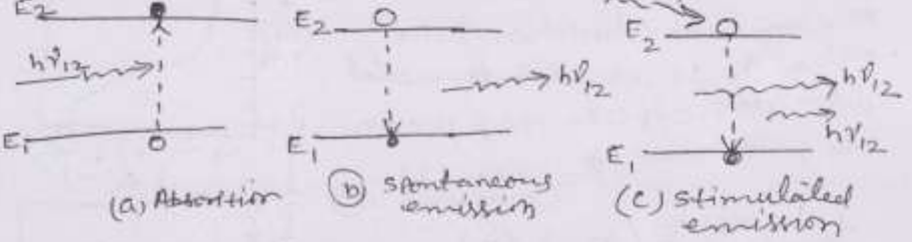


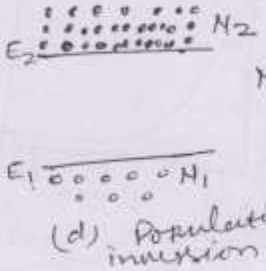
Fig. 1. F.P. resonator cavity for laser diode

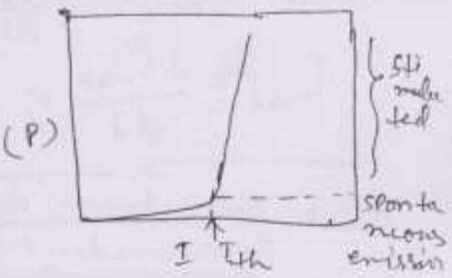


The details of laser structure to be discussed here.

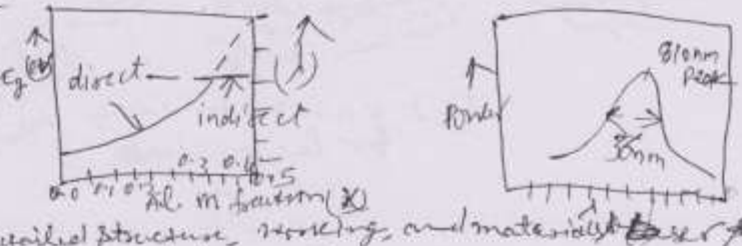
Fig 2 Structure of DFB Laser diode







Materials:- The semiconducting materials which comes under III and Vth group of periodic table can be used as emitters. These mats are as given by $Ga_{1-x}Al_xAS$; $In_{1-x}Ga_xAs_yP_{1-y}$; GaP; AlGaP etc.



The detailed structure, working, and materials of laser to be discussed here. (6)

Ans 7:- Optical Fiber Receiver

An optical receiver consists of a photodetector, an amplifier, and signal-processing circuitry. It has the task to convert the optical energy emerging from the end of a fiber into an electric signal, and then amplifying this signal to a large enough level so that it can be processed by the electronics following the receiver amplifier. In these processes various noises and distortions will unavoidably be introduced which can lead to errors in the interpretation of the received signal. Thus, it is important to consider the noise during the design of optical receivers.

In designing a receiver it is important to predict its performance based on mathematical models of the various receiver stages. These models must take into account the noises and distortions added to signal by the components in each stage, and they must show the designer which components to choose so that the desired performance criteria of the receiver are met.

Receiver configuration

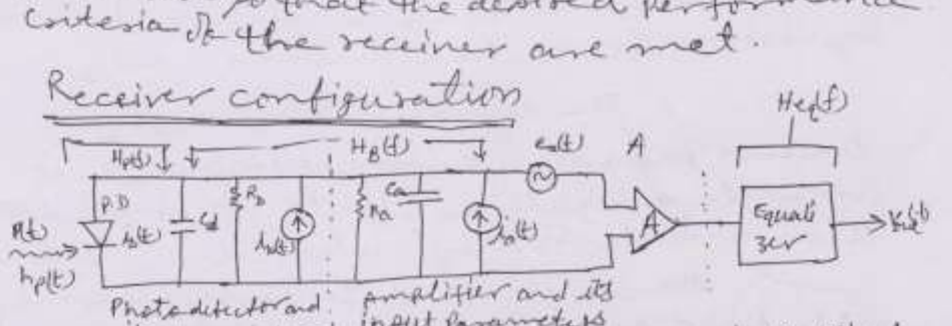


Fig. schematic diagram of a typical optical receiver

The above fig. represents the schematic diagram of a typical receiver which mainly three stages namely, a Photodetector, an amplifier and an equilizer. The P.D. can be either an APD with mean gain M or a PIN P.D for which $M=1$. The P.D. has a quantum efficiency η and a cap. C_d. The detector bias resistor has a resistance R_b which generates a thermal noise current $i_b(t)$.

The amplifier has an input impedance represented by the parallel combination of a resistance R_a and a shunt capacitance C_a. Voltages appearing across this impedance causes current to flow in the amplifier output.

There are two amplifier noise sources: The input noise current source $i_a(t)$ arises from the thermal noise of the amplifier input resistance R_a, whereas the noise voltage source $e_a(t)$ represents the thermal noise of the amplifier channel. These noise sources are assumed gaussian in statics, flat in spectrum and uncorelated. They are thus completely described by their noise spectral densities S_I and S_E.

The equalizer is normally a linear frequency-shaping filter that is used to mitigate the effects of signal distortion and intersymbol interference. In some cases, it is used to correct for the electric frequency response of the P.D. and the amplifier.

<u>Receiver noises</u>:- If $v_N(t)$ is the noise voltage causing $V_{out}(t)$ to deviate from its average value, then the actual equaliser output voltage is of the form

$$v_{out}(t) = \langle v_{out}(t) \rangle + v_N(t) \quad --- (1)$$

The noise voltage at the equalizer output for the receiver

$$v_N^2(t) = v_S^2(t) + v_R^2(t) + v_I^2(t) + v_E^2(t) \quad --- (2)$$

The mean square noise voltage $\langle v_N^2 \rangle$ can be given by

$$\langle v_N^2 \rangle = \langle [v_{out}(t) - \langle v_{out}(t) \rangle]^2 \rangle$$

$$= \langle v_{out}^2(t) \rangle - \langle v_{out}(t) \rangle^2$$

$$= \langle v_S^2(t) + \langle v_R^2(t) + v_I^2(t) + v_E^2(t) \quad --- (3)$$

The thermal noise of the load resistor R_b is

$$\langle v_R^2(t) \rangle = \frac{4 k_B T}{R_b} B_{bae} R^2 A^2 \quad --- (4)$$

Here R can be given by $\frac{1}{R} = \frac{1}{R_a} + \frac{1}{R_b}$

B_{bae} is the noise equivalent B.W. of the bias circuit, amplifier and equalizer defined for positives frequencies only.

$$2 B_{bae} = \frac{1}{|H_{out}(0)/H_p(0)|^2} \int_{-\infty}^{+\infty} \left| \frac{H_{out}(f)}{H_p(f)} \right|^2 df \quad --- (5)$$

$$\langle v_I^2(t) \rangle = 2 S_I B_{bae} R^2 A^2 \quad --- (6)$$

$$\langle v_E^2(t) \rangle = 2 S_E B_e A^2 \quad --- (7)$$

Where S_I is the spectral density of the amplifier input noise current source. S_E is the spectral density of the amplifier noise

and $$2 B_e = \frac{1}{|H_{eq}(0)|^2} \int_{-\infty}^{+\infty} |H_{eq}(f)|^2 df \quad --- (8)$$

Shot Noise

$$\langle v_S^2(t) \rangle = 2 q \langle i_o \rangle \langle m^2 \rangle B_{bae} R^2 A^2 \quad --- (9)$$

For pulse 1

$$\langle i_o \rangle_1 = \frac{\eta q}{h\nu} \frac{b_{on}}{T_b} \int_{-\infty}^{+\infty} h_p(t)\, dt = \frac{\eta q}{h\nu} \frac{b_{on}}{T_b} \quad - (10)$$

For a 0 pulse (with all adjacent pulses being 1), we assume $b_{off} = 0$, so that

$$\langle i_0 \rangle_0 = \sum_{n \neq 0} \frac{\eta q}{h\nu} b_{on} \frac{1}{T_b} \int_{-T_b/2}^{T_b/2} h_p(t - nT_b)\, dt$$

$$= \frac{\eta q}{h\nu} \frac{b_{on}}{T_b} (1-\gamma) \quad \text{---} \quad (11)$$

The Parameter

$$\gamma = \int_{-T_b/2}^{T_b/2} h_p(t)\, dt \quad \text{---} \quad (12)$$

is the fractional energy of a 1 pulse that is contained within its bit period. The factor $1-\gamma$ is thus the fractional energy of a pulse that has spread outside of its bit period as it travelled through the optical fiber.