Ministry of Higher Education & Scientific Research
University of Technology
Laser & Optoelectronics Eng. Department
Al-Kut University College
Class: **4th** Year
Subject: Optical Communication Systems

Final Examination
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Date: 25/5/2016
Examiner:
Code:
Academic Year 2015-2016

كلية الكوت الجامعة

Attempt only (5) questions

Q1: **(15 Marks)**

(a) Describe with the aid of the suitable equations the main factors which limit the speed of response in the photodiode.

(b) A lens-coupled surface-emitting LED launches 190 μW of optical power into a multimode step index fiber when a forward current of 25 mA is flowing through the device. Determine the overall power conversion efficiency when the corresponding forward voltage across the diode is 1.5 V. **(5 Marks)**

Q2: **(10 Marks)**

(a) Explain with the aid of the suitable diagrams and equations the fiber bending loss.

(b) An optical fiber has a numerical aperture of 0.2 and a cladding refractive index of 1.59. Determine: **(10 Marks)**

1. The acceptance angle of the fiber in water which has a refractive index of 1.33.
2. The critical angle at the core–cladding interface.

Q3: **(10 Marks)**

(a) Outline with the aid of the suitable diagrams the light generating mechanisms.

(b) A photodiode has a quantum efficiency of 65% when photons of energy 1.5×10^{-19} J are incident upon it. **(10 Marks)**

(1) At what wavelength is the photodiode operating?

(2) Calculate the incident optical power required to obtain a photocurrent of 2.5 μA when the photodiode is operating as described above.

Q4: **(10 Marks)**

(a) Explain with the aid of the suitable diagrams the intersymbol interference (ISI).

(b) What are the main parts of the fiber optic transmitter? Explain the role of each part. **(10 Marks)**

Q5: **(20 Marks)**

Light traveling in air strikes a glass plate at an angle $\Theta_1 = 33\ ^{\circ}$, where Θ_1 is measured between the incoming ray and the glass surface. Upon striking the glass, part of the beam is reflected and part is refracted. If the refracted and the reflected beams make an angle of 90° with each other, what is the refractive index of the glass? What is the critical angle for this glass?

Q6: **(20 Marks)**

Define the following terms with the aid of the suitable diagrams and equations:

1. Reflection
2. Refraction
3. Snell's law
4. Critical angle
5. Total internal reflection

Notice:

Speed of light (vacuum)	$c = 2.998 \times 10^{8}$ m/s
Plank's constant	$h = 6.626 \times 10^{-34} J$
Electronic charge	$e = 1.602 \times 10^{-19} C$
Boltzmann's constant	$k = 1.38 \times 10^{-23} JK^{-1}$

GOOD LUCK

Solution

Q1:

(a)

1. Drift time of carriers through the depletion region: The speed of response of a photodiode is fundamentally limited by the time it takes photogenerated carriers to drift across the depletion region. When the field in the depletion region exceeds a saturation value, the carriers may be assumed to travel at a constant (maximum) drift velocity υ_d. The longest transit time, t_{drift}, is for carriers, which must traverse the full depletion layer width w and is given by:

$$t_{drift} = \frac{W}{v_d}$$

2. Diffusion time: of carriers generated outside the depletion region. Carrier diffusion is a comparatively slow process where the time taken, t_{diff}, for carriers to diffuse a distance d may be written as:

$$t_{diff} = \frac{d^2}{2D_c}$$

where Dc is the minority carrier diffusion coefficient.

3. Time constant incurred by the capacitance of the photodiode with its load. A reverse biased photodiode exhibits a voltage-dependent capacitance caused by the variation in the stored charge at the junction. The junction capacitance Cj is given by:

$$C_j = \frac{\varepsilon_s A}{W}$$

where ε_s is the permittivity of the semiconductor material and A is the diode junction area.

(b)

$$\eta_{pc} = \frac{P_c}{P} = \frac{190 \times 10^{-6}}{25 \times 10^{-3} \times 1.5} = 5.1 \times 10^{-3}$$

Q2:

(a)

Optical fibers suffer radiation losses at bends or curves on their paths. This is due to the energy in the evanescent field at the bend exceeding the velocity of light in the cladding and hence the guidance mechanism is inhibited, which causes light energy to be radiated from the fiber. An illustration of this situation is shown in the figure below:

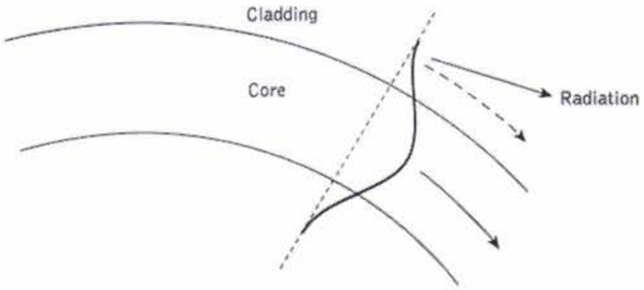
The above criteria for the reduction of bend losses also apply to SMF, the critical radius of curvature for a SMF R_{CSMF} can be estimated as:

$$R_{CSMF} = \frac{20\lambda}{(n_1 - n_2)^{3/2}} \left(2.748 - 0.996\frac{\lambda}{\lambda_C}\right)^{-3}$$

where λc is the cutoff wavelength for the SMF.

Furthermore, large bending losses tend to occur in multimode fibers at a critical radius of curvature R_{CMMF} which may be estimated from:

$$R_{CMMF} = \frac{3n_1^2\lambda}{4\pi(n_1^2 - n_2^2)^{1/2}}$$



(b)

$$NA = n_0 sin\theta_a \Rightarrow \theta_a = sin^{-1}\left(\frac{NA}{n_0}\right) = sin^{-1}\left(\frac{0.2}{1.33}\right) = 8.64^o$$

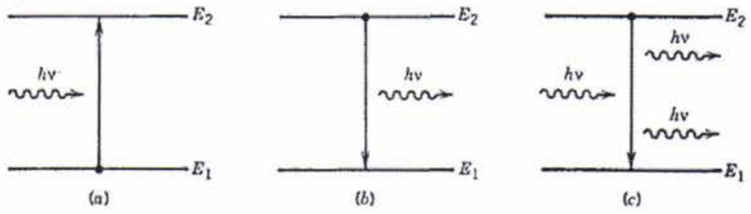
$$NA = (n_1^2 - n_2^2)^{\frac{1}{2}} \Rightarrow n_1 = \sqrt{NA^2 + n_2^2} = \sqrt{0.04 + 2.5281} = 1.6$$

$$\emptyset_c = sin^{-1}\left(\frac{n_2}{n_1}\right) = sin^{-1}\left(\frac{1.59}{1.6}\right) = 83.59^o$$

Q3:

(a)

An electron sitting in the conduction band can drop down into a hole in the valence band, thereby returning an atom to its neutral state. This process is called recombination (**or electron-hole pair recombination**), since an electron recombines with a hole. This recombination process releases energy in the form of a photon and is the basis by which a source emits light.



(b)

$$(1)\lambda = \frac{hc}{E} = \frac{6.626\times10^{-34}\times2.998\times10^8}{1.5\times10^{-19}} = 1.32\ \mu m$$

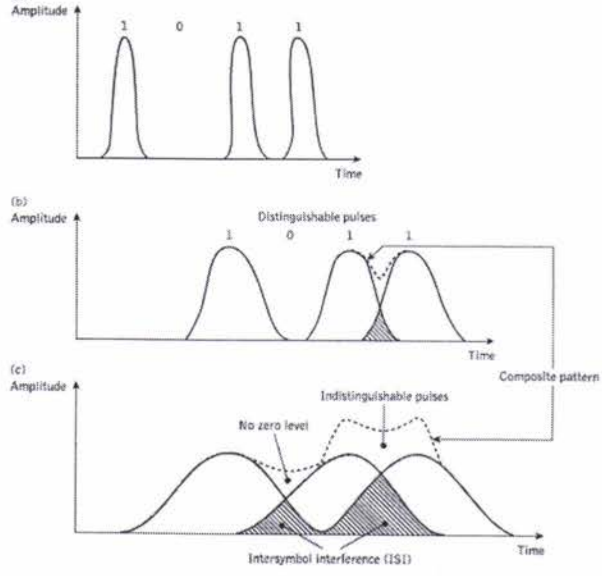
$$(2)R = \frac{\eta e}{hf} = \frac{0.65\times1.602\times10^{-19}}{1.5\times10^{-19}} = 0.694\ AW^{-1}$$

$$R = \frac{I_P}{P_o} \Rightarrow P_o = \frac{I_P}{R} = \frac{25\times10^{-6}}{0.694} = 36.02\ \mu W$$

Q4:

(a)

The phenomenon is illustrated in the figure below, where it may be observed that each pulse broadens and overlaps with its neighbors, eventually becoming indistinguishable at the receiver input. The effect is known as intersymbol interference (ISI).



(b)

1. **Interface circuit**

The **interface circuit** accepts the incoming electrical signal and processes it to make it compatible with the source drive circuit.

2. Source drive circuit.

The **source drive circuit** intensity modulates the optical source by varying the current through the source.

3. Optical source.

An **optical source converts** electrical energy (current) into optical energy (light).

Q5.

~~Q1) B~~/ Answer

Solution : **Given data :** $\phi_1 = 33^\circ$ and $\phi_2 = 90^\circ$

Assume refractive index of air = 1.00

According to Snell's law

$$n_1 \sin \phi_1 = n_2 \sin \phi_2$$

Suppose n_1 is refractive index of glass.

n_2 is refractive index of air = 1.0

$$n_2 \sin \phi_2 = n_1 \sin \phi_1$$

$$n_1 = \frac{n_2 \sin \phi_2}{\sin \phi_1} = \frac{\sin 90}{\sin \phi_1}$$

Refractive index of glass = n_1 = **1.836**

From definition of critical angle, $\phi_2 = 90^\circ$ and $\phi_1 = \phi_c$

$$\sin \phi_c = \frac{n_2}{n_1} \sin 90^\circ$$

$$\sin \phi_c = \frac{1}{1.836} \sin 90^\circ$$

$$= 0.54$$

$$\phi_c = \sin^{-1}(0.54)$$

$$\phi_c = 32.68^\circ$$

Critical angle = **32.68°**

Q6

Reflection

- The law of reflection states that, when a light ray is incident upon a reflective surface at some incident angle ϕ_1 from imaginary perpendicular normal, the ray will be reflected from the surface at some angle ϕ_2 from normal which is equal to the angle of incidence.

3 Refractive Index

- The amount of refraction or bending that occurs at the interface of two materials of different densities is usually expressed as refractive index of two materials. Refractive index is also known as **index of refraction** and is denoted by n.
- Based on material density, the refractive index is expressed as the ratio of the velocity of light in free space to the velocity of light of the dielectric material (substance).

$$\text{Refractive index } n = \frac{\text{Speed of light in air}}{\text{Speed of light in medium}} = \frac{c}{v}$$

The refractive index for vacuum and air is 1.0 for water it is 1.3 and for glass refractive index is 1.5.

Snell's Law

- Snell's law states how light ray reacts when it meets the interface of two media having different indexes of refraction.
- Let the two medias have refractive indexes n_1 and n_2 where $n_1 > n_2$.

ϕ_1 and ϕ_2 be the angles of incidence and angle of refraction respectively. Then according to Snell's law, a relationship exists between the refractive index of both materials given by,

TIR total internal reflection

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 (ϕ_2) is equal to angle of incidence (ϕ_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 :

The refractive index of first medium must be greater than the refractive index of second one.

The angle of incidence must be greater than (or equal to) the critical angle.

Critical angle

- When the angle of incidence (ϕ_1) is progressively increased, there will be progressive increase of refractive angle (ϕ_2). At some condition (ϕ_1) the refractive angle (ϕ_2) becomes 90° to the normal. When this happens the refracted light ray travels along the interface. The angle of incidence (ϕ_1) at the point at which the refractive angle (ϕ_2) becomes 90° is called **the critical angle**. It is denoted by ϕ_c.
- The **critical angle** is defined as the minimum angle of incidence (ϕ_1) at which the ray strikes the interface of two media and causes an angle of refraction (ϕ_2) equal to 90°. Fig. 1.6.5 shows critical angle refraction.