Set - D

1) Given the parameters, $\eta = 70\%$, $\lambda = 900nm$ & an optical input power of $0.7\ \mu W$, producing a multiplied photocurrent of $12\ \mu A$. Calculate the multiplication factor M.

Given

$\eta = 70\%$ $\lambda = 900nm$ $P_{in} = 0.7\ \mu W$ $I_M = 12\ \mu A$

$I_p = R \cdot P_{in}$

$R = \frac{\eta q \lambda}{hc}$

$$= \frac{(0.7)(1.6 \times 10^{-19})(9 \times 10^{-7})}{(6.625 \times 10^{-34})(3 \times 10^{8})} (7 \times 10^{-7})$$

$\boxed{I_p \rightarrow 0.355\ \mu A}$

Multiplication factor, $M = \frac{I_M}{I_p} = \frac{12\ \mu A}{0.355\ \mu A} = 33.8$

$\boxed{M \approx 34}$

∴ The primary photocurrent is multiplied by a factor of 34.

2) A research team is working on improving the efficiency of a planar LED fabricated from GaAs, which has a refractive index of 3.6. To evaluate its performance, they need to assess how much of the internally generated optical power is effectively emitted into the air & how efficiently electrical power is converted into useful light output.

a) Given that the transmission factor at the crystal - air interface is 0.68, calculate the optical power emitted into air as a percentage of the internal optical power for the GaAs LED.

b) If the optical power generated internally accounts for 50% of the electric power supplied to the device, determine the external power efficiency, considering the transmission losses at the crystal - air interface.

Optical power emitted into air as a percentage of internal optical power.

The amount of optical power emitted into air is affected by total internal reflection (TIR) due to the high refractive index of GaAs ($n = 3.6$) and the transmission factor at the crystal - air interface ($T = 0.68$).

a)
step 1: Calculate the escape cone angle

Light can only escape if it falls within the critical angle (θ_c) given by Snell's law:

$$\sin\theta_c = \frac{n_{air}}{n_{GaAs}} = \frac{1.0}{3.6}$$

$$= 0.2778$$

$$\sin\theta_c = 0.2778$$

$$\theta_c = \sin^{-1}(0.2778)$$

$$\boxed{\theta_c \simeq 16.2^{\circ}}$$

The fraction of internally generated optical power that can escape is given by:

$$\eta_{escape} = \frac{1}{2}\left(1 - \cos\theta_c\right)$$

$$= \frac{1}{2}\left(1 - \cos 16.2^\circ\right)$$

$$= \frac{1}{2}\left(1 - 0.961\right)$$

$$= \frac{1}{2}\left(0.039\right)$$

$$= 0.0195$$

$$= 1.95\%$$

since only 1.95 % of the internally generated optical power reaches the interface, and 68 % of that power is transmitted, the total emitted power fraction is :

$$\eta_{emitted} = \eta_{escape} \times T$$

$$= 0.0195 \times 0.68$$

$$= 0.0133$$

$$= 1.33\%$$

Thus, only 1.33 % of the internal optical power is emitted into air.

b) External Power Efficiency

The external power efficiency ($\eta_{external}$) is defined as the ratio of the emitted optical power to the supplied electrical power

Step 1: Calculate Internal Optical Power fraction

We are given that the internally generated optical power accounts for 50% of the supplied electrical power:

$$\eta_{internal} = 50\% = 0.50$$

Step 2: Apply Transmission losses

Since only 1.33% of the internally generated optical power is emitted into air, the external efficiency is:

$$\eta_{external} = \eta_{internal} \times \eta_{emitted}$$

$$= 0.50 \times 0.0133$$

$$= 0.00665 \text{ (or) } 0.665\%$$

Thus, the external power efficiency of the GaAs LED is 0.665%.

3) Write the conditions for achieving a higher S/N value in a photodetector circuit. Assume an InGaAs p-i-n photodiode is operating at room temperature (300 K) at a wavelength of 1.3 μm. Its quantum efficiency is 70% & the incident optical power is 500 nW. Assume that the primary dark current I_d of the device is 5 nA, R_L is 1 KΩ, and the effective bandwidth is 25 MHz. Calculate (a) the rms values of shot noise current, dark current, and thermal noise current. (b) S/N at the input end of an amplifier of the receiver.

The condition for achieving a higher SNR value in a photodetector circuit:

(i) The photodetector should have high quantum efficiency and low noise so that it generates large signal power

(ii) The amplifier noise should be kept low.

a) Primary Photocurrent:

$$I_p = R \cdot P_{in}$$

$$= \frac{\eta q \lambda}{hc} \cdot P_{in}$$

$$= \frac{0.70 \times 1.6 \times 10^{-19} \times 1.3 \times 10^{-6}}{6.626 \times 10^{-34} \times 3 \times 10^{8}} \cdot 500 \times 10^{-19}$$

$$= 3.663 \times 10^{-7} \text{ A}$$

$$= 0.3662 \ \mu\text{A}$$

Shot noise current:

$$(i_s^2) = 2 q I_p B$$

$$= 2 \times 1.6 \times 10^{-19} \times 3.663 \times 10^{-7} \times 25 \times 10^{6}$$

$$= 293 \times 10^{-20} \text{ A}^2$$

$$(i_s^2)^{\frac{1}{2}} = 17.15 \times 10^{-10} \text{ A}$$

$$\Rightarrow 1.715 \text{ nA}$$

ste Dark Current noise :

$$\langle i_d^2 \rangle = 2 q I_D B$$

$$= 2 \times 1.6 \times 10^{-19} \times 5 \times 10^{-9} \times 25 \times 10^{6}$$

$$= 400 \times 10^{-22} \, A^2$$

$$\langle i_d^2 \rangle^{\frac{1}{2}} = 20 \times 10^{-11} \, A$$

$$= 0.2 \, nA$$

Thermal noise current :

$$\langle i_T^2 \rangle = \frac{4 K_B T}{R_L} B$$

$$= \frac{4 \times 1.38 \times 10^{-23} \times 300}{1000} \times 25 \times 10^{6}$$

$$= 414 \times 10^{-19} \, A^2$$

$$\langle i_T^2 \rangle^{\frac{1}{2}} = 20.34 \, nA$$

b) Sum of mean square noise currents $= 41698.16 \times 10^{-20} \, A^2$

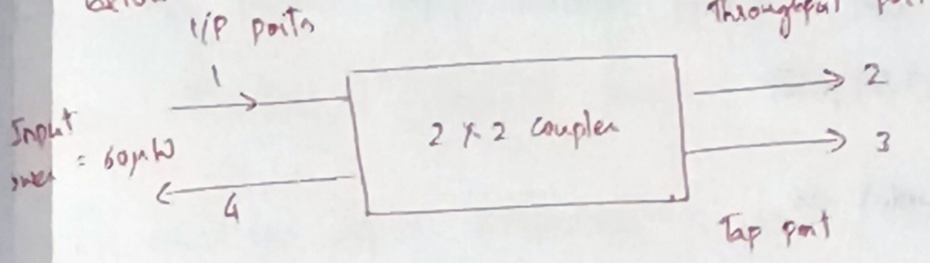
$$= 4.17 \times 10^{-6} \, A^2$$

and $I_p^2 = 1.352 \times 10^{-13} \, A^2$

$$\frac{S}{N} = \frac{1.352 \times 10^{-13}}{4.17 \times 10^{-6}} = 0.324 \times 10^{3}$$

$$\Rightarrow 324$$

4) Calculate the output power at each port in the coupler shown below:



coupler specification:

Excess loss = 1 dB

Splitting ratio = 3 : 1

Directionality loss = -40 dB

What is the value of the output power at each port?

Given:

$P_{in} = 60 \mu W$ (at port 1)

excess loss = 1 dB

Ratio : 3:1 (Throughput port gets 75%, tap port gets 25%)

Directionality loss = -40 dB (Negligible)

Calculate power after excess loss

The excess loss of 1 dB represents the total power loss due to imperfections in the coupler.

$$P_{after loss} = P_{in} \times 10^{-\left(\frac{\text{Excess loss (dB)}}{10}\right)}$$

$$= 60 \times 10^{-\left(\frac{1}{10}\right)}$$

$$10^{-0.1} \approx 0.794$$

$$P_{after loss} = 60 \times 0.794 \Rightarrow 47.64 \mu W$$

The splitting ratio of 3:1 means that port 2 (throughport) receives 3 parts and port 3 (Tap) receives 1 part of the available power (i.e. 47.64 μW)

The total power is split as:

$$P_2 = \frac{3}{3+1} \times P_{afterloss} \Rightarrow \frac{3}{4} \times 47.64$$

$$\Rightarrow 35.73\,\mu W$$

$$P_3 = \frac{1}{3+1} \times P_{afterloss} \Rightarrow \frac{1}{4} \times 47.64$$

$$\Rightarrow 11.91\,\mu W$$

Directionality loss at port 4:

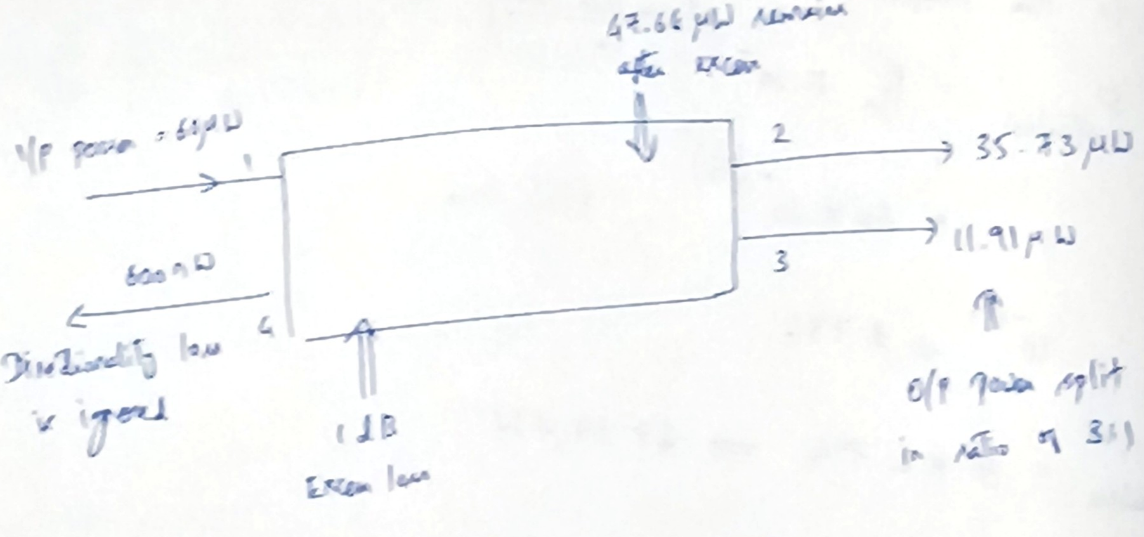
loss is −40 dB means the power at port 4 is:

$$P_4 = P_1 \times 10^{-\left(\frac{40}{10}\right)}$$

$$= P_1 \times 10^{-4}$$

$$= 60 \times 10^{-4}$$

$$= 0.006\,\mu W \Rightarrow 600\ nW$$



Power at port 2 (throughput port) = 35.73 μW

Power at port 3 (Tap port) = 11.91 μW

Power at port 4 (Negligible power) = 600 nW

Total power loss due to excess loss = $60 - (35.73 + 11.91)$

$= 12.36 \mu W$

Thus, the excess loss reduces the total power before the coupler distributes it based on the 3:1 ratio.

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