Tutorial 3

Exercise 1: Responsivity and quantum efficiency

1. Calculate the responsivity of a photodiode that has a quantum efficiency of 70% at a wavelength of 850 nm.
2. Propose a circuit that can measure the responsivity and quantum efficiency
3. Based on the last questions how can increase the quantum efficiency up to 85%.

Use the formulas bellow that apply generally for most common Photodiodes.

Quantum Efficiency ratio $\eta = \frac{Number\ of\ collected\ electrons}{Number\ of\ incident\ photons}$

Responsivity $R = \frac{I_P}{P_{in}} = \frac{\text{Current output } (I_P)}{\text{Incident optical power } (P_{in})} = \frac{\eta.q}{h.\nu} = \frac{\eta.q.\lambda}{h.c}$

Exercise 2: Photoconductors and Gain

A specialized semiconductor material is used as a photoconductor. It has a carrier lifetime $\tau = 10\mu s$ and an internal electron transit time $\tau_{tr} = 100ns$. The device is illuminated with a light source that provides a photon flux $\Phi = 5 \times 10^{14} photons/sec$ and has a quantum efficiency $\eta = 0.80$

1. If the carrier lifetime in a photoconductor is $\tau = 10\ \mu s$ and the electron transit time across the device is $\tau_{tr} = 100\ ns$, what is the gain?
2. Why Photoconductors are unique?
3. Determine the primary photocurrent (Ip):
4. Calculate the total current and analyze System Sensitivity if the transit time increase to $400ns$
5. Propose a circuit to analyze the system sensitivity

We can use the formulas $G = \frac{\tau}{\tau_{tr}}$ and $I_P = q.\eta.\Phi.G$

Exercise 3: Avalanche Photodiodes (APD)

1. An APD with a breakdown voltage of 100V is biased at 95V. If n =3, what is the internal gain M?
2. Explain the multiplication process in the APDs.
3. Recalculate the factor M for higher voltage 98V
4. Analyze the sensitivity performance

We can use this formula Factor $M = \frac{I_{multiplied}}{I_{primary}} = \frac{1}{1-\left(\frac{V_R}{V_{BR}}\right)^n}$.

V_R is reverse bias, V_{BR} is breakdown voltage, and n is a material constant called Miller coefficient.

Exercise 4: Phototransistors

A phototransistor gain $\beta = 150$. If the light-generated base current is $2\mu A$

1. Find the collector current (ignore dark current).
2. If we collect an actual $I_C = 310\mu\text{A}$ what is the dark current value?
3. Propose a circuit to evaluate the consequences of a dark current

The phototransistor uses the transistor's common-emitter current gain β to amplify the base photocurrent: $I_C = (\beta + 1). I_\lambda + I_{\text{dark}}$

I_λ is the primary photocurrent generated at the base-collector junction

Exercise 5: Smart Streetlight Sensor

A common-emitter phototransistor circuit is designed to trigger a logic high (5V) when it detects dusk.

1. Calculate the Primary Responsivity ($\boldsymbol{R}$)

2. Calculate the Base Photocurrent ($\boldsymbol{I_\lambda}$)

3. Calculate the Total Collector Current ($\boldsymbol{I_C}$)

4. Calculate the Final Output Voltage ($\boldsymbol{V_{out}}$)

5. Propose a circuit for this purpose

Data: $\lambda = 600\text{nm}$; $P_{in} = 10\mu\text{W}$; $\eta = 65\%$; $\beta = 120$; Load resistor $R_L = 10K\Omega$; $V_{CC} = 12V$ and $I_{dark} = 50nA$

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