EXP. NO: 9.1 D.C. CHARACTERISTICS OF PIN PHOTODIODE

9.1.1 OBJECTIVE

To study the characteristics of the given Photo Detector at zero-bias, Forward Bias and Reverse Bias conditions.

9.1.2 HARDWARE NEEDED

OFT power supply, A digital multi-meter, PD Module, Benchmark Fiber Optic Power Source, Benchmark Fiber Optic Power Meter, 1m Patch cord (PSTO-PC-1), 1 M,10K resistors, 10K, 6.8K, 4.7K, 3.3K, 3.9K & 2.2K resistors (for reverse bias),Ambient light arrester.

9.1.3 INTRODUCTION

A **photodiode** is a type of photodetector capable of converting light into either current or voltage, depending upon the mode of operation.

Photodiodes are similar to regular semiconductor diodes except that they may be either exposed (to detect vacuum UV or X-rays) or packaged with a window or optical fiber connection to allow light to reach the sensitive part of the device. Many diodes designed for use specifically as a photodiode will also use a PIN junction rather than the typical PN junction.

A photodiode is a PN junction or PIN structure. When a photon of sufficient energy strikes the diode, it excites an electron, thereby creating a mobile electron and a positively charged electron hole. If the absorption occurs in the junction's depletion region, or one diffusion length away from it, these carriers are swept from the junction by the built-in field of the depletion region. Thus holes move toward the anode, and electrons toward the cathode, and a photocurrent is produced.

Photovoltaic mode

When used in zero bias or photovoltaic mode, the flow of photocurrent out of the device is restricted and a voltage builds up. The diode becomes forward biased and "dark current" begins to flow across the junction in the direction opposite to the photocurrent. This mode is responsible for the photovoltaic effect, which is the basis for solar cells—in fact, a solar cell is just a large area photodiode.

Photoconductive mode

In this mode the diode is often reverse biased, dramatically reducing the response time at the expense of increased noise. This increases the width of the depletion layer, which decreases the junction's capacitance resulting in faster response times. The reverse bias induces only a small amount of current (known as saturation or back current) along its direction while the photocurrent remains virtually the same. The photocurrent is linearly proportional to the illuminance.

Critical performance parameters of a photodiode include:

Responsivity

The ratio of generated photocurrent to incident light power, typically expressed in A/W when used in photoconductive mode. The responsivity may also be expressed as a *quantum efficiency*, or the ratio of the number of photo generated carriers to incident photons and thus a unitless quantity.

Dark Current

The current through the photodiode in the absence of light, when it is operated in photoconductive mode. The dark current includes photocurrent generated by background radiation and the saturation current of the semiconductor junction. Dark current must be accounted for by calibration if a photodiode is used to make an accurate optical power measurement, and it is also a source of noise when a photodiode is used in an optical communication system.

Noise-Equivalent Power

(NEP) The minimum input optical power to generate photocurrent, equal to the rms noise current in a 1 hertz bandwidth. The related characteristic *detectivity* (D) is the inverse of NEP, 1/NEP; The NEP is roughly the minimum detectable input power of a photodiode. When a photodiode is used in an optical communication system, these parameters contribute to the *sensitivity* of the optical receiver, which is the minimum input power required for the receiver to achieve a specified *bit error ratio*

9.1.4 PRELAB QUESTIONS

1. What is photo detector?
2. List some of the operating performance and requirements of optical detectors.
3. What is impact ionization?
4. Draw the simple model of a photo detector receiver.
5. What is the figure of merit of a photodetector?

9.1.5 PRECAUTION

Before switching between the bias modes, it is recommended to switch OFF the PD module and the power supply. This ensures that the voltages are not reversed or applied quickly to the PD. Failure to do so may result in permanent damage to PD and its power supply.

9.1.6 EXPERIMENT

9.1.6.1 PROCEDURE

Photo-detector at Zero bias

Connect the OFT power supply to the module using the DIN-DIN cable provided with the power supply. Set the bias switch to the zero bias configuration (Bias switch moved to the top most position). Turn the bias voltage varying pot in the PD module to its minimum position and switch ON the module. The zero bias LED lights up.

The module at the zero bias configuration is shown in Fig.1. The photodiode is given no bias voltage. The current induced by the photo-detector due to the incident optical power on to it, flows through the load resistor.

Photo detector setup

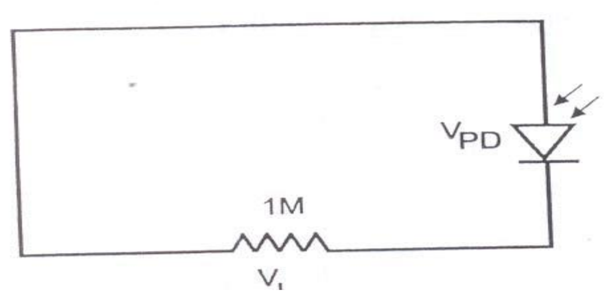

Figure 1 : PD with zero bias configuration

1. Put 1 M ohm resistor across V_L.
2. Connect the ST connector end of the patch cord supplied with the module to the power source.
3. Set the Power source in CW mode and to give maximum output power (refer Benchmark power source manual on how to adjust the power). Connect 1m patch cord between source and meter (use bare fiber adaptor – plastic at the power meter end) and measure this optical power P and adjust the power in source such that it reads -18dBm approx. Note down this power.
4. Slightly unscrew the black colored cap of the PD to loosen it without removing it from the connector assembly. Remove the patch cord from the power meter and gently push the fiber into the black cap until it is held in place. Now tighten the black cap by screwing it back. The fiber will now be held firmly in place. Now measure the voltage across V_1.
5. Vary the optical power P from -18dBm approx in steps of 5dBm.To reduce the power more than what the power source can attenuate remove the ST connector of the patch cord slightly that is connected to the power source. This gives the natural attenuation. Ensure that this loose connector is not disturbed while connecting and removing the patch cord between meter and PD. May be you can stick the cable on to the table with a sticking tape near the source. Tabulate the readings as follows:

9.1.6.2 TABULATION

S.No.	Power P dBm	Power P_0 μW	V_L Volts	I_z μA
1.				
2.				
3.				
4.				
5.				
6.				
7.				

8.				
9.				

$I_Z = V_L/1 \times 10^6$

9.1.6.3 MODEL GRAPH

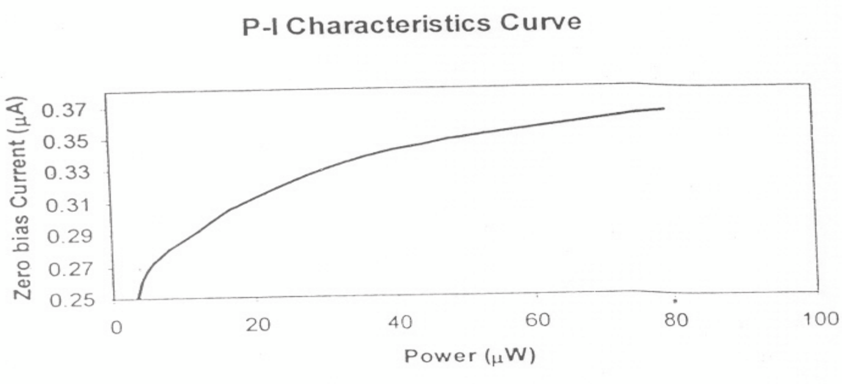

Figure 2 Power Vs Current graph

Photo-detector at Forward bias

Connect the OFT power supply to the module using the DIN-DIN cable provided with the power supply. Set the bias switch to the forward bias configuration (Bias switch moved tot eh middle position). Turn the bias voltage varying pot in the PD module to its minimum position and switch ON the module. The forward bias LED lights up.

The module at the forward bias configuration switches the photodiode to a basic configuration as shown in Fig.3. The photodiode is given forward bias voltage.

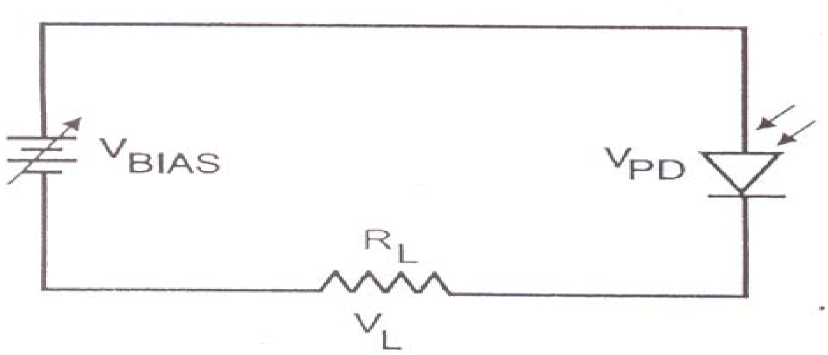

Figure 3: PD with forward bias configuration

1. Put 10K resistor across V_L.
2. Adjust the potentiometer and fix the bias voltage at 10V
3. Connect the ST connector end of the patch cord supplied with the module to the power source.
4. Set the Power source in CW mode and to give maximum output power (refer Benchmark power source manual on how to adjust the power). Connect 1m patch cord between source and meter (use bare fiber adaptor – plastic at the power meter end) and measure this optical power P and adjust the power in source such that it reads – 18dBm approx. Note down this power.
5. Slightly unscrew the black colored cap of the PD to loosen it, without removing it from the connector assembly. Remove the patch cord from the power meter and gently push the fiber into the black cap until it is held in place. Now tighten the black cap by screwing it back. The fiber will now be held firmly in place. Now measure the voltage V_L.
6. Vary the optical power P from – 18 dBm to -40 dBm approx in steps of 5dBm. To reduce the power more than what the power source can attenuate, remove the ST connector of the patch cord slightly that is connected to the power source. This gives the natural attenuation. Ensure that this loose connector is not disturbed while connecting and removing the patch cord between meter and PD. May be you can stick the cable on to the table with a sticking tape near the source. Tabulate the readings.
7. Plot the graph P vs I_f. The sample graph is shown in Fig.4

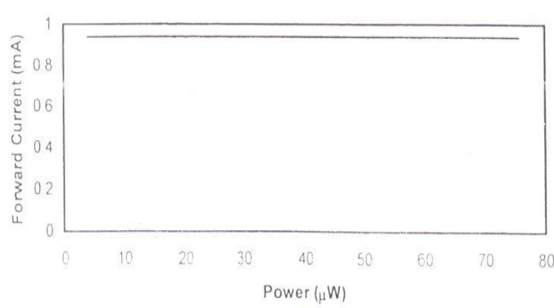

Figure 4 Power Vs Current graph

8. Now fix the power launched as – 20 dBm.

9. Vary the bias voltage from 2V to 10V by adjusting the potentiometer and measure V_L.

10. Tabulate the values and plot the graph V_{BIAS} Vs I_L. The sample graph is shown in Fig.5

Forward Voltage: -------------- V

$I_f = V_L/10 \times 10^3$

S.No.	**Power P dBm**	**Power P_0 μW**	**V_L V**	**I_f mA**
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				

Incident Power = ----------------dBm

S.No.	**Bias Voltage V_{BIAS} V**	**V_L V**	**I_f mA**

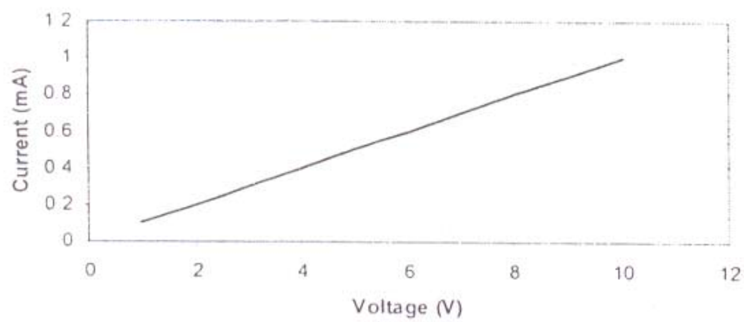

Fig. 5 Voltage Vs. Current graph

Photo-detector at Reverse Bias

Connect the OFT power supply to the module using the DIN-DIN cable provided with the power supply. Set the bias switch to the reverse bias configuration (Bias switch moved to the bottom most position). Turn the bias voltage varying pot in the PD module to its minimum position and switch ON the module. The reverse bias LED lights up.

The module at the reverse bias configuration switches the photodiode to a basic configuration as shown in Fig.6. The photodiode is given reverse bias voltage. The current induced by the photodiode due to the incident optical power on to it, flows through the load resistor.

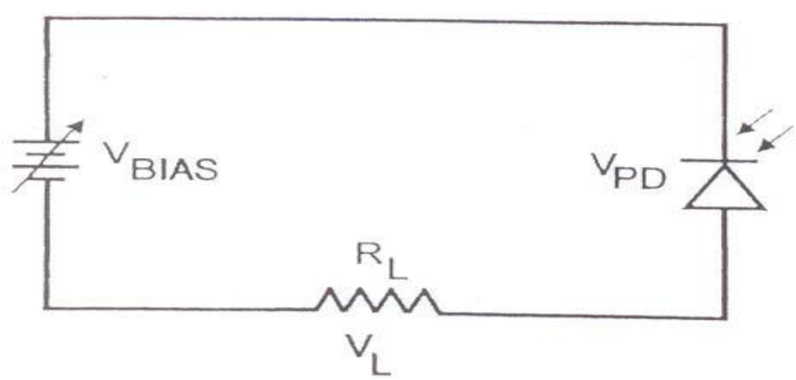

Figure 6: PD with reverse bias configuration

1. Put 10K resistor across V_L.
2. Adjust the potentiometer and fix the bias voltage at 10V.
3. Connect the ST connector end of the patch cord supplied with the module to the power source.
4. Set the Power source in CW mode and to give maximum output power (refer Benchmark power source manual on how to adjust the power). Connect 1m patch cord between source and meter (use bare fiber adaptor plastic at the power meter end) and measure this optical power P and adjust the power in source such that it reads –18dBm approx. Note down this power.
5. Slightly unscrew the black colored cap of the PD to loosen it, without removing it from the connector assembly. Remove the patch cord from the power meter and gently push the fiber into the black cap until it is held in place. Now tighten the black cap by screwing it back. The fiber will now be held firmly in place. Now measure the voltage V_L.
6. Vary the optical power P from – 18dBm to -40dBm approx in steps of 5dBm. To reduce the power more than what the power source can attenuate, remove the ST connector of the patch cord slightly that is connected to the power source. This gives the natural attenuation. Ensure that this loose connector is not disturbed while connecting and removing the patch cord between meter and PD. maybe you can stick the cable on to the table with a sticking tape near the source. Tabulate the readings as follows:
7. Plot the graph P vs I_R. The sample graph is shown in Figure 7.

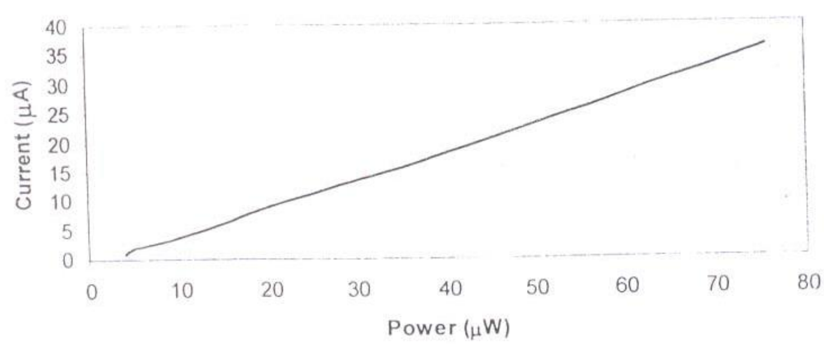

Figure 7: Power Vs Current graph

8. Now fix the power launched as – 20 dBm.

9. Vary the bias voltage from 2V to 10V by adjusting the potentiometer and measure V_L. Tabulate the values.

10. For each value of the bias voltage and current calculate the value of the responsivity from the formula. Are all the $R\lambda$ values approximately same? What do you infer from this?

    $R_\lambda = V_L/(R_L * P_S)$ A/W

    where P_S is the power in W.

11. From the average value of $R\lambda$ calculate the value of the quantum efficiency from the formula

$$\eta = R\lambda\ h\,\gamma / e \times 100\%$$

where $h = 6.624 \times 10^{-34}$ JS, is the Planck's constant

$\gamma = C/\lambda = 3 \times 10^{8} / 850 \times 10^{-9}$ Hz , is frequency of the incident photons

$e = 1.6 \times 10^{-19}$ Coulombs, is the electric charge

Repeat the above steps for various values of R_L 6.8K, 4.7K, 3.9K & 2.2K.

TABULATION:

Reverse Voltage = __V $I_r = V_L/10 \times 10^3$

S.No.	**Power P (dBm)**	**Power P mW**	**V_L V**	**I_R (mA)**
1.				
2.				
3.				
4.				
5.				
6.				
7.				

Incident Power = __________dBm

S.No.	Bias voltage V_{BIAS} (V)	V_L (V)	I_R (mA)	R_λ (A/W)	η (%)
1.					
2.					
3.					
4.					
5.					
6.					
7.					

Leakage Characteristics of Photo-detector

One among the important characteristics of a photodiode is its leakage characteristics when it is reverse biased. Since the leakage current through the photo-detector is normally very less, increased bias voltage and higher value of R_L is used in the module at the reverse bias configuration. The basic configuration of the PD module in leakage characteristics is shown in Fig.8.

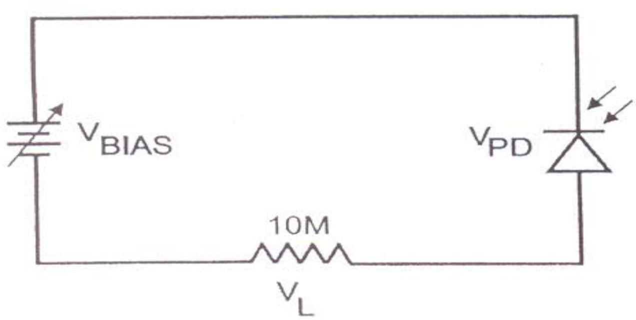

Figure 8: PD with leakage characteristics

Caution

Before switching between the bias modes, it is recommended to switch OFF the PD module and the power supply. This ensures that the voltages are not reversed or applied quickly to the PD. Failure to do so may result in permanent damage to PD and its power supply.

Procedure:

Connect the OFT power supply to the module using the DIN-DIN cable provided with the power supply. Set the bias switch to the reverse bias configuration (Bias switch moved to the bottom most position). Turn the bias voltage varying pot in the PD module to its minimum position and switch ON the module. The reverse bias LED lights up.

1. Put 10 M resistors across V_L.
2. Adjust the potentiometer and fix the bias voltage as 10V.
3. Screw in the free end of the ambient light arrester unit supplied with the module to the PD. This is done to avoid ambient light falling on the Photodiode.
4. Measure the voltage V_L.
5. Repeat the above procedure for various values of bias voltage and tabulate.
6. Plot the graph using V_{bias} and I_{dark} and the sample graph is shown in fig.9

$$I_{dark} = V_L / R_L \| R_m \text{ A}$$

where R_m is the multi-meter input impedance which is normally 10MΩ.

TABULATION:

S.No.	**V_{bias} (Volts)**	**V_L (Volts)**	**I_{dark} (nA)**
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			

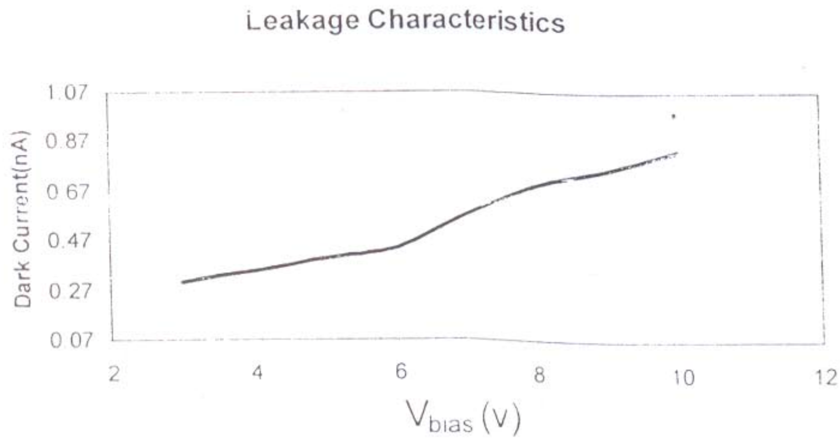

Figure 9. Voltage Vs Dark Current graph

9.1.7 POSTLAB QUESTIONS

1. Photo detector is a square law device. Justify.
2. What is quantum efficiency?
3. What is dark current?
4. Define noise equivalent power.
5. What is the cutoff wavelength of a photodetector? Give the expression.
6. An InGaAs PIN photodiode has the following parameters at a wavelength of 1300nm: I_D=4nA, η=0.90, R_L=1000Ω, and the surface leakage current is negligible. The incident optical power is 300Nw (-35dBm), and the receiver bandwidth is 20MHz. Find the various noise terms of the receiver.

9.1.8 RESULT

Thus the V-I characteristics of PIN photodiode has been studied and following parameters are determined.

Rλ =

η =

EXP. NO: 9.2 D.C. CHARACTERISTICS OF AVALANCHE PHOTODIODE

9.2.1 OBJECTIVE

To study the characteristics of the given avalanche photodiode at zero-bias and Reverse Bias conditions.

9.2.2 HARDWARE NEEDED

1. APD power supply
2. A digital multi-meter
3. APD Module
4. Benchmark Fiber Optic Power Source
5. Benchmark Fiber Optic Power Meter
7. ST-ST multimode patch cord (ST-PC-1)
8. Ambient light arrester

9.2.3 INTRODUCTION

Avalanche Photodiode, popularly called as APD, is a photo-detector that allows internal multiplication to take place and hence amplified current flows through it when its reverse bias is increased beyond certain point. APD allows normal PIN photodiode characteristics without any gain when operated under low voltage conditions.

A high gain, close to a factor of 100, is achievable when the reverse bias approaches close to its breakdown voltage. It is advisable not to cross the breakdown point as it will permanently damage the device.

APDs are high speed devices and also very highly sensitive. With its internal gain mechanism, these are useful for measuring very low value of optical power. Because of these characteristics, these are primarily used in very long-distance communications, OTDRs, WANs, optical measurements, etc,

Principle of Avalanche Multiplication

When light enters the photodiode, electron-hole pairs will be generated if the applied light energy is greater than the band gap energy of the photodiode when it is reverse biased. The movement of electron-hole pairs generates electric current in a photodiode. If the reverse bias voltage is increased, ionization of the carriers takes place thereby more number of electron-hole pairs will be generated. These newly created electron-hole pairs in turn undergo ionization and hence produce additional electron hole pairs and this continues like a chain reaction. This process of electron hole pair generation is referred as avalanche multiplication and this is the principle involved in APD. This avalanche multiplication in APD is a function of reverse bias voltage.

Light energy and the wavelength have a relationship as shown below

$\lambda = 1240nm / E$

E- band gap energy of the Si photodetector.

The band gap energy for Si is 1.12 eV at room temperature and hence Si photodetector are sensitive to light wavelength shorter than 1100nm.

9.2.4 PRELAB QUESTIONS

1. What is avalanche multiplication?
2. Draw RAPD (Reach through Avalanche Photodiode) structure and the electric fields in depletion and avalanche multiplication regions.
3. Compare the performance of Si-PIN and Si-APDs in terms of wavelength range, dark current and bias voltage.
4. Define avalanche multiplication noise.
5. List some practical applications of APD

9.2.5 PRECAUTION

Before switching between the bias modes, it is recommended to switch OFF the APD module and the power supply. This ensures that the voltages are not reversed or applied quickly to the APD. Failure to do so may result in permanent damage to APD and its power supply.

9.2.6 EXPERIMENT

9.2.6.1 PROCEDURE

APD at Zero bias

Connect the APD power supply properly to the module using the DIN-DIN cable provided with the power supply. Set the bias switch to the zero bias configuration. Turn the bias voltage varying pot in the APD module to its minimum position and switch ON the module. The zero bias LED lights up. The module at zero bias is shown in figure.1.

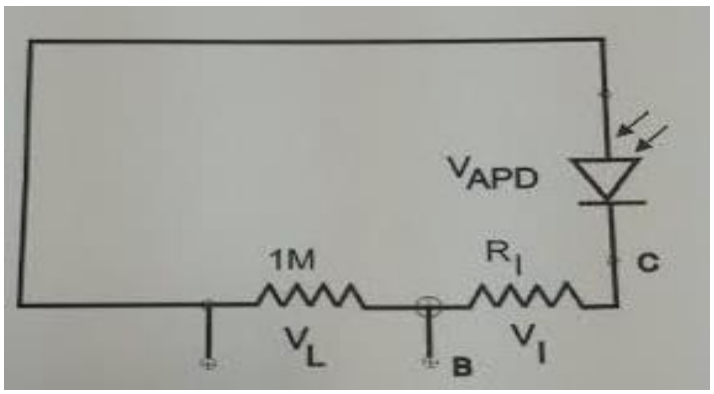

Figure 1 : APD with zero bias configuration

The photodiode is given no bias voltage. The current induced by the photo detector due to the incident optical power on to it, flows through the load resistor.

1. Put 1 M ohm resistor across VL.
2. Set the Power source in CW mode and to give maximum output power (refer Benchmark power source manual on how to adjust the power). Connect 1m ST-ST patch cord between source and meter (use bare fiber adaptor – plastic at the power meter end) and measure this optical power P and adjust the power in source such that it reads -18dBm approx. Note down this power and connect this patch cord between APD and power source. Measure the voltage across V_L.
3. Vary the optical power P from -18dBm to -40dBm approx in steps of 5dBm. To reduce the power more than what the power source can attenuate remove the ST connector of the patch cord slightly that is connected to the power source. This gives the natural attenuation. Ensure that this loose connector is not disturbed while connecting and removing the patch cord between meter and APD. Maybe you can stick the cable on to the

table with a sticking tape near the source. Tabulate the readings as follows:

9.2.6.2 TABULATION

V_{bias}=____

S.No.	**Power P** **dBm**	**V_L** **Volts**	**Power P_0** **µW**	**I_L** **µA**
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				

$I_Z = V_L/1 \times 10^6$

9.2.6.3 MODEL GRAPH

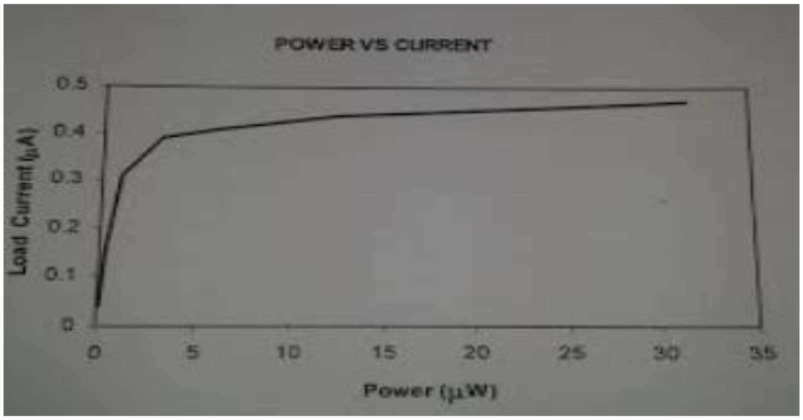

Figure 2 Power Vs Current graph

APD at Reverse Bias

Connect the APD power supply properly to the module using the DIN-DIN cable provided with the power supply. Set the bias switch to the reverse bias configuration. Turn the bias voltage varying pot in the APD module to its minimum position and switch ON the module. The reverse bias LED lights up.

The module at the reverse bias configuration switches the photodiode to a basic configuration as shown in Fig.3. This mode of operation is also called as photoconductive operation. The photodiode is given reverse bias voltage. The current induced by the photodiode due to the incident optical power on to it, flows through the load resistor.

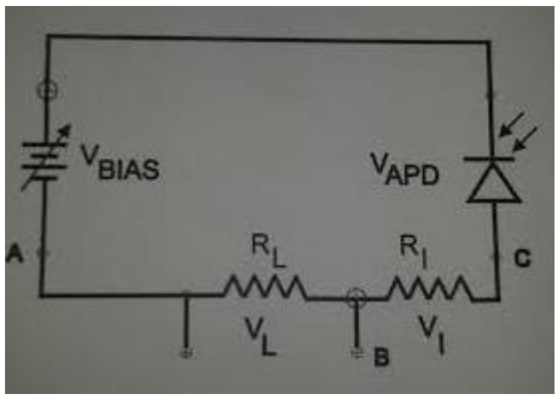

Figure 3: APD with reverse bias configuration

1. Put 1K resistor across V_L.
2. Set the Power source in CW mode and to give maximum output power (refer Benchmark power source manual on how to adjust the power). Connect 1m ST-ST patch cord between source and meter (use bare fiber adaptor plastic at the power meter end) and measure this optical power P and adjust the power in source such that it reads –18dBm approx. Note down this power and connect this patch cord between APD and power source. Set the APD bias to 10V by adjusting the bias pot. Measure the voltage across V_L.
3. Vary the bias voltage from 10V to 140V or to the maximum voltage that is possible in steps of 20V approx and note down the voltage across V_L and tabulate. Fix power P= -18dBm.
4. Plot the graph V_{Bias} Vs I_R. The sample graph for a load resistor of 100K and power of -15dBm is shown in Figure 4.

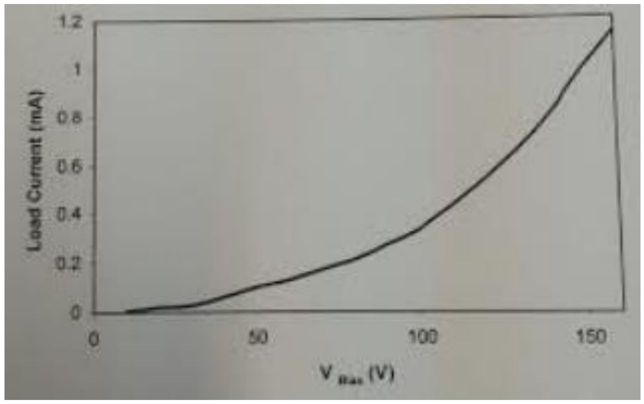

Figure 4: Bias Voltage Vs load Current graph

TABULATION:

Power

S.No.	**Bias Voltage V_{Bias} (V)**	**V_L (V)**	**I_R (mA)**	**R_λ (A/W)**	**$M=I_P/I_M$**
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					

5. From the table, for each value of the bias voltage and current, calculate the value of responsivity R_λ

   $R_\lambda = V_L/(R_L * P_S)$ A/W

   where P_S is the power in W.

6. From the value of $R\lambda$ calculate the value of the quantum efficiency from the formula

$$\eta = R\lambda \; h\,\gamma / e \times 100\%$$

where $h = 6.624 \times 10^{-34}$ JS, is the Planck's constant

$\gamma = C/\lambda = 3 \times 10^{8} / 850 \times 10^{-9}$ Hz , is frequency of the incident photons

$I_R = V_L / 1 \times 10^{3}$

$e = 1.6 \times 10^{-19}$ Coulombs, is the electric charge.

Leakage Characteristic of Avalanche Photo-detector

One among the important characteristic of a photodiode is its leakage characteristic when it is reverse biased. Since the leakage current through the photo detector is normally very less, increases bias voltage and higher value of R_L is used in the module at the reverse bias configuration. The basic configuration of the PD module in leakage characteristic is shown in Fig.5.

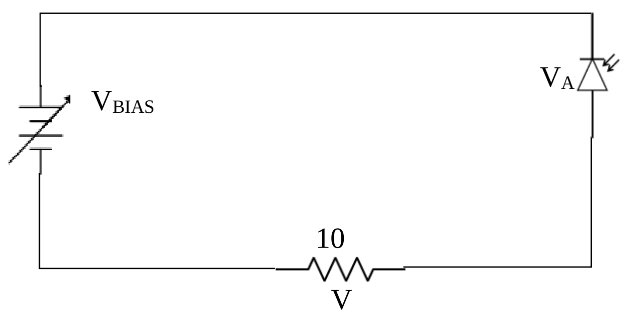

Figure 5: APD with leakage characteristics

Caution:

Before switching between the bias modes, it is recommended to switch OFF the PD module and the power supply. This ensure that the voltages are not reversed or applied quickly to the PD. Failure to do so may result in permanent damage to PD and its power supply.

Procedure:

Connect the OFT power supply to the module using the DIN-DIN cable provided with the power supply. Set the bias switch to the reverse bias configuration (Bias switch moved to the bottom most position). Turn the bias voltage varying pot the PD Module to its minimum position and switch ON the module. The reverse bias LED light up.

1. Put 10 M resistors across V_L.
2. Adjust the potentiometer and fix the bias voltage as 10V.

3. Screw in the free end of the ambient light arrester unit supplied with the module to the PD. This is done to avoid ambient light falling on the Photodiode.
4. Measure the voltage V_L
5. Repeat the above procedure for various values of bias voltage and tabulate.
6. Plot the graph using V_{bias} and I_{dark} and the sample graph is shown in Fig.5

$$I_{dark} = (V_L / R_L \| R_m)\ A$$

Where R_m is the multi-meter input impedance which is normally 10MΩ.

TABULATION:

S.No	**V_{bias}(Volt)**	**V_L (Volt)**	**I_{dark} (nA)**

9.2.7 POSTLAB QUESTIONS

7. Mention the major advantage of avalanche photodiode over PIN photodiode.
8. Write the expression for gain-bandwidth product of APD.
9. What is dark current?
10. What are the practical challenges that a designer undergoes while using APD?
11. Statement: Gain-bandwidth product is an important characteristic of an APD. Justify this statement. Why don’t we use this characteristic for p-i-n photodiode?

9.2.8 RESULT

Thus, the V-I characteristics of Avalanche photodiode has been studied and following parameters are determined.

$R\lambda$ =

η =

M =