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PHOTODIODE VARIABLE BIAS MODULE

USER MANUAL



Part Number: S101176

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WARRANTY

Ideal Vacuum warrants, to the original purchaser, this product to be free from defects in workmanship and materials, for a period of one (1) year from the original delivery date. The liability of Ideal Vacuum, under this warranty, is limited to servicing, adjusting, repairing or replacing any unit or component part which, at Ideal Vacuum's sole discretion, is determined to have failed during normal, intended use. This warranty does not cover improper installation, process related damage, product used in any way other than defined in this manual, or any misuse, abuse, negligence, accident, or customer modification to the product. Prior to returning any product, we require that you contact us by phone or email to determine if the issue can be resolved quickly. A technical support representative will try to resolve the problem. If we cannot resolve the issue quickly, we will issue an RMA number and provide product return instructions.

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This product is designed, engineered, and made in the USA with US and global materials.

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SAFETY

IMPORTANT SAFETY INFORMATION

Thank you for purchasing this equipment from Ideal Vacuum Products. We want you to operate it safely.

- **Read this manual before installing or operating this equipment. Failure to follow the warnings and instructions may result in serious injury or equipment damage.**
- **Keep this manual in a safe location for future reference.**
- **This equipment should only be installed and operated by trained, qualified personnel, wearing appropriate protective equipment.**



Always wear safety glasses and other appropriate protective equipment.

1. INTRODUCTION

The Ideal Spectroscopy™ photodiode variable bias module (S101176) is used to apply a reverse DC bias to an anode grounded photodiode to increase gain and linearity and improve response time. Included with the module is a universal 24 VDC power supply.

Photodiodes are light detectors used in many spectroscopy applications. The photodiode output may be monitored either by measuring the current produced or by applying a resistance to the photodiode output and measuring the voltage build up as current is impeded.

An unbiased photodiode acts as a photovoltaic device, which generates a single electron of current per excitation event. Photovoltaic operation is the simplest mode of action and has minimal dark current. Unfortunately, it suffers from low amplification, nonlinear voltage response over large dynamic ranges, requiring calibration for accurate measurements, and slow response due to a short depletion width and large junction capacitance. Unbiased photodiodes are best for slow or very low light applications.

Biasing photodiodes is best for applications where rapid time response or high linearity over a large range of light intensities is needed.

When photodiodes are reverse biased, their response changes from photovoltaic to photoconductive. Under reverse biasing, the depletion width increases, the junction capacitance decreases, and the response speeds up. The current response is amplified and becomes more linear over a larger dynamic range than in photovoltaic mode. The cost of these enhancements is increased dark noise and the propagation of electrical artifacts from the biasing power supply to the photodiode output signal. Therefore, a clean power supply like the one included with the module, or a high quality bench supply is critical for good response.

2. DIMENSIONS

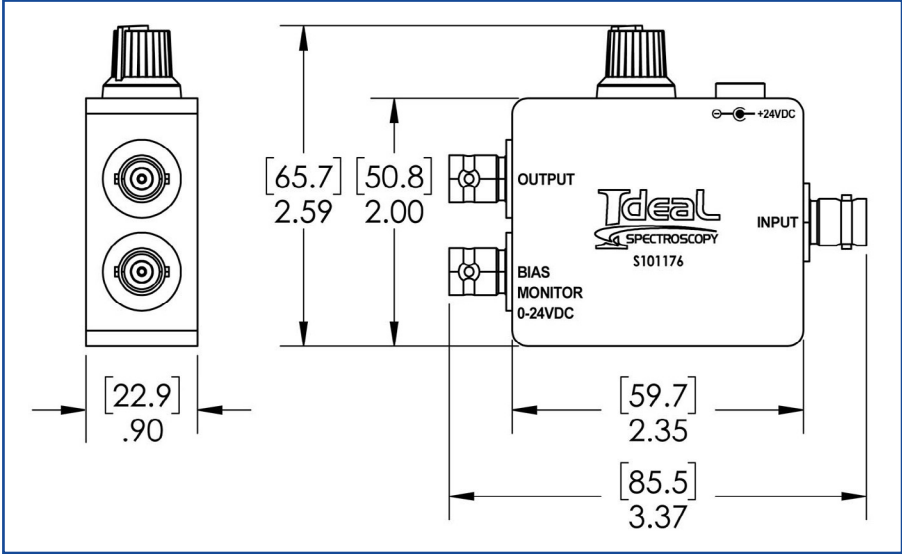


Figure 1 - Module dimensions

3. COMPONENTS

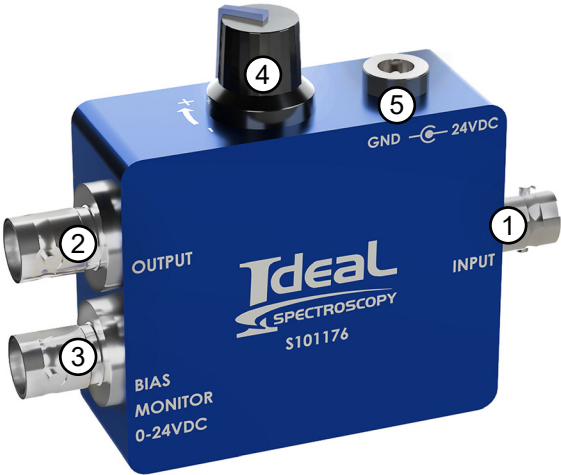


Figure 2 - Module isometric view

ITEM	Description
1	Photodiode input
2	Signal output
3	Bias monitor output
4	Bias adjustment knob
5	Power input (24 VDC)
6	Mounting point - #8-32 standard thread
7	Mounting point - M4-0.7 metric thread

Table 1 - Module component descriptions



Figure 3 - Module bottom view

4. SPECIFICATIONS

Parameter	Measure/Type
Compatible Photodiodes	Anode-grounded, photoconductive
Input Voltage	24 VDC nominal, regulated, <100 mV ripple preferred
Input Connection Type	Barrel Receptacle, 5.5 mm OD, 2.1 mm ID
Photodiode Bias Voltage	0.8 - 23.4 VDC, variable
Photodiode Bias Maximum Current	3 A, <100 mA typical
Photodiode Bias Load Regulation	±2% typical
Photodiode Bias Line Regulation	±1% typical
Photodiode Bias Ripple	<50 mV peak-peak at typical load
Photodiode Bias Connection	BNC female, center positive
Bias Monitor Voltage	0.8 - 23.4 VDC, variable
Bias Monitor Connection	BNC female
Output Voltage	0 - 5 V typical
Output Connection	BNC Female
Operating Temperatures	-40 to 85 °C
Operating Humidity	<85% RH non-condensing
Overall Dimensions	3.37 x 2.59 x .90 in. (85.5 x 65.7 x 22.9 mm)

Table 2 - Photodiode variable bias module specifications

Parameter	Measure/Type
Input Voltage	90 - 264 VAC
Input Frequency	47 - 63 Hz
Output Voltage	24.0 ± 1.2 VDC
Output Voltage Ripple & Noise	± 1% (240mVp-p Max)
Rated Output Current	2.5 A (48 W max)
Input Connector	NEMA 1-15P
Output Connector	Barrel, 5.5 mm OD, 2.1 mm ID
Output Connector Polarity	Center positive
Efficiency	DOE Level VI Compliant
Safety Approvals	UL60950-1, cUL60950-1
EMC Approvals	FCC
Cable Length	1 m

Table 3 - Module 24 VDC power supply specifications

5. PHOTODIODE COMPATIBILITY

The Ideal Spectroscopy photodiode variable bias module is compatible with most photodiodes. Performance will vary based on the photodiode used.

Photodiodes are preferably operated with reverse bias (anode grounded). It is important not to overbias a photodiode, especially in low light situations, since the increase in dark current and noise will hinder performance.

6. CONNECTIONS

Connect an anode grounded photodiode to the input female BNC connector. If a cathode grounded photodiode is used, its polarity must be changed with a suitable device, such as the [Pasternack PE9530 BNC Male to RP-BNC Female Adapter](#).

Connect the module's output to a voltage measuring device with a suitable voltage range.

Connect the module's bias monitor output to a voltage measuring device with a suitable voltage range.

7. PRINCIPLES OF PHOTODIODE BIASING

A photodiode in the dark is just a diode. When positive voltage (+ bias) is applied, it acts as a resistor and passes current through it. When a negative voltage (- bias) is applied, a photodiode acts as an insulator, and only very little current passes through it. A diode's performance can be characterized as a current-voltage relationship, also called an IV or JV curve.

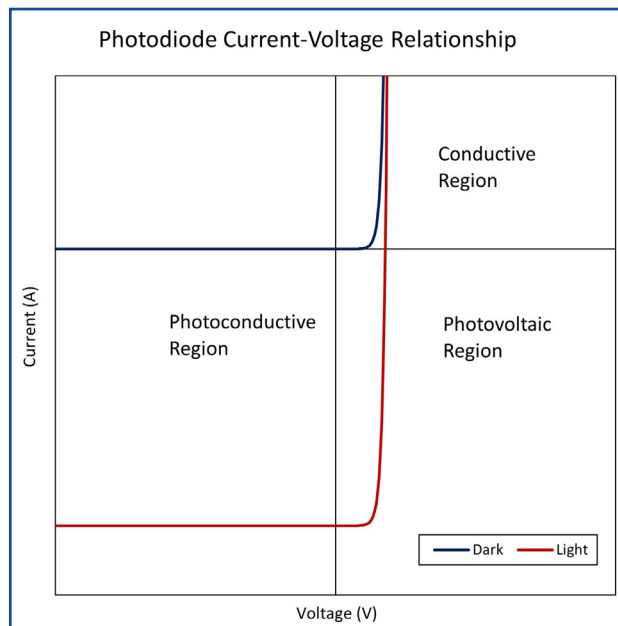


Figure 4 - Typical IV curves of a photodiode under different illumination levels

Electrically, a photodiode behaves differently than a simple diode. When a photodiode is subjected to light, its IV curve shifts. A power producing, or photovoltaic, region results. In this region, the photodiode generates a negative current, even against a positive bias. However, when a negative bias is applied, a photodiode becomes photoconductive, passing current only when illuminated.

8. PHOTOVOLTAIC MODE

The simplest method of using a photodiode is to connect it directly to a voltage measuring device. The (unbiased) photodiode acts in the photovoltaic region (Fig. 4, p. 8). When illuminated, it generates power and the measuring device measures its output voltage. Greater illumination results in greater output voltage. This method produces clean, consistent voltages with very little perturbation and requires no additional equipment.

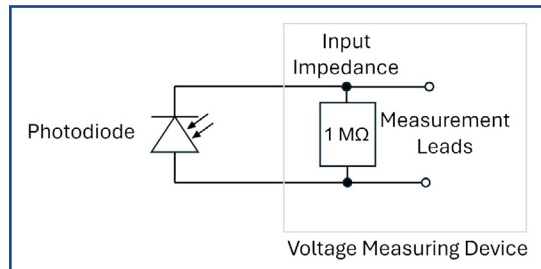


Figure 5 - Simple schematic of an unbiased photodiode in photovoltaic mode

This direct connection method works best for slow measurements (> 1 ms), and any voltage measuring device will suffice, even a handheld multimeter. Use a large-area photodiode, bandwidth filtering, and high impedance ($\sim 1\text{M}\Omega$). Cable length does not adversely effect measurements.

Unfortunately, the photodiode operates at the point on its IV curve where its output power equals the power dispersed by current flowing across the input impedance of the voltage measuring device. A higher input impedance produces a greater voltage, but a less linear response to varying illumination intensity. The higher input impedance along with the photodiode's intrinsic capacitance results in a larger circuit RC constant and slower response. This results in an undesirable tradeoff between measurement gain and measurement speed and linearity.

The figure below illustrates the typical IV curves of a photodiode under different illumination levels. 50Ω and 1000Ω input impedances are highlighted to illustrate that as input impedance increases, response nonlinearity also increases.

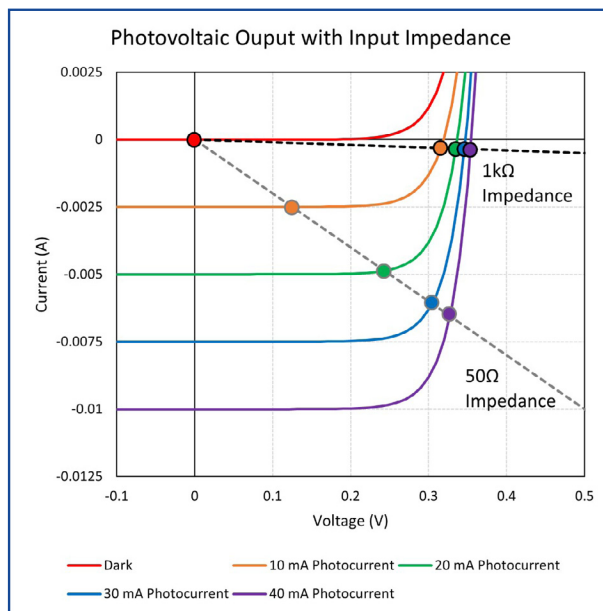


Figure 6 - Photovoltaic response at different illumination levels

9. PHOTCONDUCTIVE MODE

A photodiode may also be operated in photoconductive mode, where a reverse bias is applied to it. This is precisely what the Ideal Vacuum variable bias module does.

In photoconductive mode, the photodiode and a sense resistor are placed in series and a voltage source applies a reverse bias to them. The measuring device measures the power drop across the sense resistor instead of the photodiode. This allows the photodiode to pass current through the circuit where the amount of current passed is directly proportional to illumination level. The measured (output) voltage is the product of the combined resistance of the sense resistor and input impedance, and the photocurrent.

The reverse bias method works best for taking fast measurements, on the order of nanoseconds. It requires the use of a very stable power supply and a device that can measure fast responses, such as an oscilloscope ($\geq 250\text{MHz}$ or more). For best results, input impedance should be low ($\sim 50\Omega$), high quality, short cabling ($<1\text{m}$) should be used to reduce capacitance, and bandwidth filtering should not be employed.

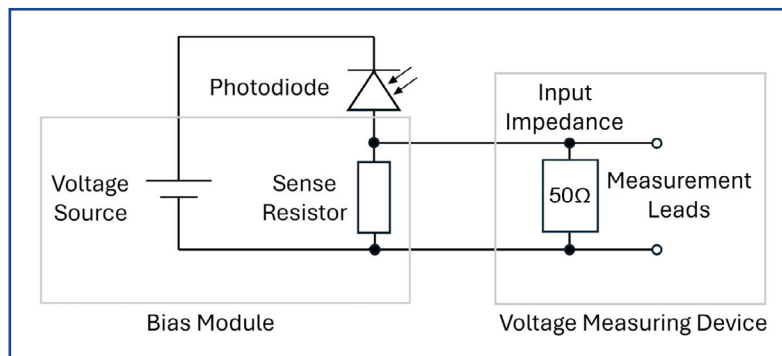


Figure 7 - Simple schematic of a reverse bias photodiode in photoconductive mode

There are many advantages to operating a photodiode in photoconductive mode using reverse bias. The measured voltage response is more linear to changes in light intensity. The maximum voltage response is equal to the bias voltage, which can result in a huge enhancement in gain. Operating a diode with a reverse bias reduces its intrinsic capacitance and RC time constant, which allows for faster measurements.

The primary disadvantage of operating in reverse bias mode is increased system complexity. The power supply and supporting electronics introduce electronic error and noise and increase dark current which can confound highly sensitive low light measurements.

If the total input impedance is too high, the measured voltage output can saturate below the dynamic range of the photodiode. This can be overcome by adding a lower valued shunt resistor or terminator between the bias module and the voltage measuring device, thereby reducing the total input impedance and increasing the dynamic range.

The figure below illustrates the typical IV curves of a photodiode under different illumination levels. 50Ω (dashed grey) and 1kΩ (dashed black) input impedances are highlighted to illustrate the high linearity of the photoconductive response.

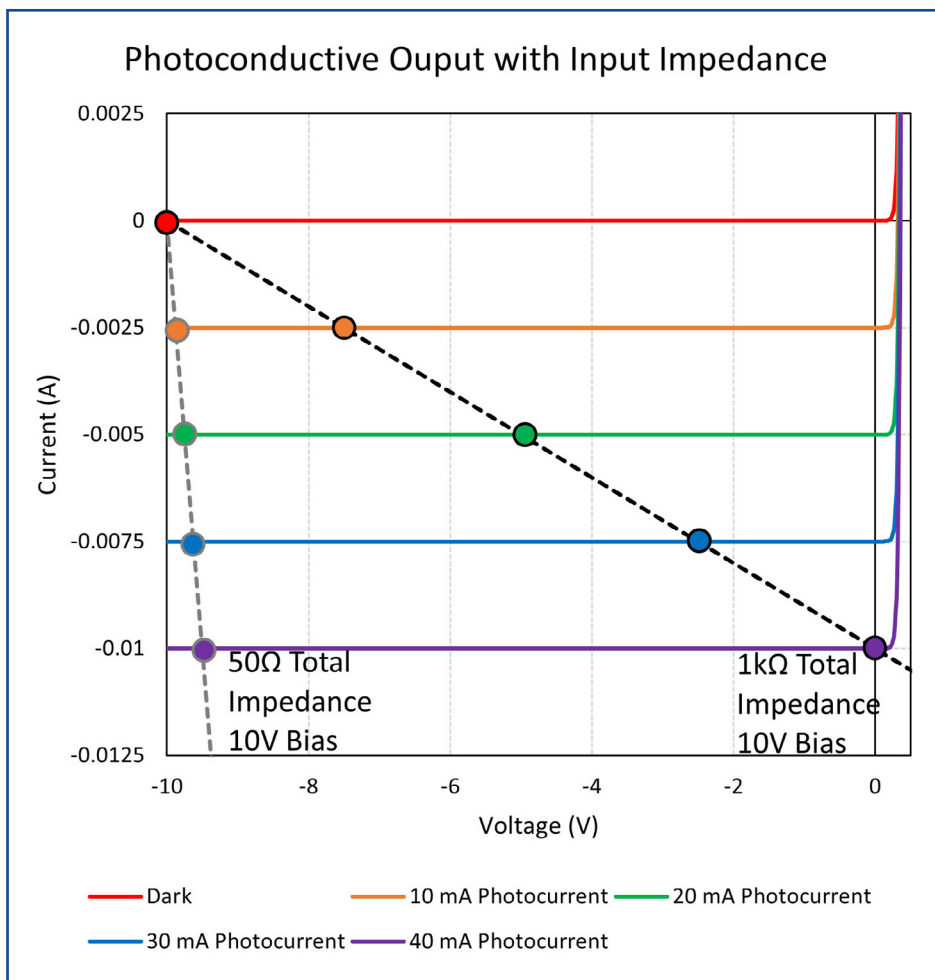


Figure 8 - Photoconductive response at different illumination levels

10. BIASED VS. UNBIASED SPEED RESPONSE TEST

The Ideal Vacuum variable bias module improves gain, rise time, fall time, and symmetric time response of fast photodiodes with minimum rise times of less than a nanosecond. Note that while the module is compatible with most photodiodes, its performance will vary based on the photodiode used.

Below is an actual example of laboratory tests which demonstrate the differences in speed response of an unbiased and a biased photodiode using the variable bias module.

A Thorlabs SM05PD2B mounted photodiode with a reported rise time of 1 ns at 830 nm at 10V reverse bias and a Tektronix MSO54 1GHz oscilloscope was used to measure a picosecond laser pulse train from a Time Bandwidth Products Lynx laser.

To achieve the maximum bandwidth output of the oscilloscope, the input impedance was set to 50Ω, DC coupled, with no bandwidth filtering. The laser pulses, with a duration on the order of picoseconds, was faster than the photodiode could measure. So, the temporal profile observed was entirely due to the photodiode, bias module, and detector.

The figure below illustrates oscilloscope traces of 2 consecutive picosecond laser pulses measured with a photodiode with a reported 1 ns rise time.

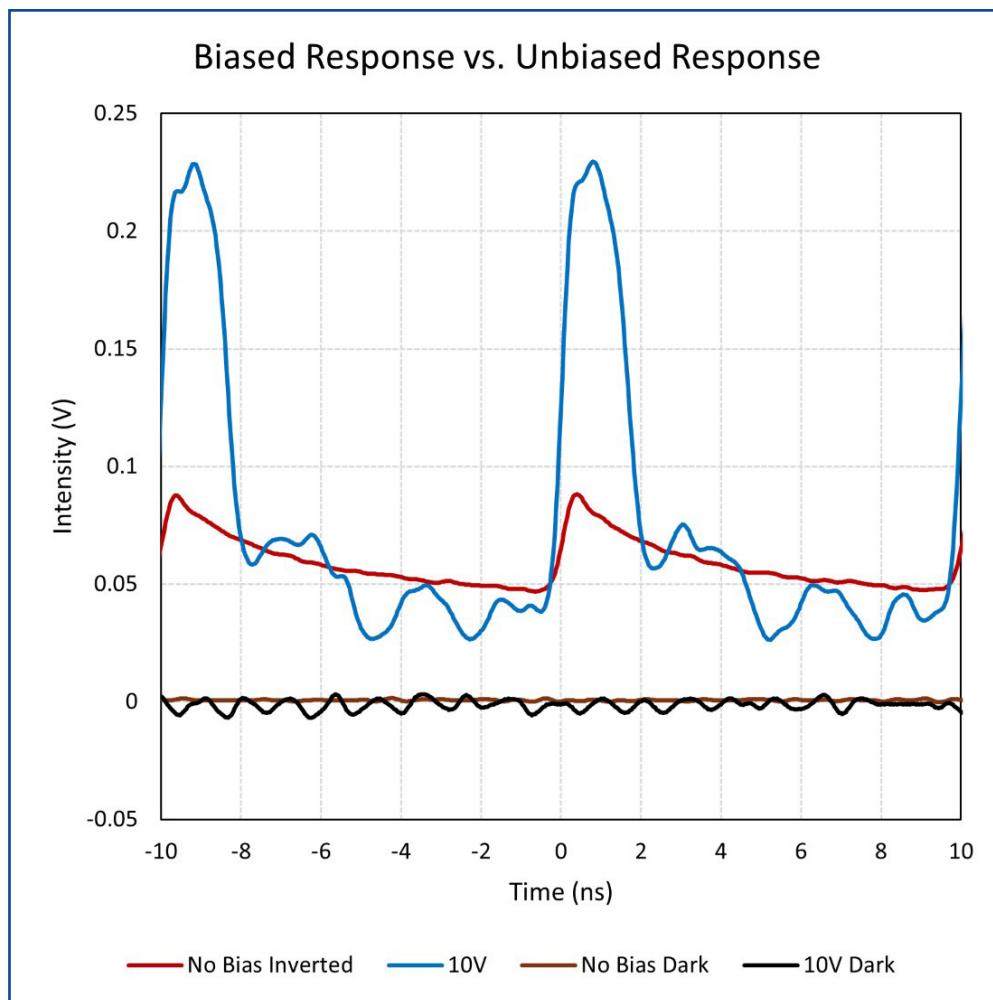


Figure 9 - Speed response of biased vs. unbiased Thorlabs SM05PD2B photodiode

Unbiased, the photodiode demonstrated a rise time of 0.8 ns from 10% to 90% of its peak value. However, its fall time was multiple nanoseconds longer, demonstrating an exponential-like decay typical of RC circuits. This asymmetric peak shape would distort fast signals such as mode beating in a nanosecond pulsed laser. Both the light and dark curves were very smooth, showing little noise or ringing effects.

With a 10V bias, the photodiode demonstrated a rise time of 0.5 ns from 10% to 90% of its peak value, better than the reported spec. The fall time was similar, resulting in a symmetric peak with a full width half max (FWHM) of less than 2 ns. The signal amplification due to use of the bias module was 4.5X. The bias module did introduce baseline ringing with a magnitude of ~ 10% of the peak signal that decayed over several nanoseconds. In the dark, a baseline oscillation with a magnitude of 10 mV and a frequency of 1GHz was visible due to the variable power supply. While use of a battery biased module would eliminate this oscillation, batteries must be checked and replaced frequently, or response quality will degrade. The power supply may be used continuously without fear of degradation.

The picosecond pulse train was measured at bias voltages from 0 to 20V and it was determined that a 5V bias was sufficient. Greater bias values did not improve signal-to-noise levels.

The laser pulse train was then measured with BNC coaxial cables of variable lengths between the photodiode and bias module, and between the bias module and the oscilloscope. All cables below 3' long performed equally well in both positions. With a 10' cable, there was noticeable distortion of the output signal.

11. BIASED VS. UNBIASED LINEARITY RESPONSE TEST

Below is an example of actual laboratory tests performed to demonstrate the differences in linearity and gain response of an unbiased and a biased photodiode using the variable bias module.

A Thorlabs SM05PD1B mounted photodiode was connected with an applied 20V reverse bias. A Tektronix MSO54 16 bit oscilloscope was used to measure a 632 nm beam generated by a power stabilized SpectraPhysics HeNe laser. The laser was attenuated by a series of calibrated neutral density filters to achieve 99 unique optical densities between 0 to 5.6 OD. To achieve the maximally stable output of the oscilloscope, the input impedance was set to 1M Ω , DC coupled, with 500 MHz bandwidth filtering.

As illustrated in the figure below, by using the variable bias module, a linear photodiode response over 5.3 orders of illumination magnitude with a 40x increase in gain relative to an unbiased photodiode was achieved.

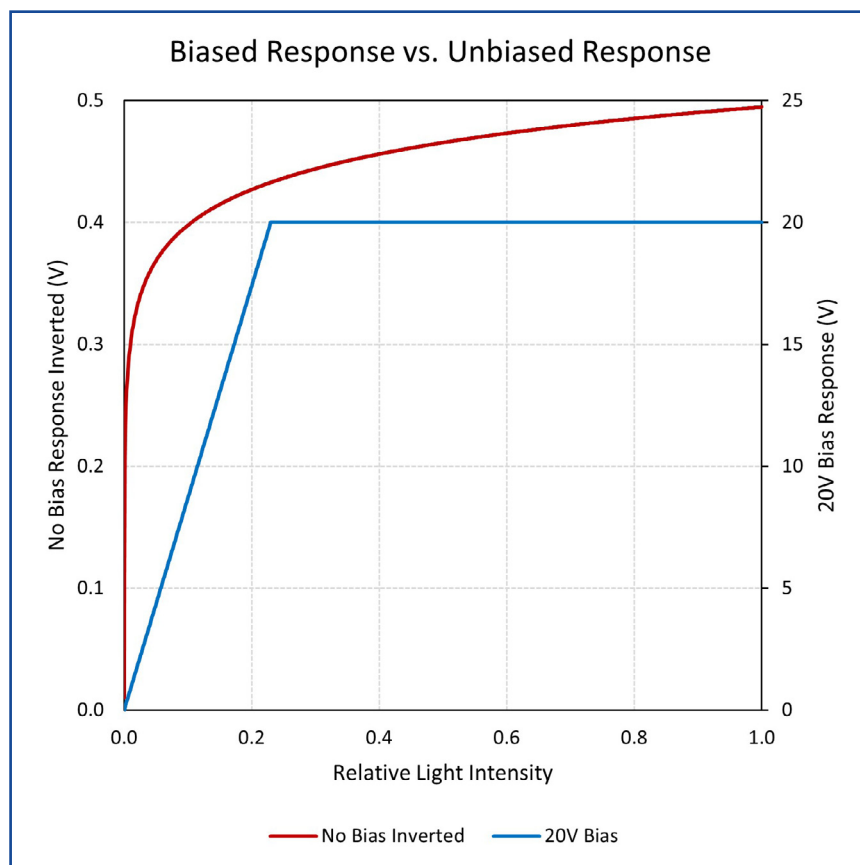


Figure 10 - Voltage response of biased vs. unbiased Thorlabs SM05PD1B photodiode

Unbiased, the photodiode exhibited a nearly logarithmic response over the full illumination intensity range with a maximum measured response of nearly 0.5 V. However, with a 20 V Bias, the photodiode and bias module demonstrated a nearly linear response. An R squared value of 0.98 with no systematic deviation was seen from the fit line beginning at 0.001 V to the full 20 V output and from a relative light intensity of 0 to 0.23. Above 20V, the photodiode saturated. Both biased and unbiased photodiode tests began with zero illumination with a minimum measurable output voltage of 0.0001 V. By adding a terminating resistor to lower the total impedance of the circuit, a greater portion of the light range could be measured without saturation.



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