Photodiode Amplifier*

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A photodiode is a light-sensing device made up of a P-N junction. It produces current as an output when photons are incident on the diode. A typical photodiode amplifier consists of a photodiode and transimpedance amplifier (Figure 1). The purpose of the transimpedance amplifier is to convert the current output of the sensor to a voltage which can then be passed onto other systems such as data acquisition systems (DAQ) or a multimeter.

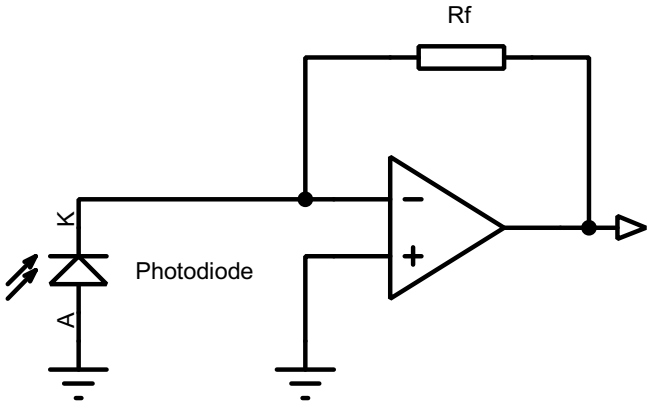


Figure 1: Current to voltage conversion using transimpedance amplifier.

1 Transimpedance Amplifier

An I-V converter is an example of a current-controlled voltage source, i.e., by controlling the input current, we can control the output voltage. An active I-V converter

can be made by using an operational amplifier (OP-AMP) with negative feedback in inverting converting configuration with the input connected to inverting terminal and fixing bias (typically grounded) at the non-inverting terminal of OP-AMP.

In such a configuration, the output of the OP-AMP circuit is proportional to the input current. This type of I-V converter is known as a transimpedance amplifier. The property of current-in and voltage-out is known as transimpedance in a two-port network. The gain is the change in output voltage to the change in input current and has units of resistance (Ω). The output voltage in Figure 1 is given as:

$$V_{out} = I_p R_f \tag{1}$$

where I_p is the current generated by the photodiode. By varying the value of the feedback resistance, we can amplify the current signal.

2 Operating instructions

To operate the photodiode (Figure 2a) you need to:

1. First, connect USB Type-C to USB-A 2.0 Male Charger Cable as this photodiode amplifier has a USB-C port (Figure 2b).
2. Input/Output ports consist of BNC terminators (Figure 2c).
3. The gain of the circuit can be modified by using the gain knob (Figure 2d). The table 1 lists the gain magnitude we can extract from our amplifier. By turning the knob, we change the feedback resistance connected between the J1 and J9 switches in the circuit (Figure 3).
4. While using the amplifier, user needs to be wary of saturating the amplifier. This device saturates at ≈ 3.25 V. Lower the gain setting if you see that the output is saturating. If the output is saturated even at the lowest gain setting, then the input signal needs to be attenuated.

Table 1: Gain knob settings.

gain setting	R_f (Ω)
10	10
10^2	100
10^3	1k
10^4	10k
10^5	100k
10^6	1M

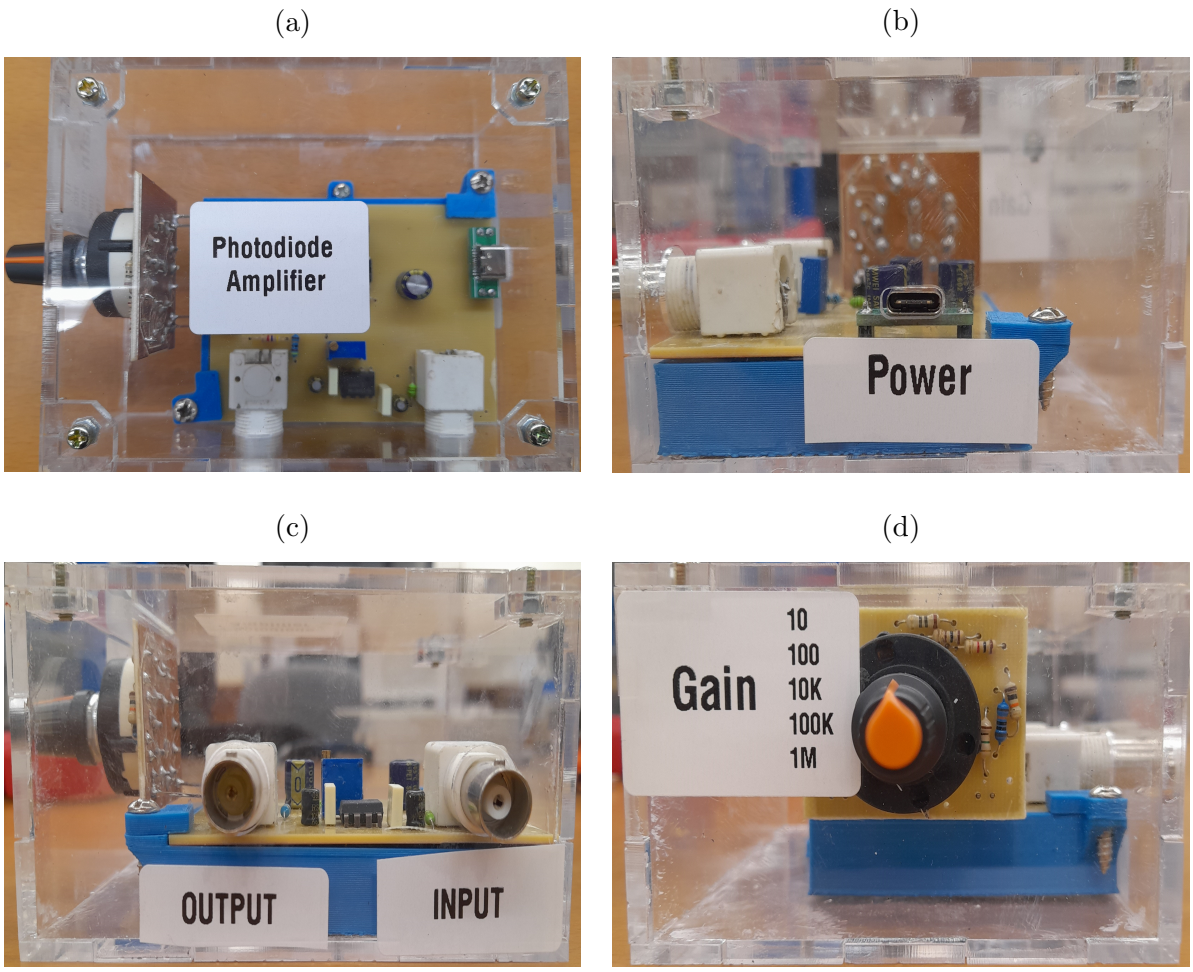


Figure 2: Various views of the photodiode amplifier device.

Figure 1 represents a simple model to explain the basic operation principle of the photodiode amplifier. In reality, we need to add many more electronic components such as capacitors and include multiple stages to make the circuit more robust. Figure 3 shows the schematic diagram of the photodiode amplifier we are using in this laboratory.

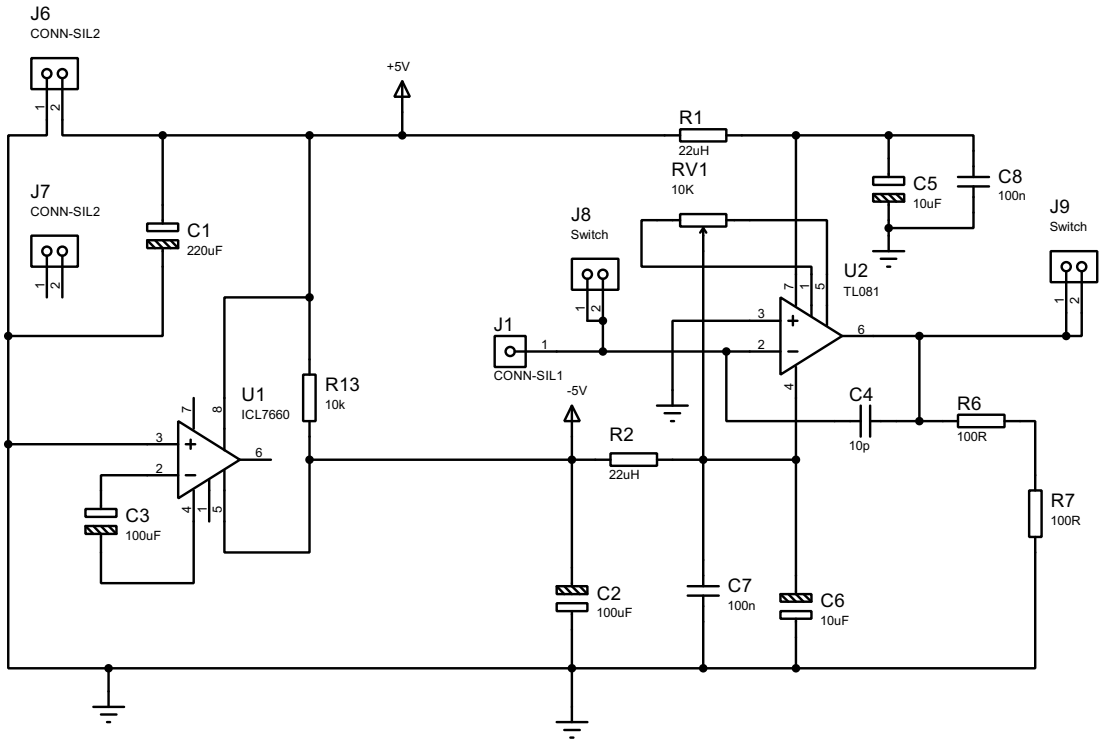


Figure 3: Photodiode Amplifier circuit schematic.

3 Device Testing

Two methods were used to test the performance of these photodiode amplifiers:

(a) Supply current of known magnitude and measure the output voltage. The gain of the circuit should match the set gain.

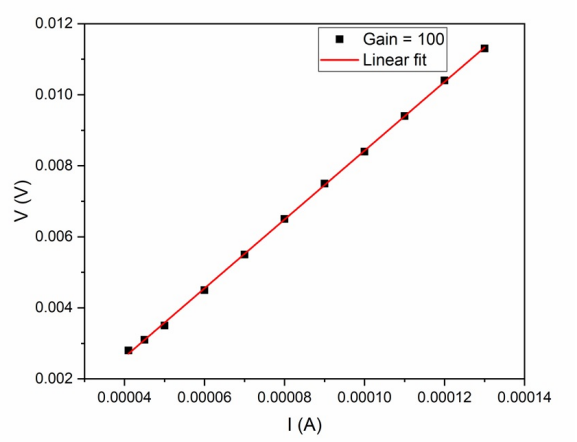
(b) Use the photodiode amplifier to convert the output of the photodetector into voltage and confirm if Malus' law is held up.

3.1 Constant current as an input

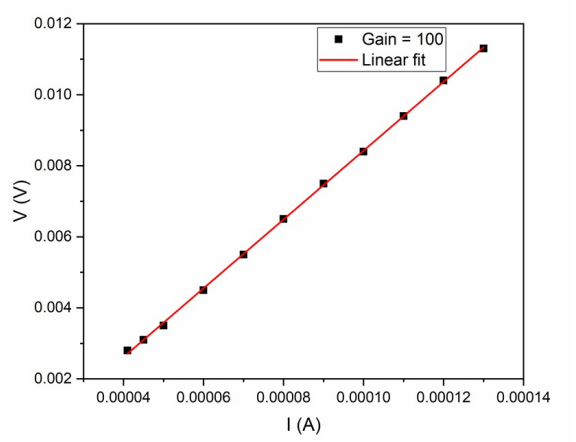
A constant current source with an output current range of 40 - 135 μA was used to drive the photodiode amplifier. Table 2 gives the output voltages at the gain setting of 10^2, 10^3 and 10^4. The output voltage at a gain setting of 10 was too low to be detected by our digital multimeter and saturated at gain settings of 10^5 and 10^6. All the voltages were negative but the sign has been dropped for convenience. The results are plotted in Figure 4. The slopes were found to be 96.9, 964, and 9505 respectively which are in close agreement with the gain setting values.

Table 2: Output voltages at different gain settings.

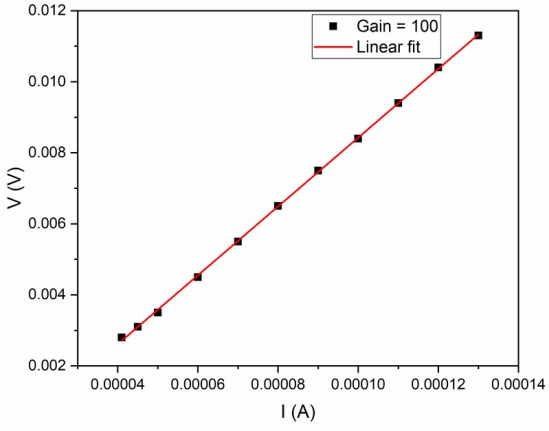
$I_{input}(A)$	$V_{out}(V)$	$V_{out}(V)$	$V_{out}(V)$
	Gain = 10^2	Gain = 10^3	Gain = 10^4
4.1E-5	0.0028	0.0414	0.414
4.5E-5	0.0031	0.0435	0.439
5E-5	0.0035	0.048	0.48
6E-5	0.0045	0.0582	0.583
7E-5	0.0055	0.0678	0.677
8E-5	0.0065	0.0777	0.775
9E-5	0.0075	0.0876	0.872
1E-4	0.0084	0.0968	0.964
1.1E-4	0.0094	0.1065	1.058
1.2E-4	0.0104	0.1163	1.153
1.3E-4	0.0113	0.1261	1.251



(a)



(b)

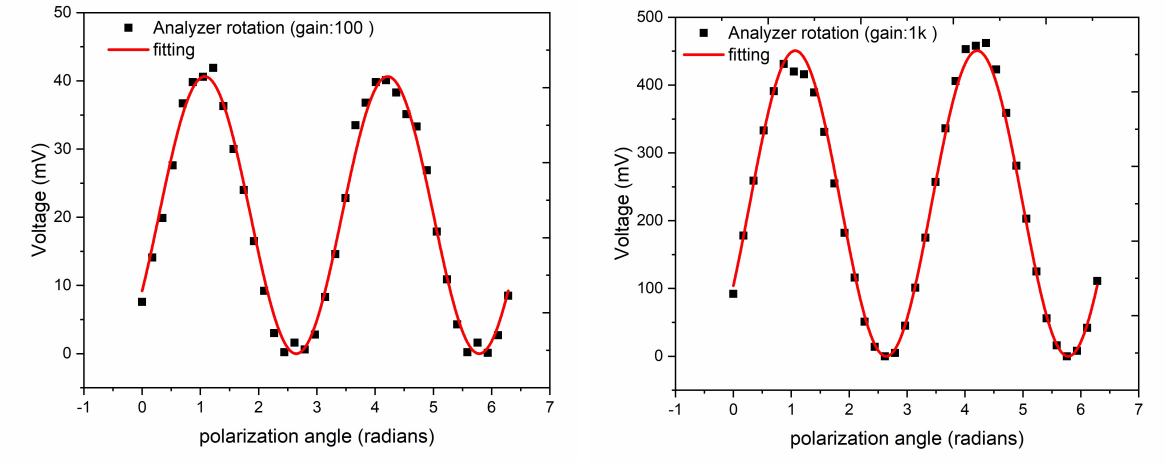


(c)

Figure 4: (a) Gain setting of 10^2, (b) gain setting of 10^3, and (c) gain setting of 10^4.

3.2 Malus' law verification using photodiode amplifier

We tested the built devices by inspecting if they obey Malus' law. For testing, we connected these devices at the output of the photodetector and measured the output voltage using a digital multimeter. The angle of the polarizer was fixed at 0° and the angle of the analyzer was varied from 0° to 360° with a step of 10°. The results are shown in Figure 5. Fitting was done using $cos^2(\theta)$ and the well-fitted results show that the device is indeed generating a voltage proportional to the intensity of light falling on the photodetector.



(a) (b)

Figure 5: (a) Gain setting of 10^2 and (b) gain setting of 10^3.