University of California, Davis

Electrical and Computer Engineering

EEC 1/89D

Introduction to Electrical and Computer Engineering

Part 2: Physical Electronics

LEDs, Photodiodes, and Transistors

Lab 3

Introduction:

a. Purpose/ Scope

In this lab you will work with three novel discrete semiconductor devices: the transistor, the light-emitting diode (LED), and the photodiode. The transistor is of course the workhorse of modern computing, and the LED and the photodiode are two very common optoelectronic devices. This lab is meant as a quick introduction to their functionality and usefulness in actual systems. During this lab, you characterize these devices and implement them in practical circuits.

b. Resources/Lab Materials

Resources, specifically Energia programs for controlling and monitoring voltages are provided. You will not be expected to write your own code during this lab.

Lab Materials:

- TI MSP432P401 LaunchPad Kit (Red kit) x1
- Breadboard x1
- Breadboard Booster Pack x1
- red LEDs x2
- green LED x1
- blue LED x1
- Jumper wires
- 330 Ohm resistor x3
- 100k Ohm resistor x1
- Potentiometer (POT) x1
- Photodiode x1
- Photoresistor x1
- Transistor PN2222A x1

Lab Exercises:

Part A: LED Testing

In this lab, you will need to test three light-emitting diodes (LEDs): red, blue, and green. You will be using the your ADALM as a power source and voltmeter throughout this exercise. LEDs take in electrical energy and then turn it into light. The electromagnetic spectrum, seen below, shows how the color of the wave is related to how much energy is in the wave.

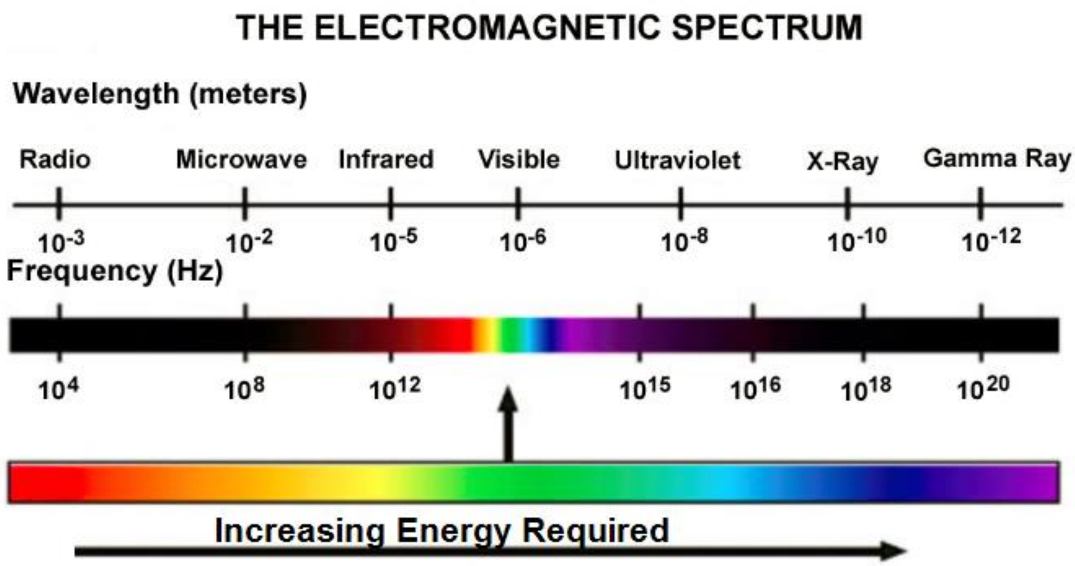
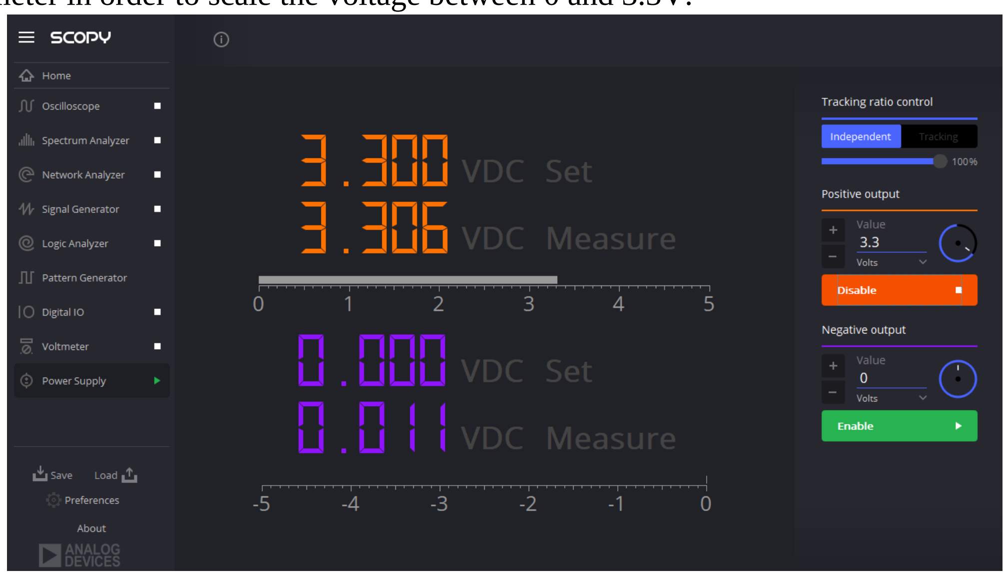


Fig. 1. Diagram of the electromagnetic spectrum

Step 1: Setup a circuit as shown in the figure below and run the Scopy voltmeter. Set the Scopy Power Supply to 3.3V as shown below. The circuit will use the 3.3V supply connected to the potentiometer in order to scale the voltage between 0 and 3.3V.



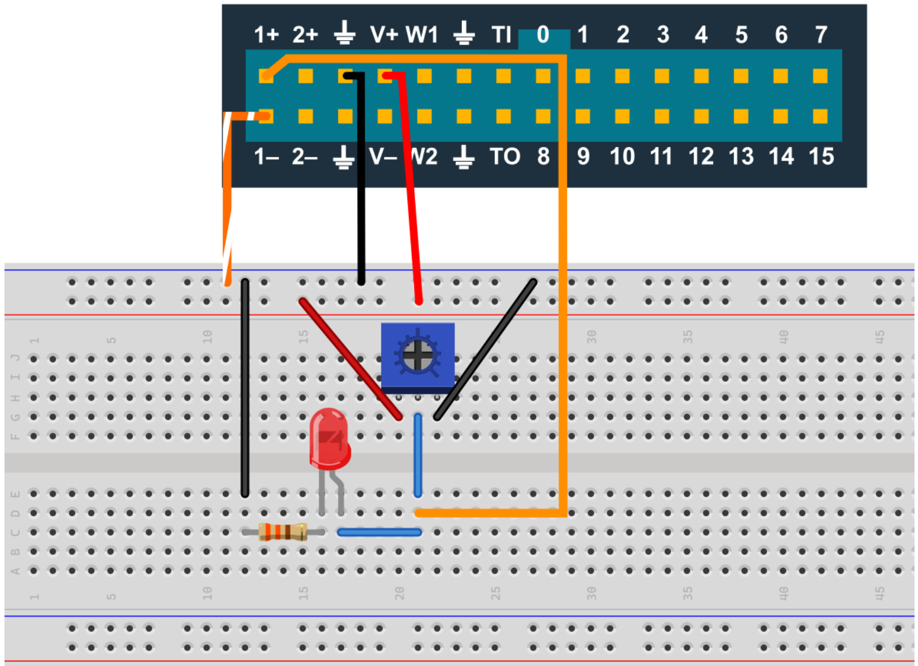


Fig. 2. Diagram of circuit for exercise 1

Step 2: Turn the potentiometer such that 0V are being applied to the LEDs. Now slowly increase the voltage delivered to the LEDs. In this exercise, we are interested in what the value of the voltage is as soon as the LED starts producing light.

SUBMISSIONS: Complete the table and questions below on Canvas.

1. Write down the exact voltage values when the LEDs <u>start</u> producing light (i.e. you can first see it).

LED	**RED**	**GREEN**	**BLUE**
On Voltage			

2. Which of the colors of light requires the least energy according to the diagram of the electromagnetic spectrum? Which requires the most?

3. Which LED required the least voltage to turn on? Which required the most?

4. Why do you think the LEDs turn on at different voltages?

5. What changes do you notice in the LEDs as the voltage increases above the "On Voltage"?

6. Now, connect two RED LEDs in ***parallel*** as shown below. Do you notice any changes in the turn on voltage or the intensity vs. when just one LED is connected? What are the changes? And why do you think they occur (or don't occur)?

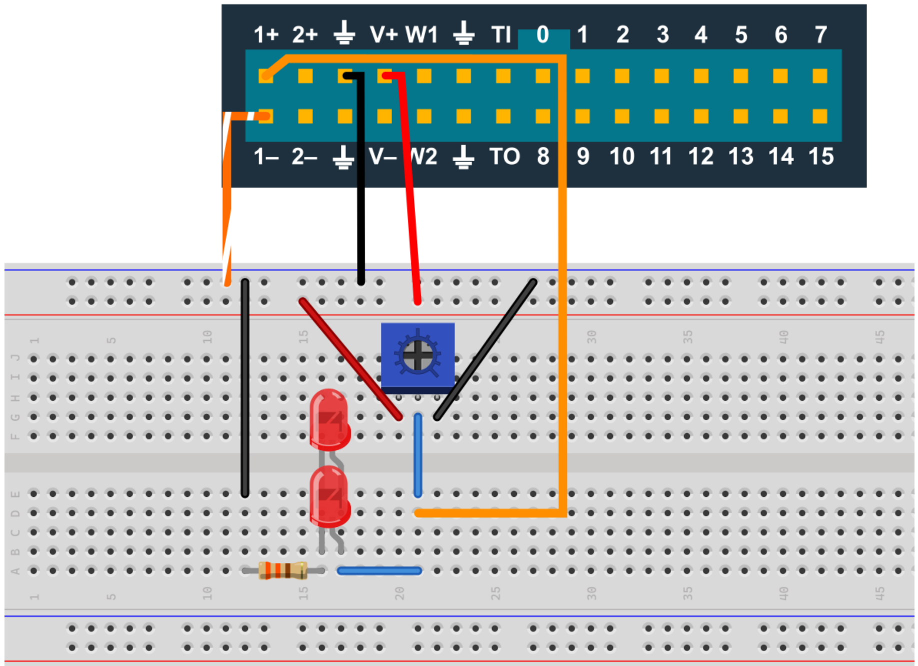


Fig. 3. Diagram for LEDs connected in parallel

7. Instead of connecting them in parallel connect them in ***series***. Note: for this question, change the Power Supply in Scopy from 3.3 V to 5 V, as shown below, and be careful not to turn the potentiometer knob to high as it can cause damage to the circuit. Now what changes do you notice in either intensity or turn on voltage? Again, explain why.

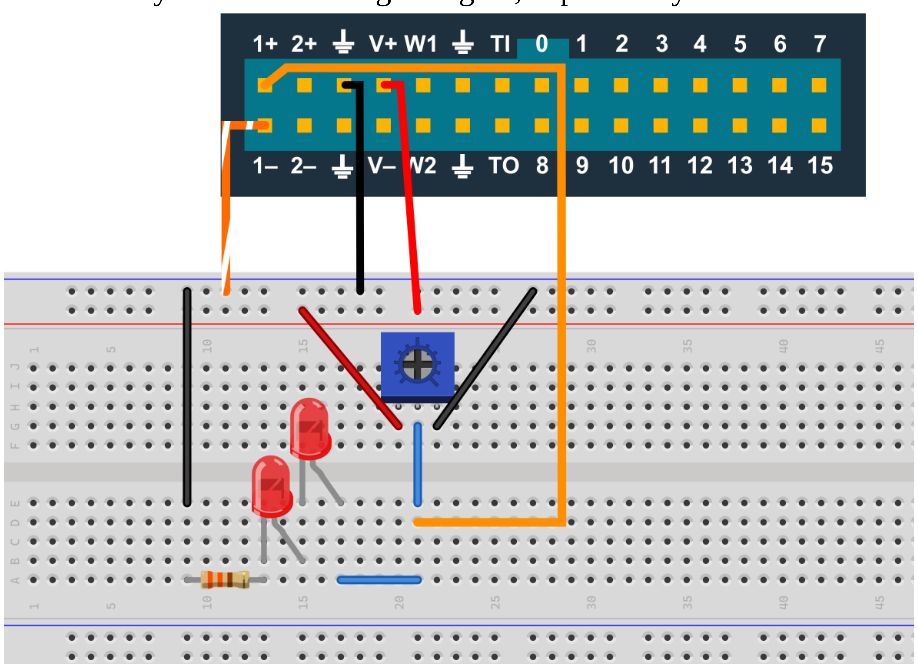


Fig. 4. Diagram for LEDs connected in series. Note the change from a supply of 3.3 V to 5 V

<u>Part B:</u> Photodiode Testing

In Part B, you will be working with a Photodiode. A photodiode's electrical properties change depending on how much light is shining on it. However, in the case of a photodiode, we are typically most interested in the amount of current moving through it as this is related to the amount of light absorbed by the photodiode. In characterizing the performance of electrical devices, one of the most common measurements is the *I-V* curve or current vs. voltage relationship. An *I-V* curve shows the relationship between the voltage applied to a device and the current flowing through that device. In this section you will find the I-V curve for the photodiode under various light conditions.

<u>Procedure:</u>

For this exercise, we will move away from working explicitly with the microcontroller and take advantage of the Keysight multimeters that are in the lab. This will simplify collecting the I-V curves vastly. The part of the lab should be completed in order given the following steps:

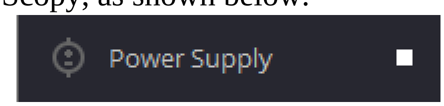
1. Assemble the circuit for the testing the photodiode shown below.

2. IMPORTANT: you will be working with higher voltages and currents than with the microcontroller and they can easily damage components or the breadboard. It is important that this section is reviewed thoroughly.

3. Collect the data indicated in the remaining instructions and answer the questions provided.

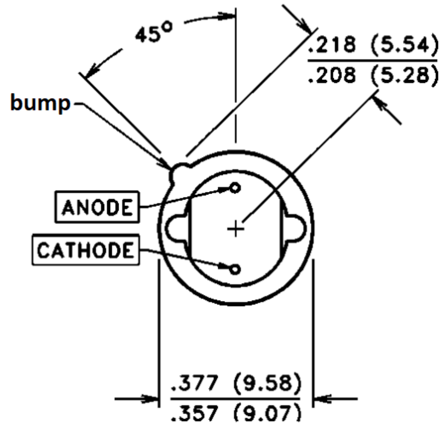
<u>Step 1:</u>

Before completing the circuit for measuring the I-V curves, make sure the power supply is off in Scopy, as shown below.



Once the power is off, assemble the circuit shown in Figure 5 below. The photodiode only produces a very small amount of current from the intensity of a single LED so we will be using a combination of 2 bright blue LEDs aimed directly at (and touching) the photodiode to maximize the current signal. It is important to note the external connections to the ADALM and Keysight Digital Multimeter. Turn on the multimeter and push the button for DC current, labeled "**DCI**".

You will need a banana-to-grabber cable to connect the multimeter to the breadboard and ADALM, this means one end of the cable is a banana jack and the other end is an alligator clip with a wire attached that will go into the board or into the ADALM extension wires.



IMPORTANT: Look for the bump on the photodiode to locate the anode and do not forget to place the photodiode on the breadboard with the positive (anode) wire on the red rail of the breadboard where you connect “W1” of the ADALM. Your results will be wrong and you may damage the photodiode if you do not orient it correctly.

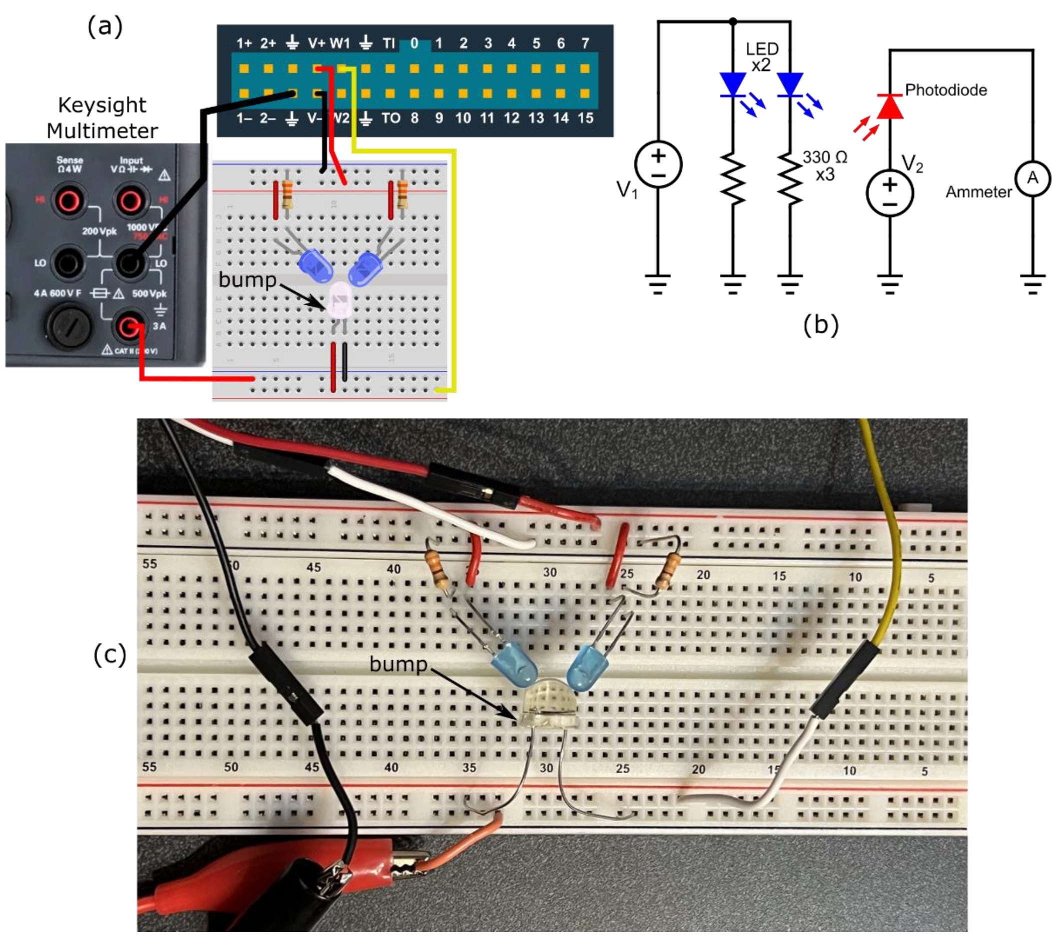


Fig. 5. (a) Diagram of circuit assembly to measure photodiode voltage and current. (b) Schematic representation of circuit. (c) Image of assembled circuit.

Step 2:

Connect the ADALM to your computer. Startup Scopy and setup the power supply with 0 volts on both outputs. Enable both outputs, otherwise you cannot guarantee 0 volts on the power rails for the LEDs. Figure 6 shows how you supply 9 volts to the LEDs when you need to in a later step. To supply 5V or less, simply keep the second output set to 0 volts.

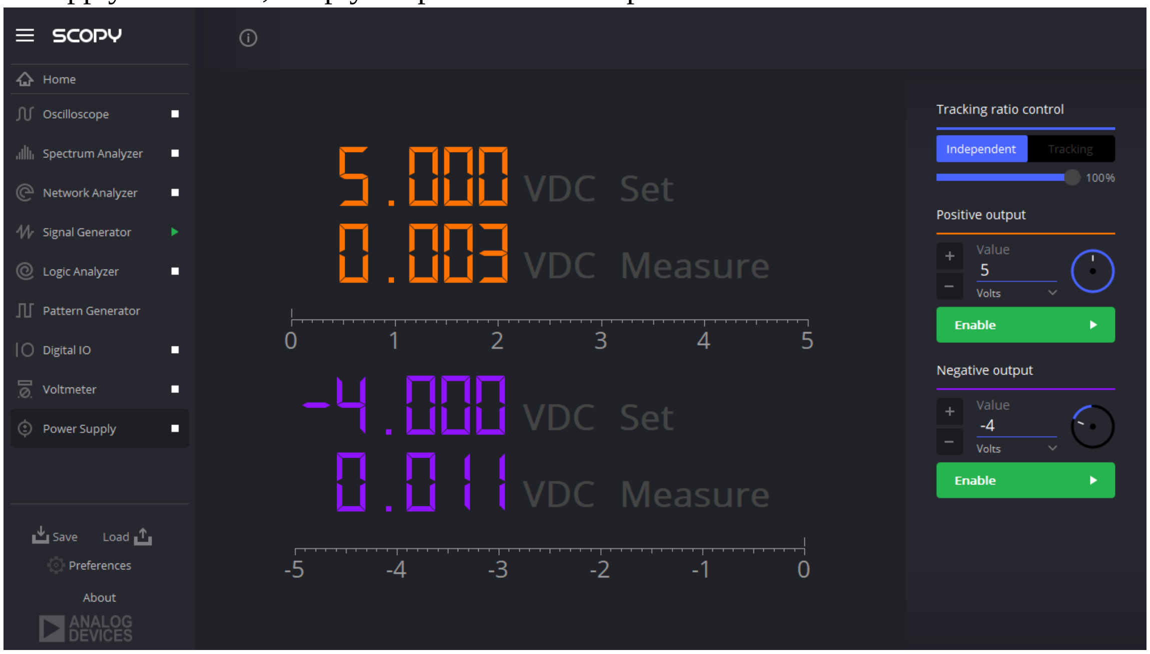


Fig. 6. Example of how to output 9 volts across the V+ and V- pins of ADALM

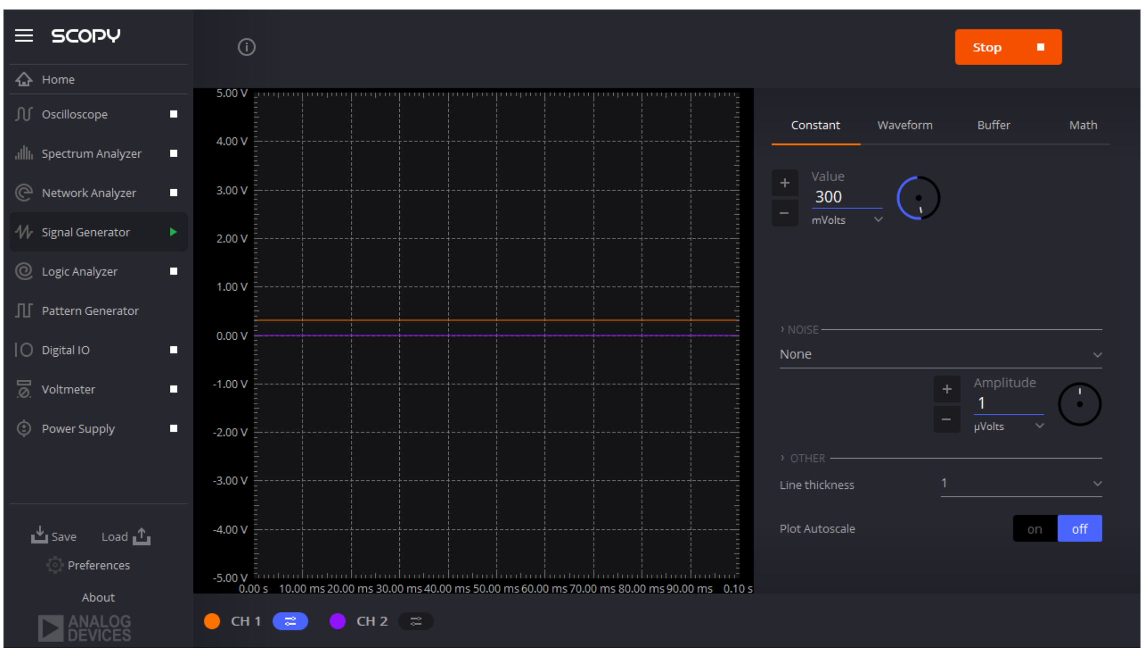


Fig. 7. Applying 0.3V across the photodiode using Scopy Signal Generator

Figure 7 shows an example of setting the photodiode voltage to 0.3V using Scopy's Signal Generator tab. You will start with 0V, however.

Step 3:

Follow the instructions for filling out the tables below. A submission box will be available for you to submit your graphs. The table which will be available for download on canvas under files > Lab 3 Materials > ForwardBias.docx. **Submit your completed table as a .pdf file.**

1. Obtain the *I-V* curve for the photodiode under several different conditions: no light (photodiode covered), and LED voltage equal several voltages. First, make sure that your Digital multimeter is set to DC current mode (DCI). Make sure the Scopy power supply is set to 0V.

Cover the photodiode and take your first I-V curve. Next, cover the photodiode and the LED together and set the Signal Generator in Scopy to the voltages in the table below. Use the multimeter measurements to fill in the current values.

Now set the Power Supply to the next LED voltage and take the other I-V curves. Remember that only the blue LEDs should be plugged in. You should also try to point the LED and photodiode at each other and maintain an equal distance throughout the experiment.

IMPORTANT: A large amount of current will be going through the LEDs at higher voltages. Make sure to turn off or reduce the voltage on the power supply once the measurement is taken as the components will begin to heat up.

Photodiode Covered	Photodiode Voltage (V)	0 Volts	0.3 Volts	0.4 Volts	0.45 Volts	0.5 Volts
	Current (μA)					
LED Voltage = 0V	Photodiode Voltage (V)	0 Volts	0.3 Volts	0.4 Volts	0.45 Volts	0.5 Volts
	Current (μA)					
LED Voltage = 3.0 V	Photodiode Voltage (V)	0 Volts	0.3 Volts	0.4 Volts	0.45 Volts	0.5 Volts
	Current (μA)					
LED Voltage = 5.0V	Photodiode Voltage (V)	0 Volts	0.3 Volts	0.4 Volts	0.45 Volts	0.5 Volts
	Current (μA)					
LED Voltage = 7.0V	Photodiode Voltage (V)	0 Volts	0.3 Volts	0.4 Volts	0.45 Volts	0.5 Volts
	Current (μA)					
LED Voltage = 10.0V	Photodiode Voltage (V)	0 Volts	0.3 Volts	0.4 Volts	0.45 Volts	0.5 Volts
	Current (μA)					

2. Make a graph that has all of the I-V curves on it. Excel, MATLAB or any computer based graphing will work best. The Current is your y-axis and your Photodiode Voltage is your x-axis.

3. What difference do you see when you compare the no-light I-V curve to the I-V curves with LEDs on?

<u>Part C:</u> Transistor Circuits

<u>Description:</u> In this portion of the lab, you will be working with transistors, specifically bipolar-junction transistors (BJTs). BJTs consist of three regions: a collector, an emitter, and a base (see figure below). BJTs are commonly used as current controlled switches in which the amount of current delivered to the base region controls the amount of current flowing through the collector. As the base current increases, so does the collector current. To illustrate the utility of BJTs, in the following exercise you will build an LED night light using another device called a photoresistor, a device with a resistance that decreases as light shines on it.

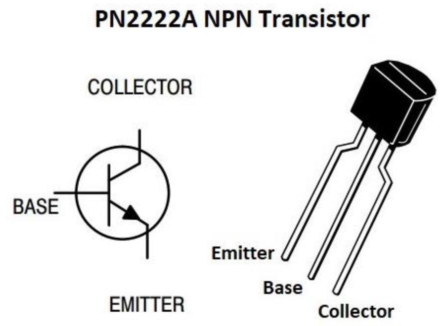


Fig. 8. Schematic symbol transistor and pin layout for PN2222A

<u>Procedure:</u>

1. Construct the circuit shown below. For the transistor shown in the diagram, the emitter pin will be connected directly to ground, the base is connected to the 100k Ohm resistor and photoresistor, and the collector is connected to the shorter end of the blue LED. A pin layout for the transistor is shown in Fig. 8.

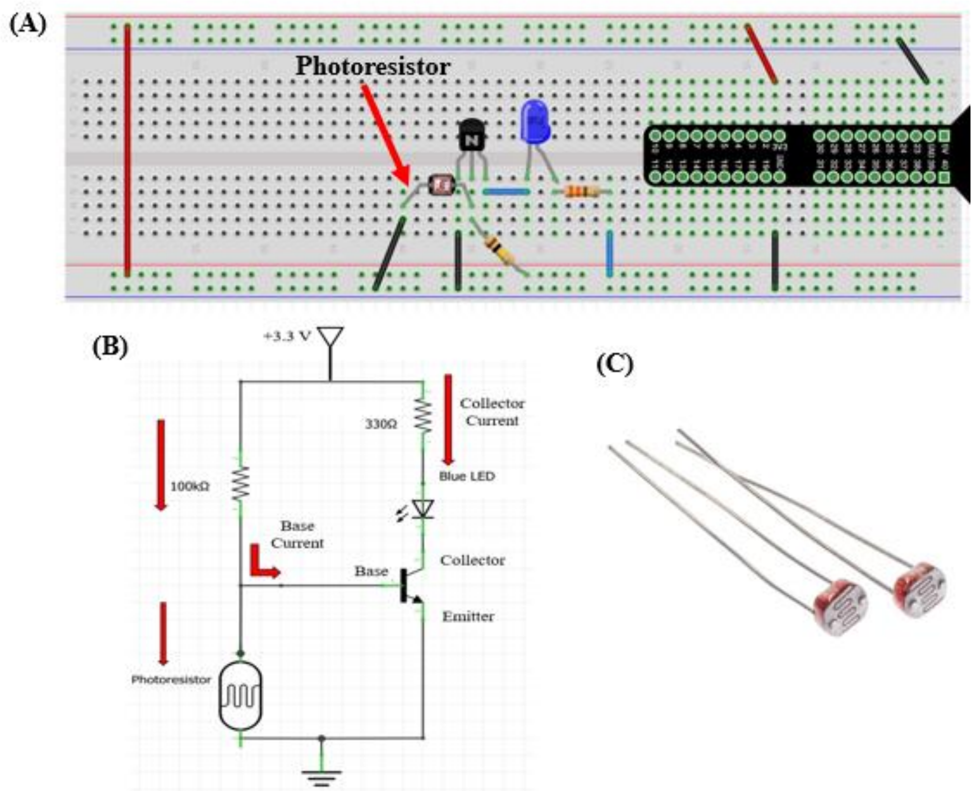


Fig. 9. (A) Diagram of circuit for part C. In the diagram, the leftmost pin of the transistor is the emitter while the rightmost is the collector. **(B)** Schematic of circuit illustrated in **(A)**. **(C)** Photoresistors used in circuit

2. Test your circuit by covering the photoresistor a little at a time and you should notice that the less light the photoresistor sees, the brighter the LED gets. If you turn out the lights in the room, the LED will be completely on. Demonstrate that your circuit is working appropriately to a TA for credit and then answer the questions on the following page.

Submissions:

Answer the following questions on Canvas

1. Demonstrate to a TA that the circuit is working correctly or upload a short (<10s) video of it working correctly.

2. Current flows down through the 100k Ohm resistor and splits between the base and the photoresistor. As light shines on the photoresistor, it's resistance decreases. As more light shines on the photoresistor, does more or less current flow through it? Why? Does current flow through the base? Why?

3. When it's dark, does more or less current flow through the LED than when light is shining on the photoresistor?

4. Now assume that the light on the photoresistor is decreased slowly until it's dark. Based on your answers to questions 1 and 2 and the discussion at the beginning of this exercise, explain the operation of this circuit in terms of the currents flowing through the photoresistor, the base, and the collector.