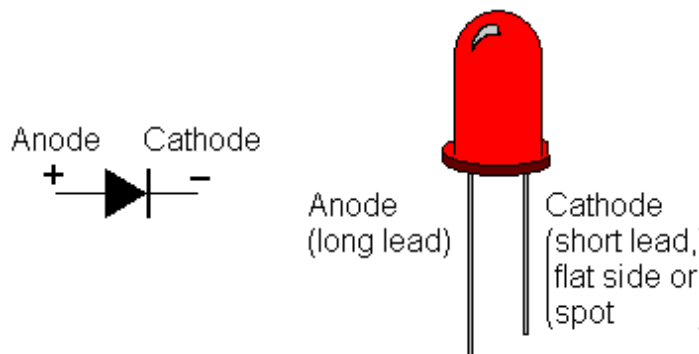


## Class #9: Experiment Diodes Part II: LEDs



**Purpose:** The objective of this experiment is to become familiar with the properties and uses of LEDs, particularly as a communication device. This is a continuation of Class #8 where diode basics were introduced with the 1N914 signal diode. We will first consider the I-V characteristic curve, which will show a significantly larger forward operating voltage and then build a some communication system.

Background: Before doing this experiment, students should be able to

- Analyze simple circuits consisting of combinations of resistors.
- Measure resistance using a Multimeter.
- Do a transient (time dependent) simulation of circuits using LTspice
- Build simple circuits consisting of combinations of resistors, inductors, capacitors, and op-amps on protoboards and measure input and output voltages vs. time.
- Generate I-V curves for resistors and diodes, both experimentally and with LTspice simulation
- Make differential voltage measurements using Analog Discovery and WaveForms.
- Do a DC sweep simulation of circuits using LTspice.
- Review the background for the previous experiments.

Learning Outcomes: Students will be able to

- Build basic LED circuits
- Generate I-V curves for LEDs
- Build light sensors with a standard resistive photocell and a photodiode or phototransistor

Equipment Required:

- **Analog Discovery** (with Waveforms Software)
- **Oscilloscope** (Analog Discovery)
- **Function Generator** (Analog Discovery)
- **Protoboard**
- Resistors, Capacitors, Diodes
- LTspice

Helpful links for this experiment can be found on the course website under Class #8.

### Pre-Lab

*Required Reading:* Before beginning the lab, at least one team member must read over and be generally acquainted with this document and the other **required reading** materials.

*Hand-Drawn Circuit Diagrams:* Before beginning the lab, hand-drawn circuit diagrams must be prepared for all circuits either to be analyzed using LTspice or physically built and characterized using your Analog Discovery board.

## Part A – The I-V Characteristic Curve

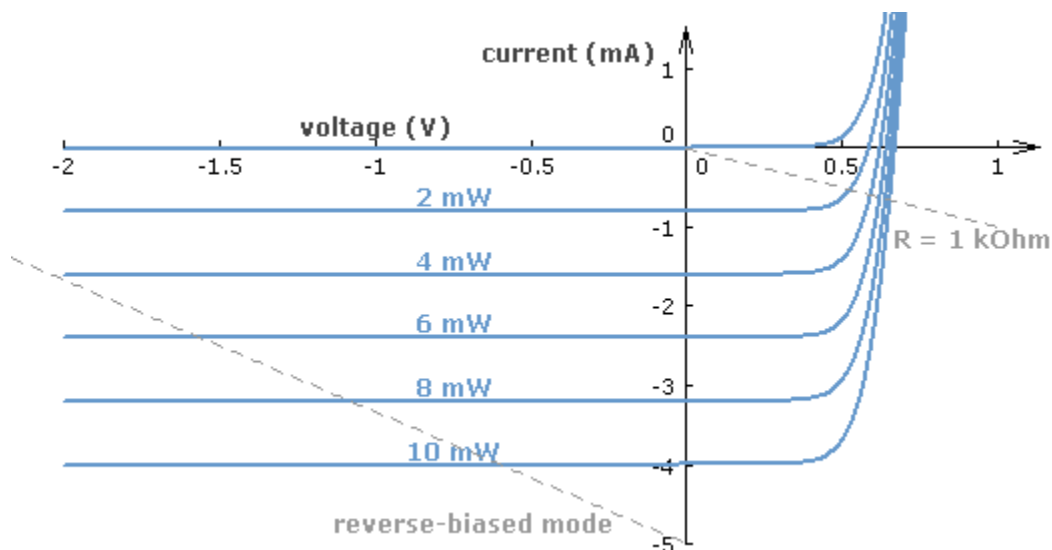
### Background

**LEDs:** An LED is a device that emits light when it is subjected to a voltage. Just like a regular diode, an LED will not turn on (and emit light) until a certain threshold voltage is reached. This threshold depends upon the color of the LED and the diode manufacturing process. Red LEDs turn on when the voltage across them exceeds about 2.2V. With green LEDs, the voltage can vary over a large range from about that required for Red up to 4V. Blue is about 3.5-4V. Note that, although diodes often have a plastic coating that matches the color of the light emitted, the light that comes from a diode is not white. It is light of the wavelength of the desired color, i.e. a red diode (even with a clear plastic covering) will put out light in the red region of the electromagnetic spectrum. The following equation can be used to decide what resistance to use with an LED, given its threshold voltage and the desired current through the diode. 20mA is a reasonable value to use for the current through the diode, although that also depends on the manufacturing process and the size of the diode. A handy calculator for determining the series resistance for a particular LED can be found at <http://led.linear1.org/1led.wiz>.

$$R = \frac{V_{in} - V_{LED}}{I_{LED}}$$

The amount of light emitted by an LED is roughly proportional to diode current. There is a well-written activity (meant for a science fair project) that addresses illumination. [http://www.sciencebuddies.org/science-fair-projects/project\\_ideas/Elec\\_p037.shtml](http://www.sciencebuddies.org/science-fair-projects/project_ideas/Elec_p037.shtml)

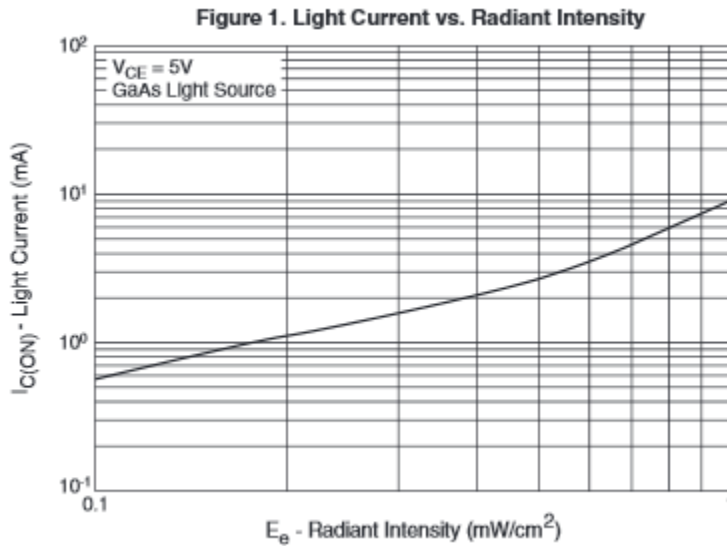
**Photodiodes:** A photodiode is a device that generates a current in the presence of light. As photons of light excite the PN junction inside the diode, a current is generated through the junction. The more light that shines on the photo-reactive surface, the more current flows through the device. In the equation for  $i_D$ , the saturation current  $I_s$ , increases with the amount of light hitting the diode. Photodiodes are reverse-biased and operate in the lower left quadrant of the I-V characteristic (both voltage and current are negative), as do Zener diodes. Solar cells also have an  $I_s$  proportional to light and operate in the lower right quadrant. See Figure A-1



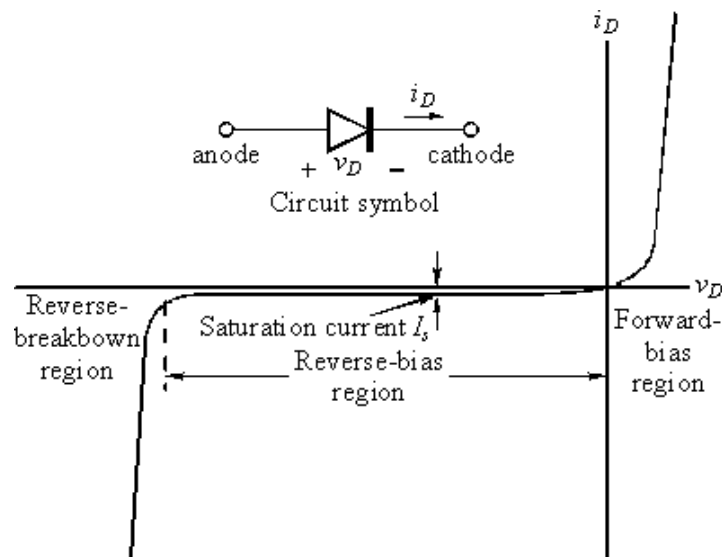
**Figure A-1**

**Phototransistors:** A phototransistor is similar to a photodiode except that it takes advantage of the ability of the transistor to amplify current in the active region. The current it generates is still proportional to the amount of incident light, but it is amplified by the properties of the transistor. The graph in Figure A-2 shows the linear relationship between incident light and current through a phototransistor in our parts kit. In effect, the light plays the

same role as the base current  $I_b$  in a standard transistor. Recall that the collector current  $I_c$  is the order of 100 times the base current (the amplification).



**Figure A-2.**

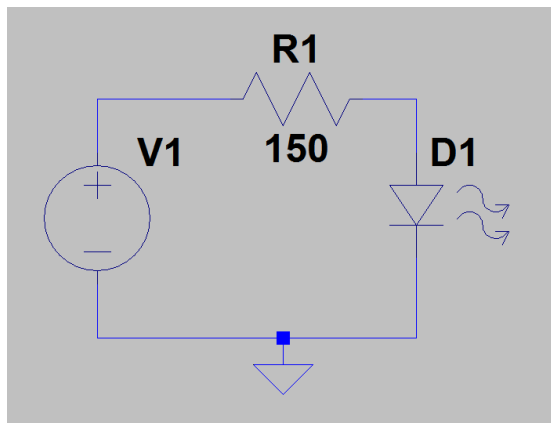


**Figure A-3.**

## Experiment

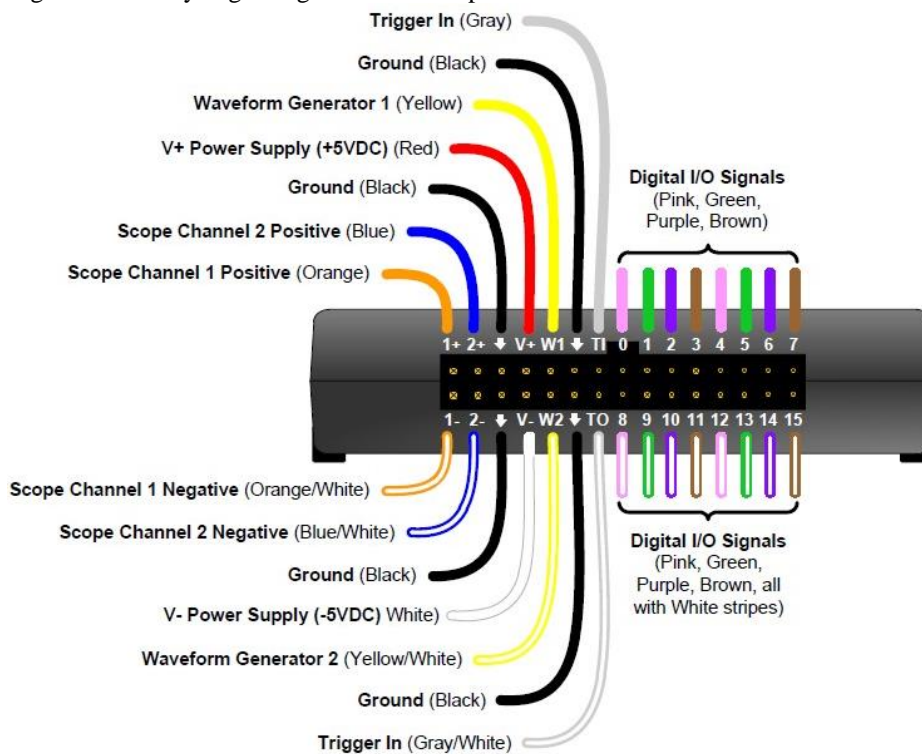
### *I-V Characteristic Curve of an LED*

The general form of an diode I-V curve is shown in Figure A-3. To generate such a curve for an LED we will plot the voltage across the LED vs. the current through the LED. The LED is labeled D1 in the figure below. LTspice allows us to plot currents, but Analog Discovery does not (at least not directly). So we will add a 150Ω “current sensing resistor,” R1. This also will have the function of limiting the current through the diode. The current through R1 is equal to the voltage across R1/150. Analog Discovery can be used to measure the voltage across the “current sensing resistor.” We will not be simulating this circuit because LTspice does not have a model for the LEDs in our parts kit.



**Figure A-4**

- Wire the circuit shown in Figure A-4 on your protoboard using any of the LEDs in your kit. Set up Analog Discovery to measure the voltage across R1 and the voltage across D1. Note that the voltage measurement across R1 is a differential measurement and not referenced to ground. Set up the function generator to produce a triangular wave with amplitude 5V and frequency 1kHz.
- The output of the Analog Discovery function generators is limited to  $\pm 5V$ , which is not quite enough to identify the features of all of the diodes we will be using. However, we will live with it for now and possibly return to our diode study when we can use amplifiers to extend the range of measurement.
  - LEDs are easy to recognize (look like little light bulbs). They are diodes so they must be placed in the circuit in the correct orientation. If you do it wrong, your I-V curve will be upside down.
  - When you wire the circuit, make sure your diode is placed so that the cathode faces toward ground as shown in the figure above. The length of LED wires allow us to find the cathode and anode, as you can see in the figure at the very beginning of this write-up.



**Figure A-5. Analog Discovery.**

- Set Function Generator 1(W1) to a 1kHz, triangle wave, 5V amplitude.
- Observe the diode voltage on channel 1 of the Oscilloscope, (1+, 1-). Remember that the negative input (1-) for channel 1 should be connected to ground.
- Observe the diode current on channel 2 of the Oscilloscope, (2+, 2-). This is what is called a differential measurement with (2+) connected above the resistor and (2-) connected between the resistor and the diode. Thus, channel 2 will measure the voltage across the resistor, not relative to ground. Remember that channel 2 is the current with a scale factor of 5mA/V because  $R_2=150$ .
- Set the oscilloscope up to display about five cycles of the signal, for example set the time base to 500 $\mu$ s/div.
- Save a copy of the plot to your report and fully annotate it.

Now we will add a math channel to display the current.

- Add a custom channel and set it up to display Channel 2 divided by 150 (which will be the current). When you do this you should see that the scale for this custom channel is still in Volts. We need to change that. The display scale window should look like Figure A-6. To change the units to Amps, open the drop-down menu just to the left of the X in the upper right. At the bottom of the next menu you will find a place to change the units to Amps. You will still be able to select the number of Amps per division in the range menu of Figure A-6. Set up the display to show 5mA/div as shown or change it to use as much of the vertical space as possible for your plot. Now you should be displaying the diode current in your plot.

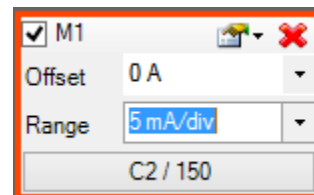


Figure A-6

Finally, we will display the I-V plot using another great Analog Discovery feature.

- Above the Run/Stop button, there is a button that allows us to Add XY. This will plot Channel 2 vs Channel 1. Again, that is not exactly what we want to do. Go ahead and select Add XY. A plot that looks like the I-V characteristic of the LED should appear along with another menu that allows us to choose what we will plot. If the additional menu does not appear, you can open it with the menu button located in the upper right of the XY window. For the Y axis, choose the Math channel. Now you should have a really nice I-V plot.
- Save the data to a file once you have a clean plot on the screen. Also save the plot in your report and fully annotate it. Again, you should label a representative number of points on your plot. You can get the points using a cursor on the main time dependent plot displayed by Analog Discovery.

## Part B – Communicating With Light

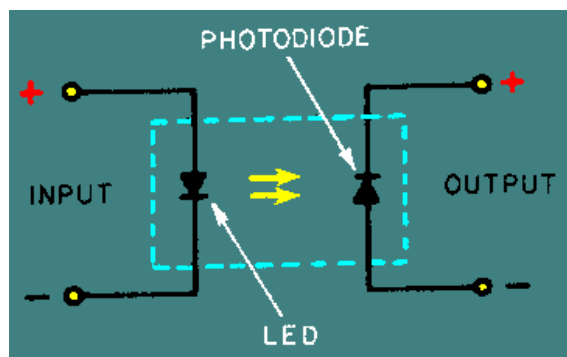


Figure B-1

In Figure B-1, the light detector is a photodiode. It is more often the case that this task is performed by a phototransistor. You have both in your Parts Kit. Thus, we will test both of them to identify some of the pluses and minuses for each choice. Because this experiment involves the construction of both a transmitter and a receiver circuit, you may find it helpful to do this with another student and build the transmitter on one Protoboard and the receiver on another. If you wish to build both on your Protoboard, separate the two circuits by at least an inch (3cm) and do not crowd components together. Both circuits require a ground, so use one black wire from Analog Discovery for the transmitter and another for the receiver.

Circuits like the one depicted generically in Figure B-1 are used in many different applications. One is called the Optocoupler, which allows a signal to be transmitted from one circuit to another without sharing a ground connection. Common grounds used throughout many electronic devices can be a significant source of noise. Also, different parts of circuits often require very different voltage levels, so it is good practice to separate such sub-circuits to minimize the chances of damaging the more sensitive circuit. This is discussed in general in <https://wiki.analog.com/university/courses/electronics/electronics-lab-22>. Another very common use is as an edge detector for a stepper motor [http://www.velmex.com/Downloads/Software/App\\_Notes/an105.pdf](http://www.velmex.com/Downloads/Software/App_Notes/an105.pdf) or a line follower for a robot <https://diyhacking.com/make-line-follower-10-minutes/>.

## Experiment

### Transmit a Signal using Light

We will build two circuits. The first circuit will cause an LED to blink. A current will be created in the second circuit when the photodiode or phototransistor detects the light from the blinking LED.

- Wire the circuit in Figure B-2 on your protoboard. Actually, we are only going to use this circuit as a guide, since we will be changing many of the component values. Each circuit has an active device (LED or photodiode/phototransistor) and a resistor. For LED power, connect to the function generator (W1) and set it up as a square pulse with amplitude 2.5V, offset 2.5V and frequency 10Hz. For the +5V power, use the Analog Discovery DC power supply (Red Wire). Use the scope to monitor the operation of both circuits. In the parts kit, the IR phototransistor is called an IR transistor. There are two devices that look like LEDs but their plastic lenses are black. In the present parts kit, the transistor is the smaller of the two devices. If you use different light sensors, be sure that you check their spec sheets to be sure that you have the correct one. In the Analog Devices ADALP2000 Parts Kit (nearly the same as the Digilent Kit), the two devices look almost identical. The phototransistor has shorter leads, which is often a way that manufacturers identify them. The IR LED has its correct name and is the only device that looks like an LED with a clear lens in your kit. For the transmitter (LED circuit), use a 2.2kΩ resistor rather than the 330Ω resistor shown. Either will work, but the IR LED does not need a lot of current to work in a satisfactory manner and you will get a more realistic sense of how the circuit can perform.

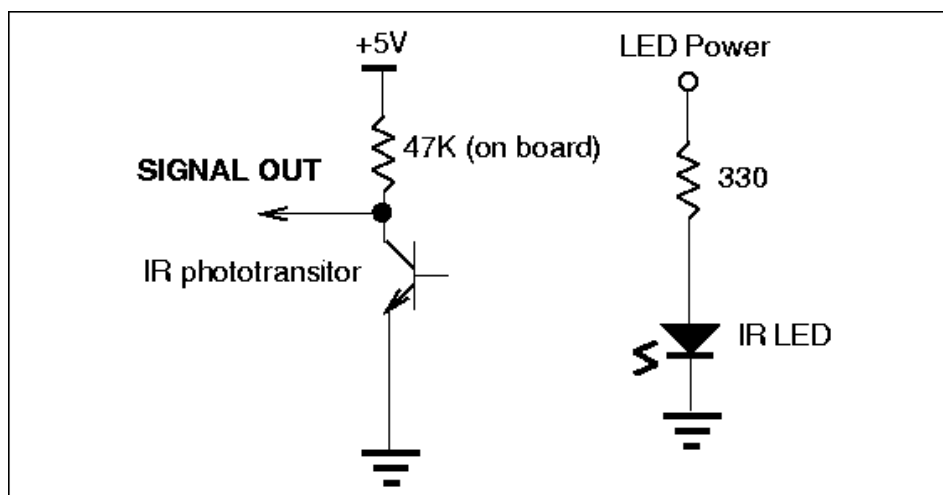


Figure B-2.

For the receiver circuit, we will start by using the phototransistor, so use 2.2kΩ for that resistor too.

- Make sure you can identify the phototransistor using the information provided in the Digilent parts kit list. It is a transistor but the base doesn't have an external lead. Light supplies the base current.
- There is a flat side on the phototransistor. The lead next to the flat (collector) goes to the resistor. This information is on its spec sheet. This convention is not necessarily standard, although it is common. The phototransistor in the ADALP2000 kit should be oriented in the other direction. If yours is in backwards, you will be able to tell by how the circuit works. More on this below.

- For the receiver circuit, connect Channel 2 (blue wires) across the 2.2kΩ resistor, with 2+ connected to the +5V power and 2- connected between the resistor and the phototransistor. For the transmitter, connect channel 1 (orange wires) from the LED Power to ground so that the total input voltage can be observed. 1+ should be connected to LED Power (W1 - yellow) and 1- to ground (black). Be sure to connect a ground wire to each circuit.



- **When you wire your circuits, point the LED and the phototransistor towards one another so that the rounded tips (lenses) face each other.** Recall that the light from the diode is most visible from the top. The photodiode or phototransistor takes in light primarily at the top as well. Having them face each other provides the maximum light transmission and also minimizes the secondary effects caused by other lights in the room. Here is where having the two circuits on separate boards will have a small advantage. You will be able to move them more easily to find the maximum possible signal.
- Observe the output of your circuit.
  - Turn on the function generator (Wavegen), the +5V DC supply, and the scope.
  - If the output signal doesn't show a significant square wave then:
    - Make sure the phototransistor is correctly installed. Simply reverse the phototransistor and see if the signal increases. If it is working correctly, the receiver pulses should look similar to the transmitter pulses. They will likely be smaller, but easily observable using the same vertical scale for both channels. Note that if you see the voltage across the receiver resistor near 5V when there is no signal from the LED, you probably have installed the photodiode rather than the photo transistor. Phototransistors should have zero volts across their series resistor when they are not detecting light because they are not conducting current. They only conduct significant current when they detect light.
    - Make sure that the tip of the LED points toward the tip of the phototransistor. Move both devices until you achieve the maximum possible signal.
- Take your data.
  - Save a picture of the output when the circuit is working well.
  - Include this plot in your report.
  - After obtaining a clear signal with this optical link, block the light by placing a piece of paper, your finger, or something similar between the transmitter and receiver. Do you observe anything on the oscilloscope?
  - Also move the receiver away from the transmitter and aim the transmitter so less signal is detected.
  - Change the frequency of the square wave to 500Hz and 2kHz. Does the output look like the input?

Repeat the same tasks using the photodiode from your parts kit. Photodiodes can work like small solar cells but they are faster and more effective if they have a small bias current. Replace the phototransistor with your photodiode. Also replace the 2.2kΩ resistor with a 220kΩ resistor. You should still use channel 2 to observe the voltage across the resistor rather than across the photodiode because the detected signal should look like the transmitted signal. If your photodiode is installed correctly it will track the input voltage but not drop completely to zero when the input voltage is low. If it is installed backwards, it will just sit at a voltage of about 5V and not respond to the IR pulses from the LED.

## Summary

Photodetection is a very important use of diodes. LEDs and photodiodes can be used to emit and detect light in the visible spectrum and also in the infrared. These devices are used in remote control devices to transmit modulated signals of certain frequencies. They are also used to sense and/or display information in countless other applications. A phototransistor is very much like a photodiode, but it also has the gain of a transistor. We usually use the phototransistor for this reason. However, photodiodes can be made to pulse faster. We use photodiodes when better frequency response is required.