University of California at Berkeley
College of Engineering
Department of Electrical Engineering and Computer Sciences

EE 105 Labs
Lab 3: Diodes, Rectifiers, Optical Transceivers

Contents

1 Objective

In this lab, you will examine diodes and LEDs. In addition, you will explore using LEDs and photodiodes to make a transmitter and receiver, respectively–this is called an optical transciever. We will build an electrical receiver that will amplify the received signal to drive another LED. The relevant datasheets are attached to this assignment on bCourses.

2 Introduction

Before we can build our optical transceiver, we should get familiar with diodes, which are two-terminal semiconductor devices. The circuit image for a diode is shown in Figure 1.

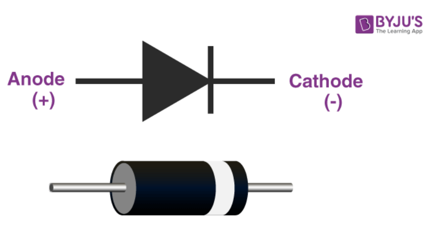

Figure 1: Diode schematic symbol.

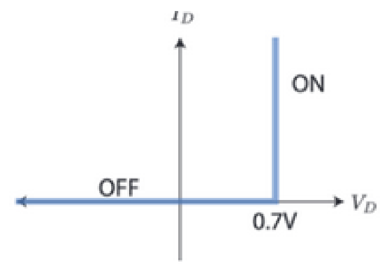

Figure 2: Ideal diode I–V characteristic.

A diode has two terminals, the anode (base of the arrow) and the cathode (point of the arrow). Applying a positive voltage from anode to cathode, called forward bias, will allow current to flow. Applying a positive voltage from cathode to anode, called reverse bias, will not. It is common to consider diodes to have the I–V characteristic shown in Figure 2. None of the diodes in this lab have that IV characteristic though. We include it here just to show how bad it is.

Figure 3: LED and photodiode schematic symbols.

LEDs are diodes that emit light and typically have a higher threshold voltage. In our optical link, you will use three diodes: 1. the red LED will be the transmitter (converting electrical signals into light), 2. the photodiode will be the receiver (converting light into electrical signals), and 3. the green LED will be the indicator (so we know that the photodiode is actually receiving).

You can see the IV curves of the red and green LEDs in Figure 4. You will want to run them at around 10-20 mA so that they are nice and bright, but you don't want to push too much current through them or they will break. The photodiode is a silicon diode with the junction exposed to light with a plastic lens on top. You can see from Figure 5 that at room temperature not very much current flows in reverse bias. Under illumination, however, significantly more current will flow.

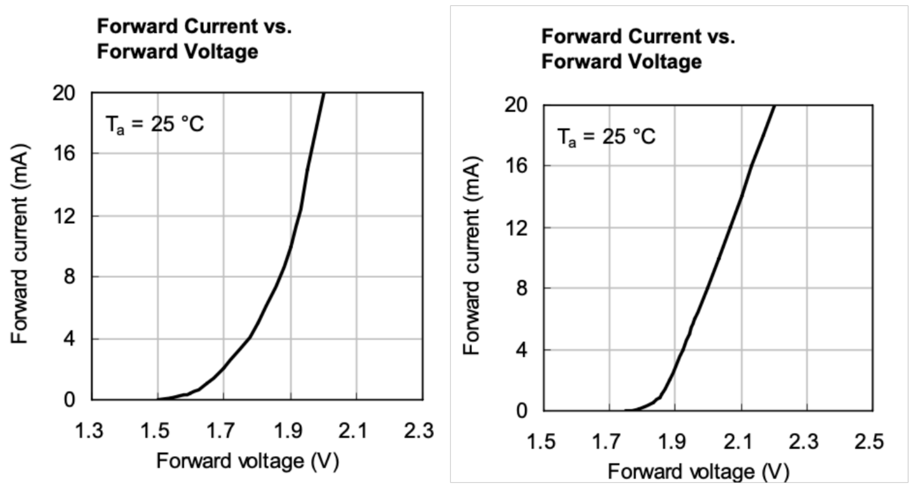

Figure 4: IV curves from the datasheets for the red (left) and green (right) LEDs. Note that these do not look like typical 60 mV/decade exponentials.

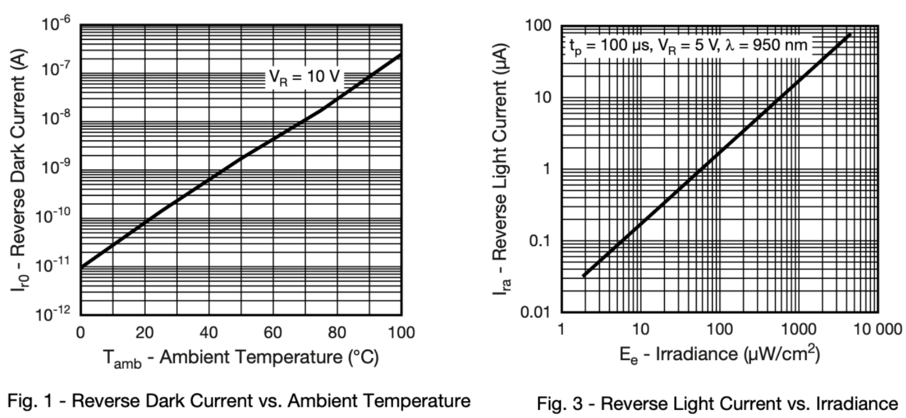

Figure 5: IV curves (from the datasheet) for the reverse-biased photodiode. The dark current (left) is a strong function of temperature. The light-induced current (right) is quite linear in received irradiance over many decades.

3 Pre-Lab

There are two circuits that you will be analyzing in this lab: a half-bridge rectifier and a LED based transmitter/receiver.

Often it is desirable to convert an AC power source to a DC one. For example, this is (part of) what your phone chargers do when they take power from the 120 Vrms, 60 Hz (in the US) wall outlet and convert to 5 V output at DC. A half-bridge rectifier is shown in Figure 6. This circuit is called a half-bridge rectifier because, for a sinusoidal AC input, half of the period is cut off, and the other half remains.

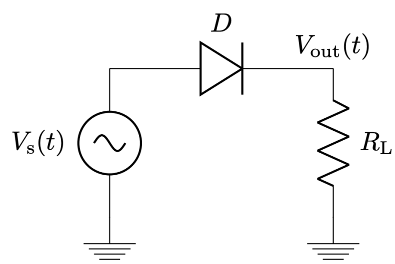

Figure 6: Half-bridge rectifier.

For our receiver, we would like to convert the transmitter LED light into an electrical signal, and use it to drive an indicator LED, as shown in Figure 7.

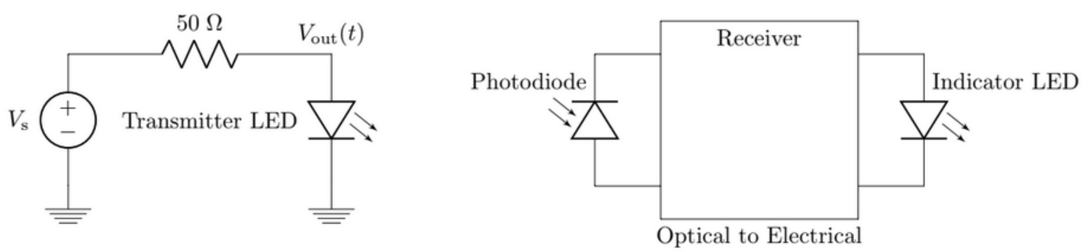

Figure 7: Transmitter and receiver block diagram.

The indicator LED will be a Green LED, which requires approximately 2.2 V and 20 mA for operation. The TEFD4300 photodiode datasheet is included in bCourses (Files → Lab Documents → Datasheets).

P1. Using the model given in Figure 6, draw the expected output of the circuit for a sinusoidal input. Be sure to mark the amplitude and zero crossings on your axes (can be in terms of variables).

P2. For the red LED circuit in Figure 8, what should the supply voltage V_s be to get 20 mA of current? Hint: Use the datasheet for the red LED (in bCourses, Files → Lab Documents → Datasheets; also displayed in Figure 4.) and find the voltage where 20mA of forward current is conducting.

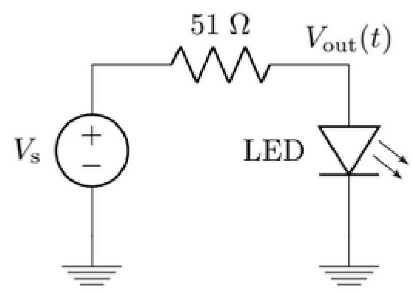

Figure 8: Red LED circuit.

P3. For the diode curve in Figure 9, label the curve with the following: forward bias, reverse bias, equilibrium, breakdown.

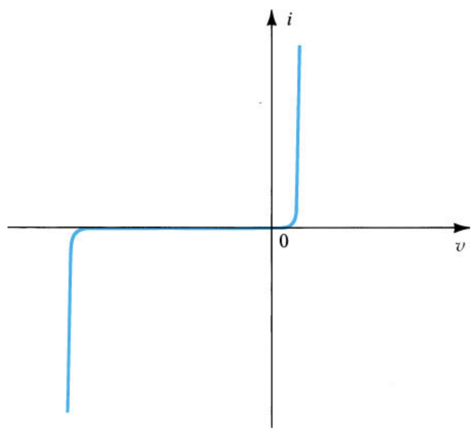

Figure 9: Diode curve.

P4. Based on Figure 5 and the datasheet:

P4.1 What level of irradiance is needed to get 1uA of reverse current? That figure assumes a diode bias of -5V, and a wavelength of 950nm (infrared).

P4.2 What is the wavelength of your red LED?

P4.3 What is the relative sensitivity of the photodiode at that wavelength (see datasheet's Figure 5)?

P4.4 What irradiance is necessary from your red LED to get 1uA at -5V bias?

P5. In full sun at noon on a clear day the irradiance outdoors is about 100 mW/cm^2. Indoor illumination is typically three or four orders of magnitude lower. What current in the photodiode do you expect from indoor illumination? What wavelength did you use to make that calculation?

P6. For the two receiver configurations in Figure 10 and Figure 11:

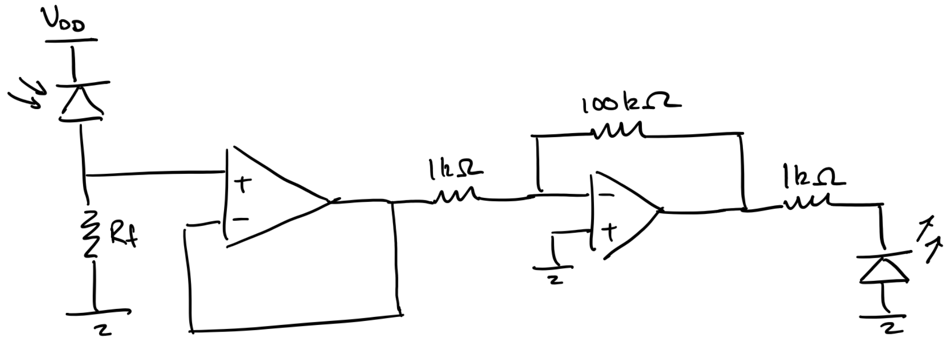

Figure 10: Receiver implementation 1.

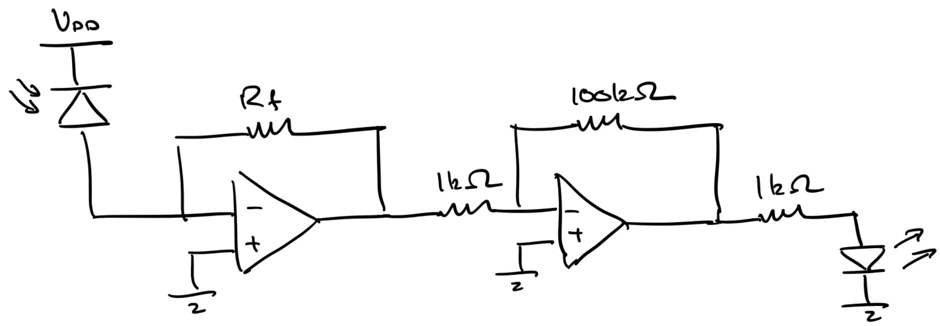

Figure 11: Receiver implementation 2.

P6.1 Why do we need the amplifier in Receiver 1? Can we connect the photodiode directly to the indicator LED?

P6.2 For each implementation, calculate the Rf and Vdd values that will give 8 mA of current through the green LED, 1 uA through the photodiode, and a -5 V bias on the photodiode.

P6.3 Why is the LED flipped in Receiver 1?

P6.4 From a DC biasing standpoint, which configuration is preferred?

P7. The photodiode has a parasitic capacitance that depends on the reverse bias voltage and can be modeled as shown in Figure 12.

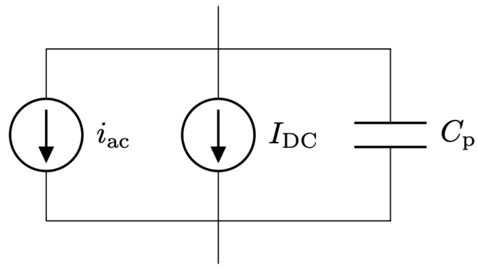

Figure 12: Photodiode model.

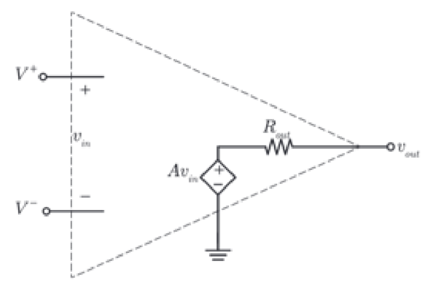

Figure 13: Op-amp model.

P7.1 For now, we will assume that the amplifier is ideal and can be modeled as shown in Figure 13, with infinite bandwidth, zero output resistance (Rout = 0), and a gain of 100 (Av = 100). For the first stage amplifier, what is the expected bandwidth (−3 dB frequency) for each implementation in Figures 10 and 11? Use the photodiode model in the figure above.
Hint: In AC analysis, any DC voltage sources are shorted/grounded and DC current sources are opened.
Hint 2: The input in this case is not a voltage, but a current! The photodiode creates a current input, and we measure the output voltage at the LED. This is what is known as a transimpedance amplifier, or TIA.

P7.2 Simulate the first stage of each implementation in LTspice using AC simulation. You can model the photodiode as shown above in Figure 12. Use a voltage-controlled voltage source (component 'e' in LTspice) to model the amplifier, and an equivalent resistor to model the indicator LED voltage drop. Attach both schematics to your worksheet. Plot the AC gain (from the input current i_{ac} to the output voltage across the indicator LED) vs frequency. Attach a screenshot of both curves on the same plot to your worksheet. Record the bandwidth and compare to your calculations.

P7.3 The second stage amplifier has a gain of -100. Assuming that the op-amp has a unity gain bandwidth of 1 MHz, what is the bandwidth of the amplifier in feedback? If you were to add a third amplification stage, while keeping the product of the second and third stage gains the same at 100 (in magnitude), how would that affect the bandwidth?

4 Materials

You will need the following components.

Component	Quantity
WP7113IT Red LED	1
TEFD4300 Photodiode	1
WP7113GT Green LED	1
1N4148 Diode	1
LM324 Quad Op-Amp	1
51 Ohm resistor	1
1 kOhm resistor	2
100 kOhm resistor	1
Breadboard	1

Table 1: Components used in this lab.

5 Procedure

5.1 Half-Bridge Rectifier

1. Build the half-bridge rectifier shown in Figure 14 with the 1N4148 diode. Apply a 100 Hz sinusoid to your rectifier with an RL = 1 kΩ resistor load. Starting from 100 mVpp (ensure you are in "High-Z" mode), vary the amplitude applied until you see a 250 mV signal at the output *on the oscilloscope*. Is the voltage displayed on your function generator the same as the amplitude on the oscilloscope? Why or why not?

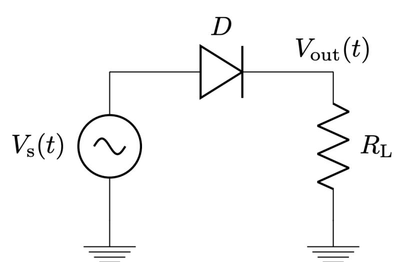

Figure 14: Half-bridge rectifier.

2. For the remaining parts keep the amplitude of the signal generator at the value found in the previous part. Now try adding a 1 µF capacitor in parallel with the resistor load. Vary the frequency from 100 Hz to 5 kHz. What happens to the amplitude of the waveform? What happens to the shape of the waveform? Attach a photo of the oscilloscope output.

3. Try the same circuit with a 10 µF and 1 nF capacitor at the load. At what frequencies does the output begin to change for those capacitors at the load?

4. What does the capacitor do to the output waveform? Explain why this is happening.

5.2 LED Transmitter

The transmitter in our system will be a forward-biased red LED, shown in Figure 15. We would like to operate the LED with 20 mA of current. It is very common to add a resistor in series with an LED to limit the amount of current that will flow if the supply voltage varies a little, or the temperature goes up. You should use a 51 Ω standard resistor in lab.

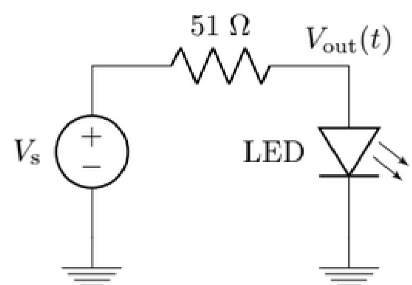

Figure 15: LED transmitter circuit.

1. On your 6V supply set a current limit to 30mA. Do not set a supply voltage yet.

   Note that the LED and the photodiode have different pin lengths for the anode and the cathode (Figure 16):

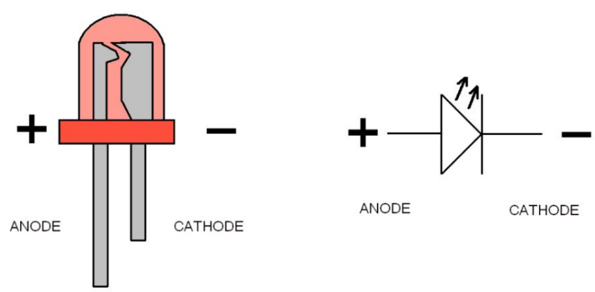

Figure 16: Diode anode and cathode.

2. Set the multimeter to ammeter mode to measure current: Shift → DC I (make sure probes are plugged into the correct ports). Connect the ammeter in series with the circuit and observe the current while you increase the voltage. Set the DC voltage V_s to the supply voltage you calculated in your pre-lab to achieve a 20 mA current reading on the ammeter through the LED. Make sure to increase the voltage slowly, so you won't have current larger than 20 mA. Write this DC voltage in your lab worksheet.

5.3 Photodiode

1. Connect the photodiode to the breadboard using another supply voltage and measure its current:

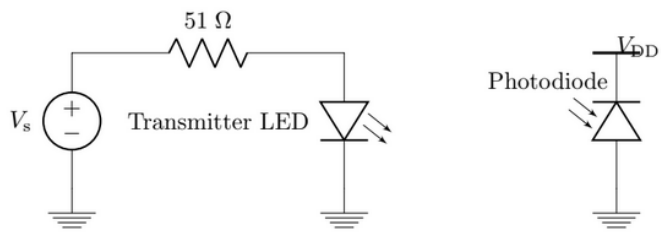

Figure 17: LED transmitter and photodiode.

2. Set VDD to 5 V and find a distance between the photodiode and the LED that will result in photodiode current of $\sim 10\,\mu$A. *Note:* The received light intensity is maximized when the LED and the photodiode are positioned "face to face" with their bulbs. Now vary the supply voltage from 1 V to 10 V. Is the current dependent on the supply voltage V_{dd}? Why or why not? (Hint: What region of the diode curve are we operating in?)

5.4 Receiver — DC

1. Using the transmitter and LED circuit from 5.2 and 5.3 along with your prelab calculations for Rf, build receiver implementation 2 shown in Figure 18 using the LM324 quad op-amps.

   Note: Make sure your diodes have the correct orientation, especially the photodiode. It wants to be reverse biased. If you get that one wrong, it might blow up!

   Note 2: Make sure to get the op-amp orientation right. Ensure +15 V goes to the positive supply (i.e. don't blow up the op-amp). Positive supply is on top if the cutout is to the right.

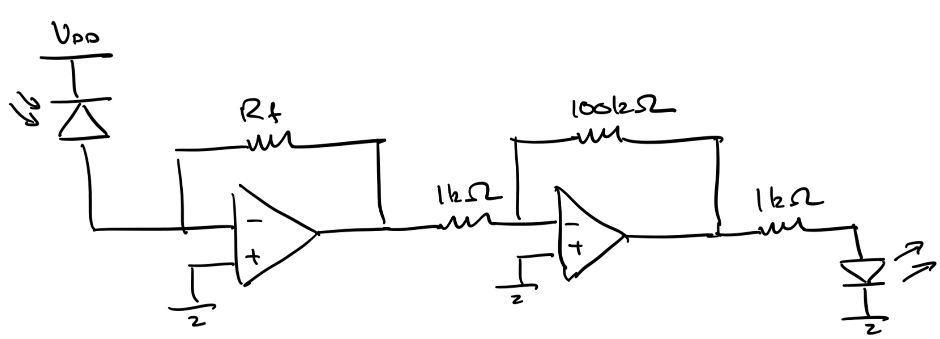

Figure 18: Receiver implementation 2.

2. Measure the voltage output at the first and second op-amp. Then, measure the voltage and current across the green LED. To get the green LED to light up, the red LED will need to be head to head with the photodiode.

3. With the red LED off, what voltage do you see at the output of the second op-amp? Use that value to calculate the current in the photodiode and the indoor irradiance level.

4. If you use the flashlight on your cell phone, what irradiance can you achieve?

5.5 Receiver — AC

1. Set the function generator to a 0–V_s square wave at 5 Hz, where V_s is the DC supply voltage that you measured previously. Connect the function generator to the oscilloscope, and make sure that the voltages are as expected (*Hint:* You will need an offset).

2. Now, instead of the DC supply, connect the function generator. Make sure to set it in "High Z" mode (or leave it in 50 Ohm mode and remove the 51 Ohm series resistor). Connect the oscilloscope probes to the transmitter LED and the output of the receiver. Attach plots to your lab worksheet.

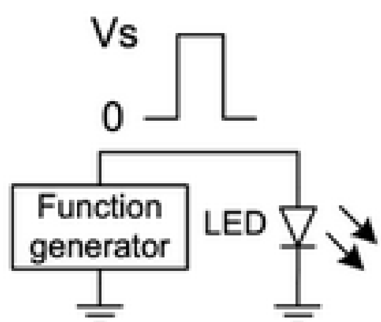

Figure 19: Function generator and LED.

3. Look at the output as you increase the frequency to the kHz and MHz range. What happens to the output waveform as the frequency increases?