UNIVERSITY OF CALIFORNIA AT BERKELEY
College of Engineering
Department of Electrical Engineering and Computer Sciences

**EE 105 Lab Experiments**

Fall 2022

# Prelab 3: Diodes, LEDs, Photodetectors

In this lab, you will use examine diodes and LEDs. In addition you will explore using LEDs and photodiodes to make a transmitter and receiver, respectively. We will build an electrical receiver that will amplify the received signal to drive another LED. The datasheets of the LEDs and the photodiode are on bCourses.

## 1 Pre-Lab

### 1.1 Intro to Diodes

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. A diode has two terminals, the anode, 'A', (base of the arrow) and the cathode, 'K', (point of the arrow).

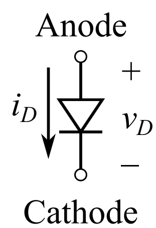


**Figure 1:** Diode schematic symbol.

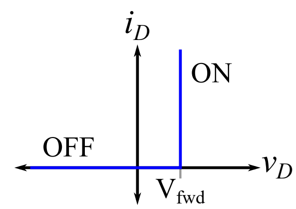


**Figure 2:** Ideal Diode I-V characteristic.

Applying a positive voltage from anode to cathode, called forward bias, will allow current to flow. However, 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. This representation models the diode as an open circuit for voltages below the threshold voltage (also called the forward voltage $V_{fwd}$, and a short circuit for voltages above threshold.

**Q 1.1.1**: Look at the datasheet for the 1N4148 diode (on bCourses) and identify the threshold voltage.
*Note: The plot for forward current vs. forward voltage is in log scale. As an estimate, consider where the diode current is 2 mA.*

LEDs are diodes that emit light and typically have a higher threshold voltage. In our optical link the LED will be the transmitter (converting electrical signals into light), and the photodiode with be the receiver (converting light into electrical signals). You need to forward bias the LED in order to emit light and reverse bias the photodiode to detect light, as shown in Figures 3 and 4.

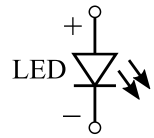


**Figure 3:** LED schematic symbol.

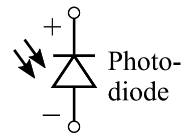


**Figure 4:** Photodiode schematic symbol.

## 1.2 Rectifiers

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-wave rectifier is shown in Figure 5. This circuit is called a half-wave rectifier because, for a sinusoidal AC input, half of the period is cut off, and the other half remains.

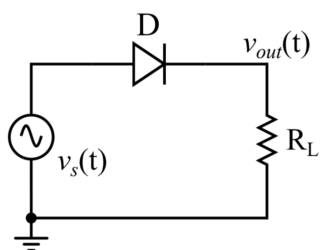


**Figure 5:** Half-wave rectifier circuit.

**Q 1.2.1**: Using the diode model given in Figure 2, draw the expected output, $V_{out}(t)$, of the half-wave rectifier circuit (Fig. 5) for a sinusoidal input, $v_s(t) = V_s sin(\omega t)$. Be sure to mark the amplitude and zero crossings on your axes (can be in terms of variables, e.g $V_s$, $V_{fwd}$, $R_L$, $\omega$).

## 1.3 LED Transmitter

The transmitter in our system will be a forward-biased red LED, as shown in Figure 6. We would like to operate the LED with 20 mA of current. The series resistance will be 50 Ω, so later we can change the DC supply to a function generator.

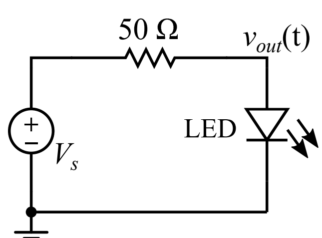


**Figure 6:** LED transmitter circuit.

**Q 1.3.1**: What should the supply voltage $V_s$ be (DC value)? *Hint: Use the datasheet for the red LED to estimate the threshold voltage. Assume that when on, the LED drops that threshold voltage always. To estimate the threshold voltage, find the voltage where 2 mA of forward current is conducting.*

## 1.4 Receiver - DC

In 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.

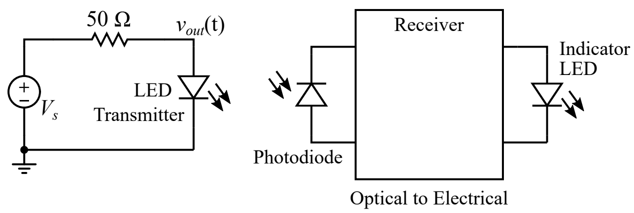


**Figure 7:** Transmitter and receiver block diagram.

The indicator LED will be a green LED, which requires 2.1 V and 20 mA for operation. We will assume that the photodiode current is 9.32 $\mu$A, and the voltage drop across the photodiode is 5 V.

Two receiver implementations are suggested in Figures 8 and 9.

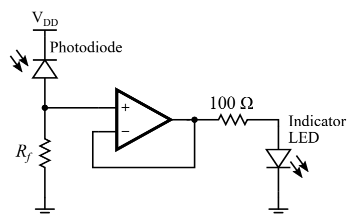


**Figure 8:** Receiver implementation 1.

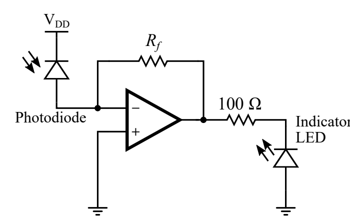


**Figure 9:** Receiver implementation 2.

**Q 1.4**: Answer the following:

1. Why do we need the amplifier in Receiver 1? Can we connect the photodiode directly to the indicator LED?
2. Why is the indicator LED flipped in Receiver 2?
3. For each receiver implementation:
   (a) Calculate the required values for Rf and VDD.
   (b) Attach a schematic showing the DC voltages at every node and the current through every resistor. You can assume that the op-amp is ideal for the calculations.
4. From DC standpoint, can you see an advantage to one of the implementations?

## 1.5 Receiver - AC, Finite-Gain Op-Amp

The photodiode has a parasitic capacitance of 15 pF, and can be modeled as shown in Figure 10. For now, we will assume that the amplifier is ideal and can be modeled as shown in Figure 11, with infinite bandwidth, zero output resistance (Rout = 0), and a gain of 100 (Av = 100).

Simulate each circuit in LTspice using AC simulation. (Remember that for AC response, you short dc voltage sources to ground and open dc current sources.) You can model the photodiode as shown above in Figure 10. Use a voltage-controlled voltage source (component 'e' in LTspice with gain 'E' equal to 100. Ports are shown in Fig. 12) to model the amplifier. Use an equivalent resistor to model the indicator LED (from 1.4.3a calculations).

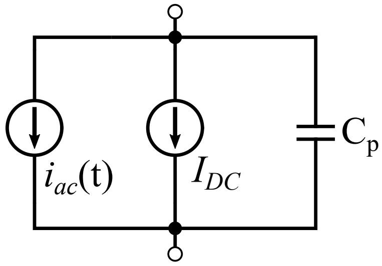


**Figure 10:** Photodiode equivalent circuit model.

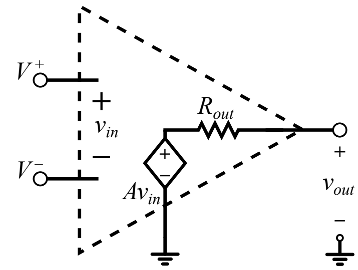


**Figure 11:** Ideal op-amp circuit model.

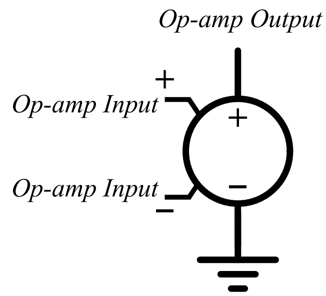


**Figure 12:** LTspice voltage-controlled voltage source port connections.

**Q 1.5**: Address the following:

1. Calculate the expected bandwidth (-3 dB frequency) in each implementation in Figures 8 and 9? *Hint: You can find this by finding the frequency response of the transfer function from the AC input current $i_{ac}$ to the output voltage across the indicator LED, but you do not actually have to find the complete transfer function.*

2. Simulate both circuits in LTspice. Attach the LTspice schematics for both receiver implementations.

3. In LTspice, plot the AC gain (from the input current $i_{ac}$ to the output voltage across the indicator LED) vs frequency.

4. Compare the bandwidth to your calculations.

# Pre-lab Report

**Pre-lab Report Total is 50 points**

1.1.1 (**2 points**)

1.2.1 (**3 points**)

1.3.1 (**5 points**)

1.4.1 (**3 points**)

1.4.2 (**3 points**)

1.4.3 (**16 points**)

1.4.4 (**3 points**)

1.5.1 (**3 points**)

1.5.2 (**5 points**)

1.5.3 (**5 points**)

1.5.4 (**2 points**)