ECED3901 Lab #3: Optical Sensor Basics

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Lab Due: June 15, 2015 @ 12:30 PM - Submitted via BBLearn Website (PDF files only), OR printed files in 3901 Mail-Slot at ECED Office

Lab Objective

The goals of this lab are to:

1. Characterize the amount of received photocurrent as a function of observer angle in a simple LED-to-phototransistor optical link.
2. Characterize the amount of received photocurrent as a function of separation length in a simple LED-to-phototransistor optical link.

Part 1: Photocurrent vs. Observer Angle

The datasheets of most LED lamps provide a figure called a *Radiation Pattern*, also referred to as a *Radial Distribution* or *Spatial Distribution*. The figure shows, given a fixed distance and constant input electrical power, how much optical power a *point sink* (as opposed to a *point source*) would detect as a function of **Observer Angle** which we will define as the angle between the optical axis of the LED and the optical axis of the observer or detecting device (see below, Figure 1).

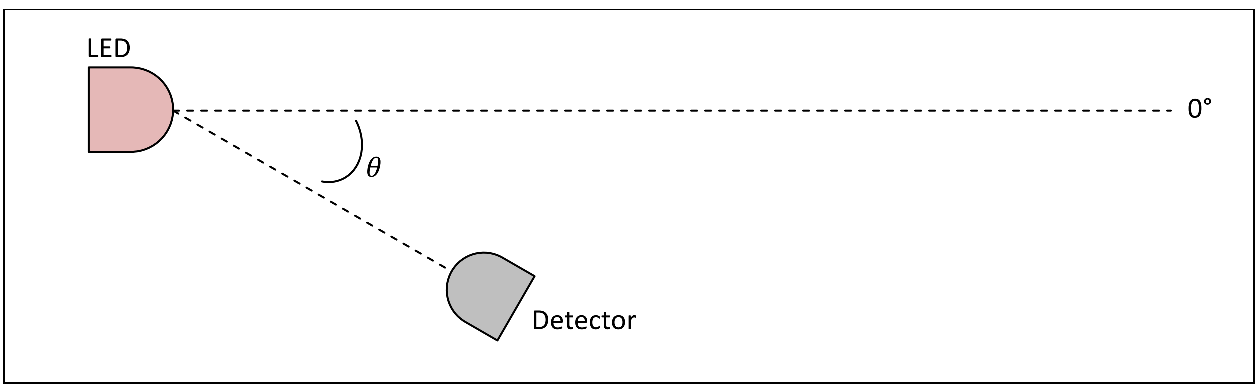

Figure 1: Definition of Observer Angle, θ

Provided the LED is producing a constant amount of optical power (its forward current is constant) and the separation between LED and Detector is held constant we can assume that the only variable that affects the detected amount of optical power is this angle.

1. On one breadboard, construct the following circuit (Figure 2, Left) using a **Red or Green** LED. If you want to know why the color is important, refer to the Spectral Sensitivity figure of the TEPT4400 phototransistor. Choose the values of R_D and V_{CC} so that the LED receives a current of 20mA. Ensure the LED overhangs the narrow edge of the breadboard (Figure 2, Right).

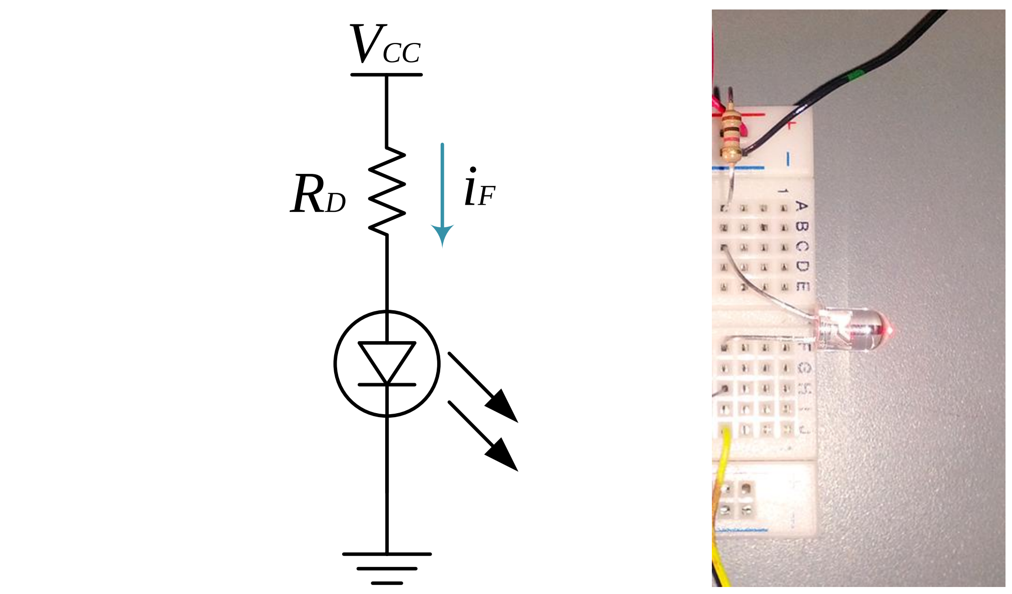

Figure 2: ***Left***, LED Driver Circuit. ***Right***, LED overhanging the narrow edge of a breadboard.

2. **On a separate breadboard,** construct the following circuit (Figure 3, Left) using the TEPT4400 phototransistor. Power the 5V rail using a separate supply channel (be careful with your power supply, do not exceed 5.5V in this circuit). Choose $R_{PD} = 1k\Omega$ for now. Ensure the phototransistor overhangs the narrow edge of the breadboard (Figure 3, Right).

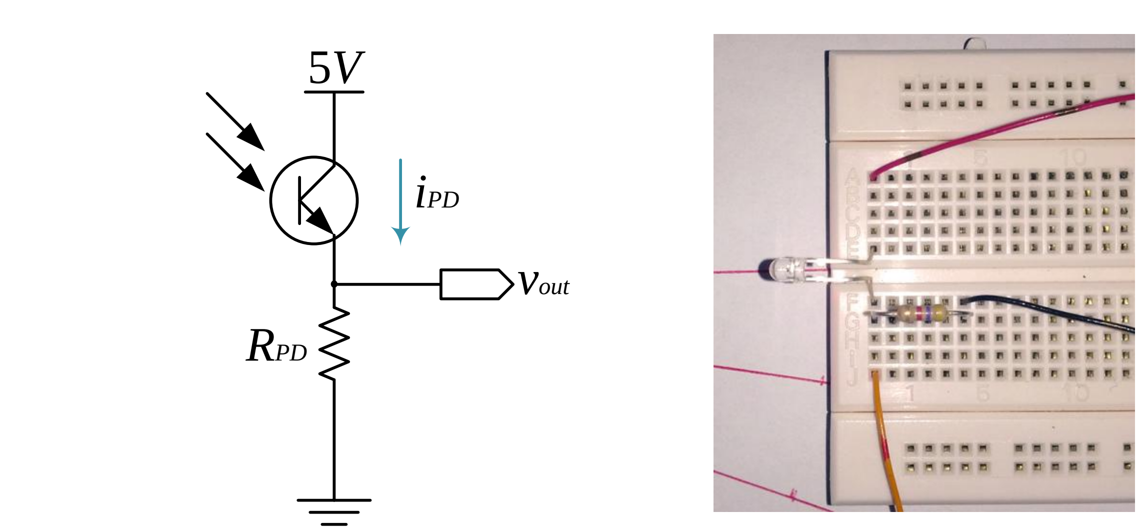

Figure 3: ***Left***, Phototransistor Circuit. ***Right***, PT overhanging the narrow edge of the breadboard.

3. Place both breadboards on the **Reference Angle Sheet** provided. Connect an oscilloscope probe to v_{out} and power the circuits. Position the two breadboards so that the two devices are axially aligned as below (Figure 4) along the 0° line. Keeping the alignment, reduce the lens-to-lens separation to about 3-5 cm. Finally, vary the resistor value R_{PD} until the voltage at v_{out} is roughly 4-4.5 volts. **Record the Resistor used for R_{PD}, and the value of the separation between the devices: you must keep these constant throughout. Record the voltage at v_{out}.**

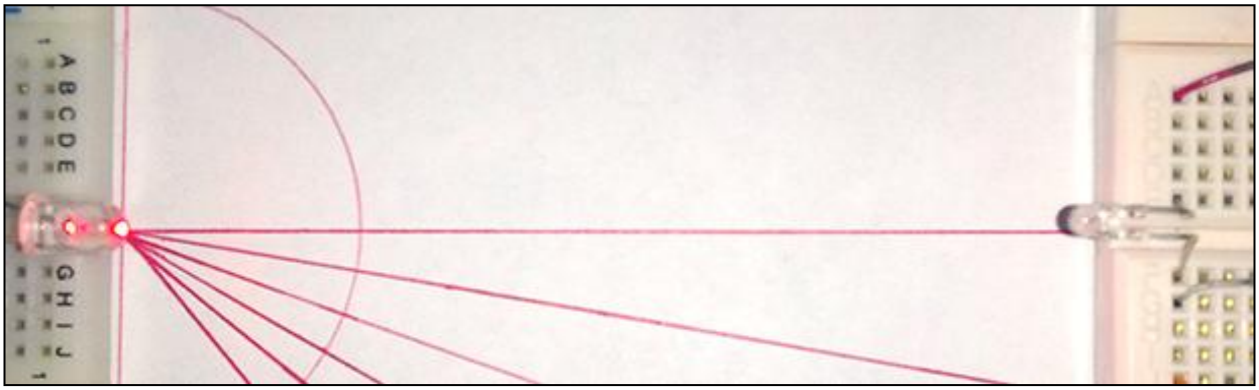

Figure 4: Alignment of LED and Phototransistor

4. In the denoted steps of ~5°, rotate the phototransistor breadboard about the LED while keeping the separation constant. **Record v_{out} at each step**.

5. The **Viewing Angle** of the LED is defined as *twice* the angle where the detected optical power will have dropped to 50% of the value detected at 0°. **Record the Part Number/Color of your LED. Determine the nominal Viewing Angle from the datasheet**. Due to our limited setup, we will take the first angle step where v_{out} stops changing appreciably to be our experimental Viewing Angle. **How do the Experimental and Nominal Viewing Angles compare**?

Part 2: Photocurrent vs. Separation Length

Unlike Lasers, which emit light in a *collimated* (column-like) beam, LEDs and other sources emit light in a *cone* (actually, the Radiation Pattern from the data sheet implies this fact!). As the waves emitted travel and spread, the optical power becomes less concentrated in space: the **Intensity** of the light (that is, its power per unit area) decreases with increasing propagation length (See Figure 5, below).

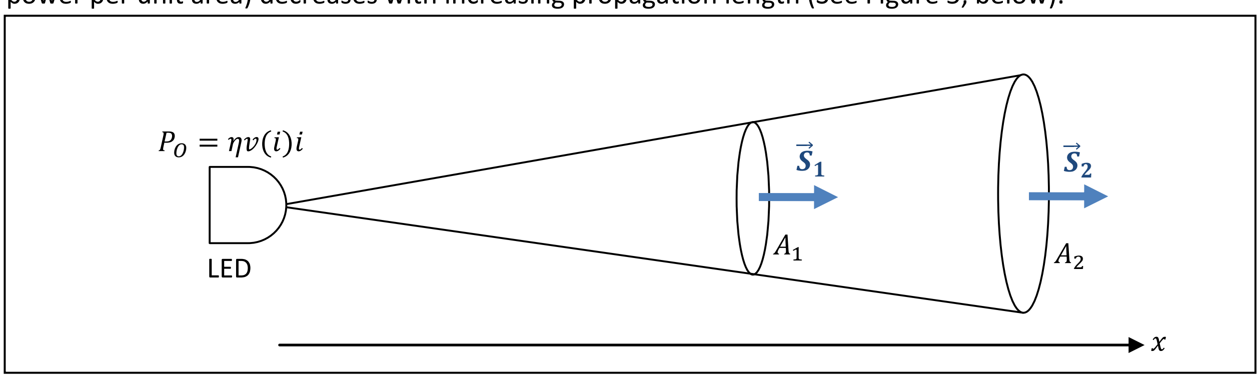

Figure 5: The optical power produced by the LED is constant (for a given current). The same optical power must flow through each disc as the waves propagate. Since the power is the same and the area increases, the intensity, S, must therefore decrease.

Since real detectors have a nonzero surface area, the optical power they detect (and therefore the photocurrent they produce) is actually proportional to the *intensity* of the light at the detector, not the total optical power produced by the LED (though under some circumstances the detector can capture practically all of the optical power being produced, such as being *very* close to the LED).

To model the effect increasing the separation length between LED and Detector has on the photocurrent developed, we can start by assuming that the LED and Detector are far apart and the radiation pattern of the LED is such that every point on the disc experiences a uniform Intensity, or:

$$\vec{\boldsymbol{S}}(x,y,z) = S\hat{\boldsymbol{n}}.$$

The limits of the cone are defined by the **Viewing Angle**, denoted by $2\theta_{1/2}$. Using basic trigonometry, we can relate the radius of the disc to the distance from the LED, x, as:

$$r = x\tan\left(2\theta_{1/2}\right).$$

So the area of the disc is:

$$A = A(x) = \pi x^2 \tan^2(2\theta_{1/2})\,.$$

Next, the total power passing through any arbitrary disc in the cone is given by:

$$P_O = \iint \vec{\boldsymbol{S}} \cdot d\vec{\boldsymbol{A}}\,.$$

but we know:

$$P_O = \eta v(i) i = const,$$

so:

$$P_O = \iint S(\hat{\boldsymbol{n}} \cdot \hat{\boldsymbol{n}}) dA = S \iint dA = SA\,.$$

Rearranging and inserting the known expression for A, we have:

$$S(x) = \frac{P_O}{\pi x^2 \tan^2(2\theta_{1/2})}\,.$$

As mentioned, the photocurrent developed by the detector is proportional to the intensity, through two constants: $\mathcal{R}$ (responsivity, in Amps per Watt), and A_{PD} (the area of the photodetector), so:

$$I_{PD} = \mathcal{R}P_{PD} = \mathcal{R}A_{PD}S(x) = \frac{\mathcal{R}A_{PD}P_O}{\pi x^2 \tan^2(2\theta_{1/2})}$$

We don't usually have access to the area of the photodetector, so we can simply state the more enlightening conclusion:

$$I_{PD} \propto \frac{1}{x^2}, \qquad x \gg 0$$

This explains how the photodetector current (photocurrent) behaves for large separation lengths. For very small separation lengths, the area of the disc would actually be totally enclosed by the area of the photodetector: as long as this is true, the detector is receiving (practically) 100% of the optical power, and would therefore be *constant* with respect to separation, or:

$$I_{PD} \propto x^0, \qquad x \approx 0$$

Graphing, the following characteristic is obtained, Figure 6:

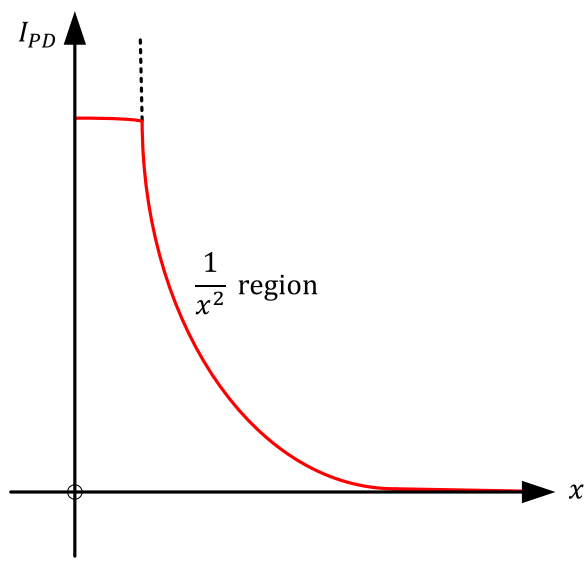

Figure 6: Theoretical photocurrent versus separation length curve.

Now it's your turn!

1. Return your LED and Phototransistor circuits to the axially aligned position at 0°, as in Figure 4. **In a new table of values, record the value of v_{out} at this separation length**.

2. At your discretion, choose additional separation lengths and **measure and record the corresponding value of v_{out}. You should make sure you have enough points adequately plot the relationship between the photocurrent and the separation length.**

Lab Questions / Report Requirements

A standard lab report (as described on ECED3901 BBLearn site) is required. This lab report does not need to duplicate material such as the procedure already recorded here. Be sure to include:

1. Recorded values of R_{PD}, the constant separation length used in Part 1, the LED Part Name/color used for the experiment, the nominal LED Viewing Angle, the experimental LED Viewing Angle, and a short comparison between the two Viewing Angles.

2. A table of values for Part 1: v_{out} versus Observer angle for each step given in the Reference Angle sheet.

3. A table of values for Part 2: v_{out} versus Separation length for many choices of Separation length.

4. Answers to the questions listed below (in a section called 'discussion'):

Questions:

1. Throughout the entire lab, we discussed photocurrent, yet we never once measured it. Making direct reference to the circuits used and what we know about photodiodes/phototransistors, can we calculate the photocurrent with the data collected?

2. Plot the table of values obtained in Part 1 using Excel, MATLAB, etc. How does this figure compare to the Radiation Pattern provided in the LED datasheet?

3. Plot the table of values obtained in Part 2 using Excel, MATLAB, etc. Does this figure reproduce the graph suggested in Figure 6?

4. The setup used in this experiment is very simple but also very limited: it is subject to interference from external sources. Identify the most obvious of these sources of interference. Can you propose an improvement to the circuit(s) that would allow you to *isolate* the signal of interest? (Hint: think about bandwidth!)

5. The relationship of received photocurrent over a distance is (at least approximately) an Inverse Square law. Using this as a starting point, explain why using simple LED-Phototransistor setups (without additional optics) is unreliable for long distances. Try to refer to SNR or Dynamic Range (or both!) in your answer.