ECE 342 Fall 2016 Optoelectronic Link Project
Lab 1: Transimpedance Amplifier Module for the Receiver: LEDs, Photodiodes and Transimpedance Amplifiers

Overview
This lab investigates the performance of light-emitting diodes (LEDs) and photodiode detectors. You'll use circuits similar to that shown below to use infrared, red, green, and blue LEDs with the OP999 photodiode.

As you select component values and power supply voltages, please be aware of the diode specifications provided on the course Blackboard site. Do not exceed the specified maximum values. For example, all of the LEDs have a maximum reverse-bias voltage of only 5 V.

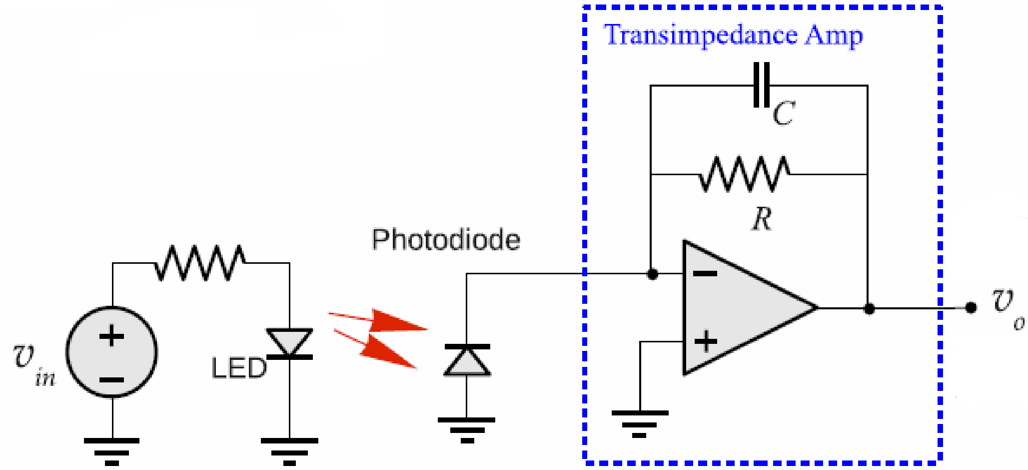

Figure 1. Optical link for Lab 2

The above circuit shows a standard transimpedance amplifier (TZA), used to convert the current output supplied by the photodiode to a measurable voltage. To reduce sensitivity to ambient light, the LED light source will be modulated by switching the LED on and off using a square wave with a frequency 20 kHz and 50% duty cycle. Use a function generator to produce $v_{in}(t)$. The photodiode output current drives the transimpedance amplifier, which in turn will drives the active bandpass filter which you will design and build in Lab 2.

The Photodiode
A photodiode generates a current as a function of the optical power incident on the device. A typical conversion efficiency would be less than one electron per photon, except for avalanche photodiodes and phototransistors, which have internal gain. It should be noted that the photodiode is a *light dependent current source*, which can be modeled by the circuit in figure 2:

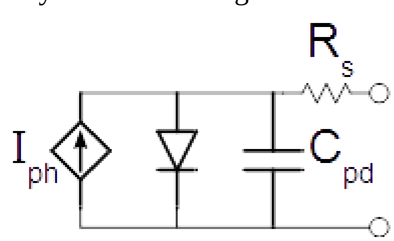

Figure 2. Equivalent circuit model of a photodiode as a light dependent current source (I_{ph}), in parallel with a diode, a capacitor (C_{pd}) and series resistance (R_s).

The photodiode model consists of a *light dependent current source* in parallel with a diode, a parasitic capacitance, and in series with a parasitic resistance. For the purposes of this lab, we need to be concerned only with the parasitic capacitance, which will limit the frequency bandwidth of the signals.

The datasheet for the OP999 diode is attached. Relevant information include its responsivity, spectral response, dark current and capacitance. *Responsivity* is the output current as a function of incident light's power at a fixed wavelength. *Spectral response* refers to the output current as a function of incident light's wavelength at a fixed optical power. *Dark current* is the current that flows through the diode in the equivalent circuit when no optical signal is present.

The spectral response of the photodiode will determine which LED is best for the optical link. The LED's output spectrum should overlap with the photodiode's spectral response as much as possible to get optimum signal strength. The dark current will determine the *noise floor* of the system, and therefore the minimum signal strength that is needed. Responsivity will allow us to determine the minimum optical power that is needed to generate a signal current measurable above the noise floor, and therefore the maximum distance between the photodiode and LED for a given LED output power.

The Transimpedance Amplifier

A transimpedance amplifier is an amplifier circuit which converts a current input into a voltage output. An op-amp based TZA as shown in figure 1 is generally preferred, as the signal (ac) voltage across the photodiode is nearly constant due to the virtual short between the non-inverting and inverting terminals of the op-amp. Hence the charge stored in its parasitic capacitance is also *nearly* constant, which almost eliminates the photodiode's parasitic capacitance from the frequency response, resulting in a large frequency bandwidth [1,2]. The upper limit to the 3 dB frequency bandwidth of the TZA is given by

$$f_{\text{limit}} = \sqrt{\frac{GBW}{2\pi RC_{pd}}} \qquad \text{(Eq.1)}$$

where *GBW* is the gain-bandwidth product of the operational amplifier, and *R* is the feedback resistor in figure 1, and C_{pd} is the parasitic capacitance of the photodiode in figure 2.

The TZA allows a large signal gain, large output voltage and large frequency bandwidth at once, compared to a simple photodetector biased with a large resistor followed by a voltage amplifier.

A downside of having a TZA with a large gain resistor is that it will probably be unstable. A real op-amp has a finite gain and a frequency response such that this gain drops with frequency and a phase shift occurs between its output voltage and input voltage. Stability under feedback will be studied in ECE 343 Electronics II. A solution to make the amplifier stable is to use a phase compensation capacitor, *C*, in parallel with the gain resistor, as shown in figure 1. The values for R and C are chosen to achieve a large gain while ensuring that the pole frequency $f_{3dB} = \frac{1}{2\pi RC}$ is small enough to avoid a 180° phase shift in the feedback loop.

Tasks

1. ***<u>Transimpedance Amplifier Design:</u>*** Complete the design of the TZA to operate at 20 kHz. Use component values which are stocked in the ECE store. The op-amp will be the LF347 (or other LF356 compatible op-amp), and the photodetector will be the OP999. Your design must include a "compensation capacitor" C as shown, which will limit the bandwidth of your amplifier. Select component values so that the gain of the amplifier is as large as possible, while keeping the pole location for the transimpedance amplifier at $f_{3dB} \geq 2f_0$ =40 kHz. The supply voltages should be ±12V[1].
2. ***<u>Simulation:</u>*** Use a simulation to determine the frequency response of the transimpedance amplifier. Be sure to accurately show the frequency region near f_0. Your gain values should be in units of volts per amperes or volts per microamperes. To model the photodiode, use a current source input with a 11 pF capacitor in parallel.

3. ***Diode/Detector Sensitivity:*** Build the transimpedance amplifier. Pulse each LED with a peak current of 40 mA using 50% duty cycle at a frequency of 20 kHz. Evaluate the response of your detector for each light source, and determine the diode for which your detector is most sensitive. Use this diode for Task 4.

4. ***Detector Construction:*** Measure your TZA's frequency response from (at least) a decade below f_0 to a decade above f_0.

5. ***Report and Demonstration:***

- Your *full* report should clearly describe your design process, and present your theoretical, simulated, and experimental results. All lab partners should collaborate in the writing of the report.
- Your *draft report* should be submitted to your TA electronically as a PDF file by Monday, 25 September 2017 at 2:00 PM. The TA will comment on your report by Wednesday, 27 September 2017 at 2:00 PM.
- The *final report* for this task should be submitted to your TA electronically as a PDF file by Friday, 29 September 2017 at 2:00 PM. Make sure that you make necessary corrections as indicated by Prof. Payne as well as the TAs.
- You'll be asked to schedule a short demonstration of your amplifier in the week of the due date. Each lab partner will be asked to reproduce a measurement from the report, and show where the measurement and measurement technique was recorded in their lab notebook. (Lab partners each receive a separate grade.)

References

[1] J. Graeme, Photodiode Amplifiers: Op Amp Solutions, McGraw-Hill, 1996
[2] M. Johnson, Photodetection and Measurement: Maximizing Performance in Optical Systems, McGraw-Hill Professional Engineering, 2003

Time Management and Lab Notebook Documentation
ECE 342 Fall 2016 Lab 1

Team #______ Names:________________________________

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The deadlines for Task 1 are given below. In unusual circumstances, you may request a change of one or more of the deadlines listed below. This request must be approved either Monday or Tuesday of the week in which the lab is assigned.

If a change in schedule is approved, have the instructor/TA change and initial the dates listed below, and sign here:

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1 September 2017	**Watch the lab briefing and review the deadlines given below**.
Thursday 13 September 4:50 PM	***(10 pts)*** **Circuit design and simulation results completed.** All designs must be entered into lab notebooks *TA's: Rate from 1(worst) to 5 (best)...* Clarity of Design Process: 1 2 3 4 5 Lab Notebook Procedures: 1 2 3 4 5 Simulations Completed: 1 2 3 4 5 Clarity of Simulation Results: 1 2 3 4 5 Successful Design Complete: 1 2 3 4 5 Early Check-off: 1 2 3 4 5 Signature: Date:
Thursday 20 September 4:50 PM	***(10 pts)*** **Experimental measurements completed and entered into lab notebooks.** *TA's: Rate from 1(worst) to 5 (best)...* Experimental Procedures Clearly Described: 1 2 3 4 5 Lab Notebook Procedures: 1 2 3 4 5 Preliminary Analysis of Results: 1 2 3 4 5 Clarity of Results Presentation: 1 2 3 4 5 Successful Design Demonstrated: 1 2 3 4 5 Early Check-Off: 1 2 3 4 5 Signature: Date:
Monday 25 September 2:00 PM	***(10 pts)*** **Rough draft of report completed by 2:00 PM**. Text should be complete, requiring editing primarily for grammar, consistency, or presentation. Submit as a PDF file.
As Scheduled:	***(30 pts)*** **Demonstration:** Reproduce a measurement from your report for a grader. Expect to show the grader where the requested measurement and measurement technique was recorded in your notebook.
Friday 29 September 2:00 PM	***(40 pts)*** **Final Report Due by 2:00 PM.** Turn in your final task report as a PDF file. Reports are not accepted late.