Photodiodes and lock-in amplifiers: Signal and noise
Physics 240

Purpose:

In this lab you will become familiar with lock-in amplifiers and use them to measure extremely small optical signals on a photodiode detector. You will learn about the different kinds of noise sources and how to reduce their influence.

Equipment:

In lab:
- Lock-in amplifier
- Lock-in amplifier manual
- Datasheet for LMC6001 op-amp
- Application note for UDT sensors Photoconductive Series photodiodes

In box:
- 1 LMC6001 op-amp
- 2 10-pin dip sockets
- 1 red, 1 orange, and 1 yellow high efficiency LED
- 1 M resistor
- 4 AA batteries
- 2 AA battery holders
- UDT PIN13DI photodiode

Grading:

Take notes in your laboratory notebooks except where indicated that it’s not necessary. Your lab notebook will be graded during the experiment; make sure you are keeping the notes as you are doing the experiment. You will also be graded on completion of each part of the experiment.

The grading will be as follows:
- Build LED and photodiode circuits and verify they work - 10 pts.
- Determine LED efficiencies - 10 pts.
- Measure LED detection limit - 5 pts.
- Measure LED noise limitations - 10 pts.
- Laboratory notebook - 15 pts.

LED’s and Photodiodes:

Troubleshooting suggestion: read each section completely and make sure you understand it before proceeding with the measurement.

Build the LED and photodiode circuits

Build the following LED circuit and photodiode amplifier circuits in your two separate 240 circuit boxes. For the amplifier circuit you will use the 8 pin dip sockets to hold both the LED and the LMC6001 op-amp and thereby avoid overheating them when soldering.

Since the LMC6001 may be damaged by a supply voltage over ±8 volts, power it with ±3 volts from the AA batteries. Verify that the amplifier circuits works by monitoring the amplifier output with the oscilloscope while pointing the photodiode at the room lights (observe the 60 Hz oscillations). Now use a five volt supply to drive the LED circuit and verify that you can detect the LED light with the photodiode.

Determine the LED efficiency

If you use the oscilloscope to make your voltage measurements, make sure the “cal” knob is in the calibrated position.

You will measure the efficiency of each of the three colors of LED (red, yellow, and orange) in your electronics box. The efficiency $E$ is the ratio of the optical power out of the LED to the current in (in units
Determine a procedure to use the photodiode to make this efficiency measurement. You will need to take into account the responsivity $R$ of the photodiode. The responsivity of the photodiode is the ratio of the current produced by the photodiode to the optical power incident on the active surface of the diode

$$R = \frac{I_{\text{out}}}{P_{\text{in}}}.$$

The responsivity is different at different wavelengths. Use the “typical spectral response graph” on page 1 of the Application note for UDT sensors “Photoconductive Series” photodiodes. Not all of the light generated by the LED will fall on the active area of the photodiode; how will you account for that? Use your procedure to measure the LED efficiency remembering to carefully document your procedure, your data, and any observations in your notebook as you make the measurements. The efficiency of an LED in terms of photons out per electron in is called quantum efficiency. What is the quantum efficiency of each of the three LED’s?

**Lock-in amplifier**

**Learn the basic function of the lock-in amplifier**

- Read pages 3-1 through 3-3 of the lock-in manual
- Work through Getting Started in the Lock-in manual (No lab notes need be taken during this tutorial)

**Use a light emitting diode (LED) as a transmitter and a photodiode as a receiver to make a transmission measurement**

Remember to take notes on your measurements in your lab notebook.

Use the sine wave output from the lock-in to create a modulated signal at 500 Hz from the LED. Use an oscilloscope and then the lock-in amplifier to read the signal from the photodiode. How does this signal vary with distance between the LED and the photodiode? Does the phase vary?

**Determine the noise limitations of the photodiode measurement at 500 Hz.**

- Read pages 3-21 through 3-25 in the lock-in manual.
• Measure the noise of the photodiode and lock-in system (LED off) with and without the room light on the photodiode and determine the optical detection limit in a 1 Hz bandwidth (ENBW). The detection limit is the amount of light detected when the signal has decreased to the point where it is equal to the noise. Here the signal to noise ratio (S/N) is equal to one. Try this with both the oscilloscope and the lock-in amplifier.

• Calculate the shot noise and Johnson noise of the setup with and without the room lights on. What resistance creates the bulk of the Johnson noise? Compare the calculated values to the measured noise values. What is the dominant source of noise? Would increasing the size of the feedback resistor increase or decrease the S/N for small signal measurements?

• With the detector 1 meter away from the LED, how small an ac current in the diode can be detected? Is the smallest detectable current frequency dependant?

• **Challenge:** How far can the detector be from the diode and still detect the signal caused by a 5 mA modulation at 1.7 kHz?