ECE 35 Lab 3 Analog Optical Data Link

The objective of this lab is to design and build an analog optical data link. Optical links are light emission and detection that can pass analog or digital signals, but most are optimized for the latter with low interference through free space and with excellent rate of data transfer. They are also excellent isolators with no physical contact/connection requirements. Optical links are used for long distance communications via fiber lines but they are also commonly used for a wide variety of short distance applications such as the fiber-channel disc interfaces within hard drives and simple TV infrared (IR) remote controls. The circuit will make use of operational amplifiers as well as photonic devices such as LED and photodiode.

Prelab: You should follow the introduction of op-amp, LEDs and photodiodes in sections 1 and 2 below. Complete circuit analysis of the Lab Exercise. Attach your work to your lab report and be prepared to show it to the TA when asked. You should understand the use of an op-amp to build a voltage-controlled current-source, and as a current-to-voltage transducer.

1. Operational Amplifiers (Op-amps): Op-amps are a type of active integrated circuit to help with circuit design. You must read §6.1~6.3 of Dorf and Svoboda and familiarize yourself with the concept of ideal op-amps before coming to this lab. The op-amp in this lab is the LF411 chip. It is considered an ideal op-amp when it operates within the linear limit stated in its datasheet (available for download on class website), that is, with output node voltage always smaller than V_{sat} and output node current smaller than i_{sat}. Remember to make use of the two basic rules of an ideal op-amp when solving circuits: First, input currents are zero ($i_1 = 0$, $i_2 = 0$); Second, input voltages are equal: $v_1 = v_2$.

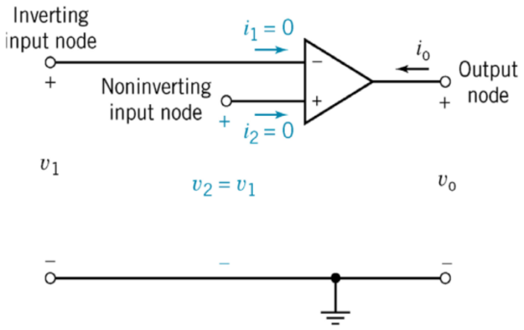


Fig. 1 Ideal op-amp

Lab Exercise: Inverting Amplifier (Fig. 2) using LF411. For prelab, if $R_1 = 1$ k, $R_2 = 10$ k, derive the voltage gain from the input to the output: $A_v = V\text{out}/V\text{in}$. If the input voltage is a triangular waveform that is ±1V, what is the relation of the output to the input waveform? What is the peak value of the output? What if input voltage is increased to between ±3V? (Hint: consider limitations of output voltage from the power supply rail and V_{sat} from the LF411 datasheet). Build the circuit on your breadboard and use the LF411 diagram on the last page. The supply terminals, pin 4 and pin 7 must be connected to ±15 V. Ground pin 3. The *balance* terminals and pin 8 can be left "floating", i.e. not connected. Connect your resistors in their appropriate pins to form an Inverting Amplifier. Set a 10Hz, ±1V triangular wave as input, no offset. Display both input and output traces on the O-scope. Verify the gain with your calculations. Now increase the input to ±3V, describe the change in output. Lastly, with ±1V input, increase the frequency to 10kHz, is the gain still ×10? If not, what could be the reasons?

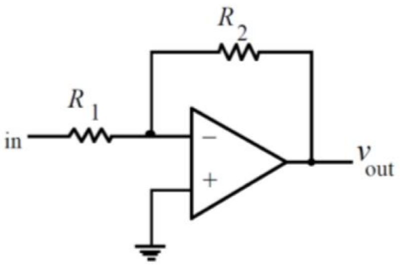
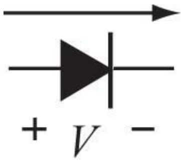


Fig. 2 Inverting Amplifier

2. LED and Photodiode Devices: Light-signal is generated by a *light-emitting diode* (LED) which converts current to light and a *photodiode* converts light to current as signal receiver. A diode is a simple two-terminal component with two wires sticking out. A diode has polarity. It’s most basic property is that current flows easily in one direction but not in the reverse direction because of its nonlinear semiconductor property within. The detailed mechanism is not important for us in this class.

A diode’s “forward bias” direction is sketched as:



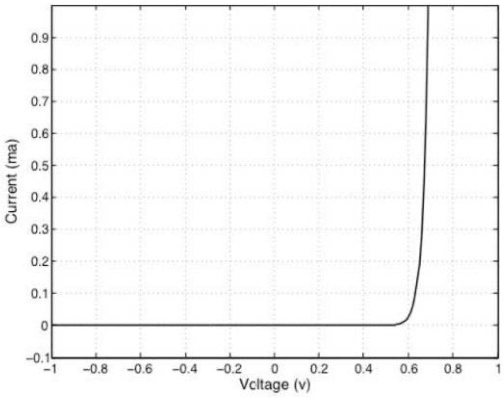


Fig. 3 Typical nonlinear diode I-V behavior

With the arrow points to the current flow direction. LEDs convert current into light with the light power output (watts) proportional to forward current (amps): $P = C_{\text{LED}} \cdot I$. The color (wavelength) of the light is defined by a combination of gallium, arsenic and phosphorus atoms in the diode. One can simply adjust the brightness of an LED by changing its current. However, a diode is a nonlinear device with the forward current increasing very rapidly, almost exponentially after a “knee voltage” which depends on the type of diode (Fig. 3). This means that unlike a resistor, it is almost impossible to control the current in an LED by fixing its voltage because even a very small fluctuation in voltage will lead to huge variation in its current and its light output. **Thus LEDs need to be driven by a precise current source, not a voltage source.** In the lab, and in electronics in general, we normally have quite good voltage sources (batteries, power supply etc.) but we seldom have good current sources. **To drive the LED linearly we need a voltage-controlled current source. We will design a voltage-controlled current-source (VCCS) as LED driver for this lab**. This can be done with an ideal op-amp as sketched in Fig. 4(a) below. Analyze this circuit and derive the LED current I as a function of Vin and R (Hint: Since the op-amp input current is zero, the same current must go through the LED as the resistor).

Photodiodes are diodes that are reverse biased, i.e. when the voltage across the diode is backwards. They conduct a very small reverse current (called dark current). However, photodiodes will increase this reverse current when illuminated by photons. This is the inverse process to LED emission since one photon creates roughly a conducting electron that contributes to electrical current. This reverse “photocurrent” is linearly proportional to the incoming optical power, $I = C_{\text{PD}} \cdot P$. Photodiodes are very useful detectors of light intensity. Similarly in the lab and in practice, it is always more convenient to readout a voltage signal than a current. To use the photodiode as optical receiver we need a circuit to convert its photocurrent into voltage readout. This can be done with an ideal op-amp as sketched in Fig. 4(b) below. Analyze this circuit and derive Vout as a function of photocurrent I and R . (Hint: The negative input terminal is a “virtual ground.” The voltage across the diode is constant.)

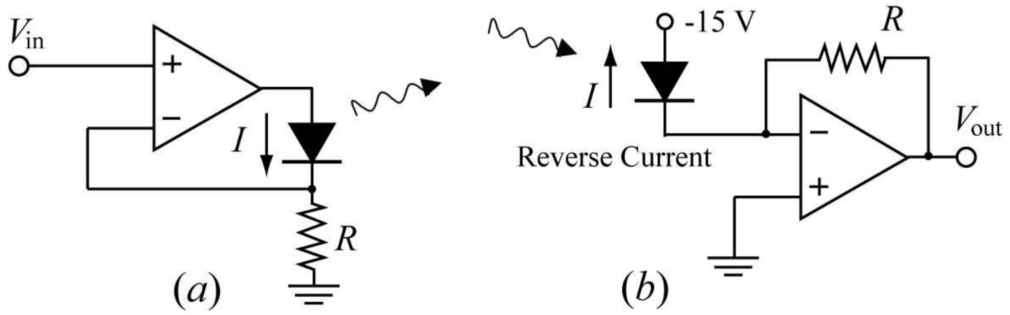
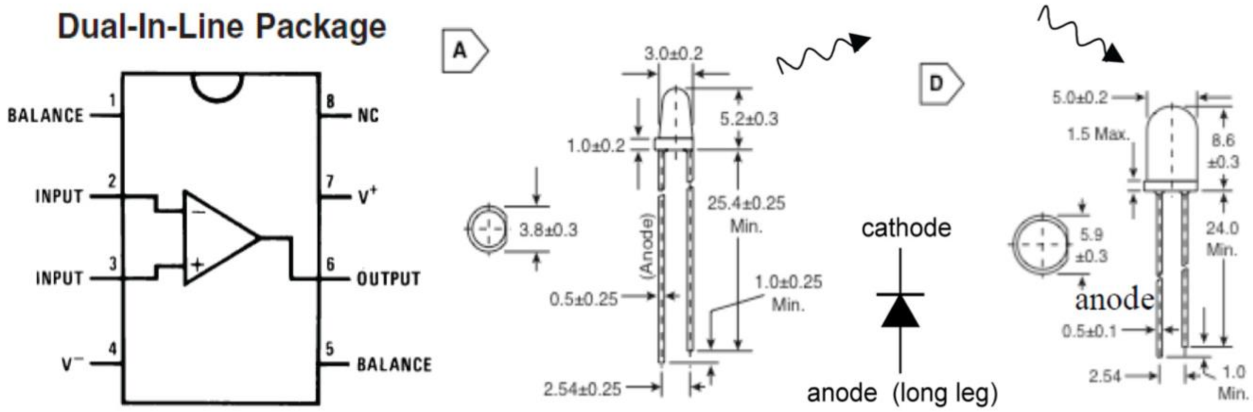


Fig. 4 (a) LED driver and (b) Photodiode readout circuit

3. Test the LED driver: Setup the LED driver circuit using an LF411 Op-amp and a red LED (**notice the difference in polarity of the diagram above to what the actual pin outs for LF411**). We have the LED stored in a container labeled “bright red LEDs.” The LED part number is1224SDRCS530-A4. Connect the longer pin of the LED to the output of the Op-amp. The *balance* terminals and pin 8 can be left “floating”, i.e. not connected. The supply terminals must be connected to ±15 V. The supply ground must be connected to the signal generator ground and the resistor although there is no ground connection on the chip. Use a 1k resistor so 10 V corresponds to 10 mA. Adjust the signal generator amplitude and offset controls, until you have a sine wave of 0.5 Hz with a peak to peak voltage of 10 V and a minimum voltage of 0 V. You should be able to see the brightness of the LED change sinusoidally.

4. Test the photodetector: Set up the photodetector circuit about 5 cm from the driver circuit, using another LF411 Op-amp and the photodiode (part # EAPDLP05RDDA1) with a 1 M resistor. The short leg of the photodetector will connect to the same pin as the resistor. The *balance* and supply terminals are connected the same as for the LED driver. In this case, ground pin 3. Connect channel one of the O-scope to the function generator, the LED driver circuit. Connect the channel two probe to the output of the photo detector circuit. Aim the red LED at the photodiode (they emit and receive out of their tops). You should see the output reflecting the change in LED brightness that you can see. You will also see significant noise from room lights and electrical interference. Move your hand over the photo detector and observe the background change. Put something dark around the photo detector, e.g. the cap off a ball point pen, and measure the voltage. Use it to calculate the “dark current”. Make a hard copy of the scope display showing the LED driver and the photo detector response. Change the scope waveform to a triangle wave. The photo detector should also become a triangle wave. Make a copy of this plot too.

Put a 5 pF capacitor across (in parallel with) the 1 M resistor. What happens to the photodetector signal? You may have to change the wave into a square wave and zoom in on one of the waves to notice anything. Make another hard copy. Explain what you think might be happening. Demonstrate your circuit to the TA and have your plots signed.



LF 411 Op-amp

351-3230-RC LED

PD333-2C Photodiode

Fig. 4 LF 411 Op-amp, LED and photodiode components in this lab

The complete datasheets for these devices are widely available online and also on the class website.

Discuss in your lab report:

- Compare your prelab analysis to the results observed with the inverting amplifier. Do they agree? If not, explain
- How does the frequency effect the V_{out}/V_{in} of the inverting amplifier? Does it agree with your prelab analysis?
- Why is there clipping at the output of the Op-Amp when you increase the input voltage V_i?
- For the LED driver circuit, discuss how it is affectively a voltage controlled current source, VCCS?
- For the Photodetector circuit, discuss how it is affectively a current controlled voltage source, CCVS?
- What is observed between the LED driver signal and the signal for the Photodetector? How does changing the input signal affect the Photodetector output?
- Discuss what dark current is and how you obtained its value for this experiment
- What did you observed when you connected the capacitor in parallel with the 1M ohm resistor? What is the purpose of the capacitor for this experiment?