

**University of Pennsylvania**

**Electrical & Systems Engineering Undergraduate Laboratories**

**ESE 112: Introduction to Electrical & Systems Engineering**

**Lab 2: Light Sensor Circuit**

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**Objective**

The objective for this lab is to introduce students to basic application of operational amplifier (op-amp), circuit assembly and prototyping.

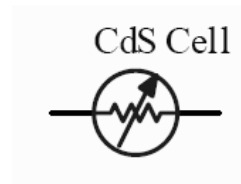
**Background**

**CdS (Cadmium Sulfide) Cell**

CdS cell is in essence a resistor that changes its value with light intensity. The resistance of the CdS cell is lower in bright light and higher in low light. They are relatively cheap and commonly used as light sensors in applications where response time is not a design constraint.



a.



b.

Figure 1 – CdS Cell Pictures (a) and Circuit Representation (b).

CdS cell comes in different shape and size as shown in figure 1a. There is no hard convention in representing a CdS cell in circuit diagrams but the symbol that we will be using is shown in figure 1b.

## Operational Amplifiers (Op-Amps)

Op-amps are extremely useful and common devices that are used as voltage amplifiers. Op-amps are active elements that need to be powered by an outside source as opposing to passive devices such as resistors. The most common op-amp found in academia is the LM741 in the 8-pin dual in-line Package (8-DIP) (see figure 2a). The DIP packaging makes the pin spacing compatible with protoboards which serves the purposes of prototyping and education.

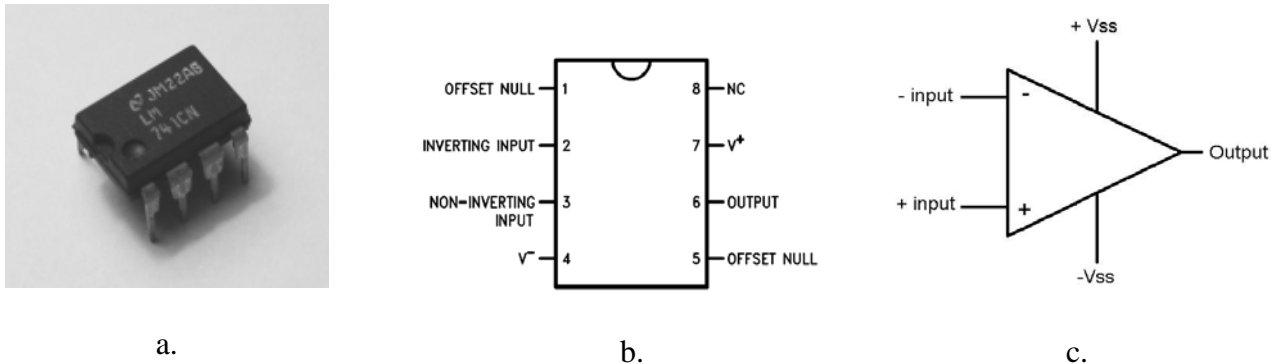


Figure 2 – 8-DIP LM741 Op-Amp picture (a), pinout (b). Circuit Representation of an Op-Amp (c).

Observe the four pins on each side of the op-amp in figure 2a. Notice that +Vss in figure 2c and V+ in figure 2b are referring to the same positive supply terminal. The same assumptions can be made that -Vss is V-, non-inverting input is + input, and inverting input is - input. Keep in mind that different documentations may refer to the same thing with different names or symbols. It is up to the readers' experience to be able to make correct assumptions. However, you should go to great lengths to maintain consistency in your own documents. The inconsistencies shown here are solely for illustration purposes. This particular op-amp is powered through the +Vss and -Vss terminals (see figure 2c). The LM741 in particular requires a negative supply (ie. supply +10V to +Vss and -10V to -Vss). The electrical specification and functional description of electrical components are described in what is called a datasheet or spec (short for specification) sheet provided by the manufacturer. There are several who make the LM741, the picture shown in figure 2a is one made by National Instruments (observe the logo). Learning how to read spec sheets is a very useful skill and will determine how quickly one can pull out information from the document and make use of that knowledge. Thus this skill is essential for engineers when it comes to integrating systems with hundreds or even thousands of components each having a separate datasheet. To provide a practical example, one may be interested in knowing what voltage and current that is required to power the op-amp. Too much will burn the IC and too little will result in the IC not turning on. This information can be found in the datasheet's electrical specification section.

Two common configurations of the op-amp are the non-inverting amplifier and the inverting amplifier. The inverting configuration is shown in Figure 2.

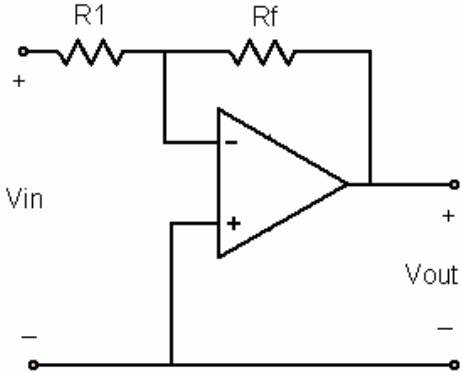


Figure 2: Inverting Amplifier

The inverting amplifier takes an input and output an amplified, inverted signal. The gain of the amplifier is given by:

$$A = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_1}$$

The non-inverting configuration is shown in Figure 3.

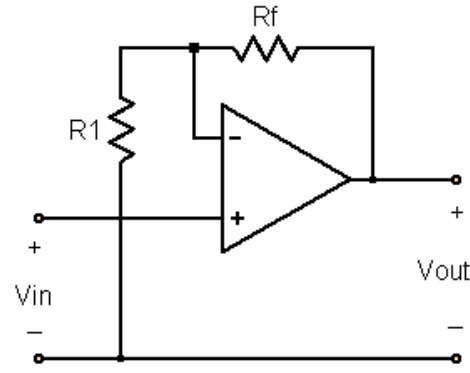


Figure 3: Non-inverting Amplifier

The non-inverting amplifier takes an input and output an amplified, non-inverted signal. The gain of the amplifier is given by:

$$A = \frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_1}$$

The gain of an op-amp can be viewed as the multiplication factor that determines the output from the input voltage. As an example for a gain of 10 ( $A=10$ ) in a non-inverting configuration, the op-amp circuit should output 10V for an input of 1V ( $1V \times 10 = 10V$ ). It is important to understand that this can only happen when the supply voltage is equal to or larger than 10V. Convince yourself by intuition that the circuit cannot generate a voltage level higher than its own supply voltage.

### Light Emitting Diode (LED)

An LEDs is a low power light source found in many consumer electronics such as televisions, radio, DVD players, and video game console. Common uses of LEDs are indicator light in electronic systems, displays (alarm clocks), and higher power applications like flashlights or household lighting. LEDs come in many different colors, shape, size and power rating. The most commonly used in academia and hobbyist are the 5mm diameter red color LEDs (picture shown in figure 4a).

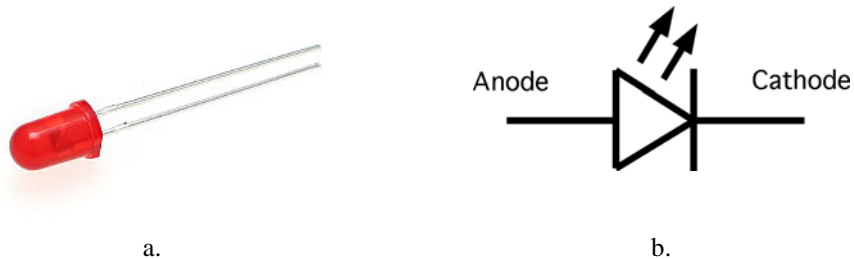


Figure 4 – LED Picture (a), circuit representation (b)

The circuit representation of an LED is shown in figure 4b, the arrows indicate light being emitted. A regular diode has the same symbol without the arrows. The anode is the positive side of the LED usually the longer of the two legs. However, some manufacturer, although rare, uses the longer leg as the anode. The user must make sure of this point or risk burning out the LED. Current should only flows from the anode to the cathode and the voltage drop across the LED is referred to as the forward-biased voltage of the diode. LEDs are also rated for the recommended amount of current it could take. For our purposes, this lab will assume the LEDs are rated at 2.2V and 20mA which means that the voltage drop across the LED should be 2.2V and at that voltage 20mA of current will flow through it. Any larger amount of current flowing through will risk damaging the device. It is a common practice to use put a current limiting resistor in series with an LED. This is done in order to power LED from a constant voltage source such as 5V or 3.3V commonly used to power transistors and CMOS ICs.

## Material

Protoboard  
Clear Green LED  
CdS Cell  
LM358 Op-amp  
Resistors  
Potentiometer  
9V Battery with battery clip  
DMM  
Hookup wires

## Prelab

1. Search the web for information about a protoboard (also known as breadboard). Explain with your own words how they are used and the internal connections. Below is a picture of a protoboard.

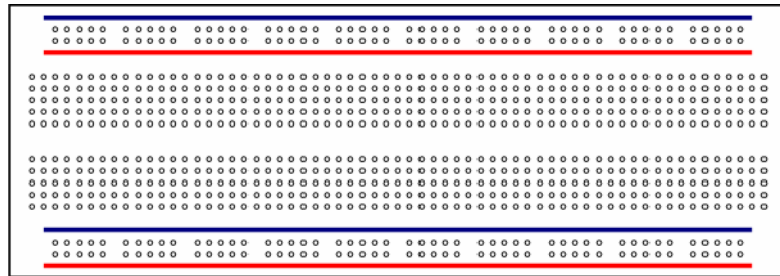


Figure 5 - Protoboard

2. The op-amp that we will be using in this lab is not the LM741 but the LM358. The LM358 is a single supply (does not require negative voltage supply) dual op-amp (has 2 op-amp circuits inside) that we will use to design our light sensor circuit. Search and download the datasheet for the LM358. Look for the pin assignment of the op-amp in the document and bring a hard copy to class.
3. Design (ie. find  $R_f$  and  $R_1$ ) a non-inverting op-amp circuit with gain 10 ( $A=10$ ). Draw a diagram of your design. Make sure the components are labeled and values are clearly shown. Can a gain of less than 1 be attained with a non-inverting op-amp?
4. Design an inverting op-amp circuit with gain -12 ( $A=-12$ ). Draw a diagram of your design. Make sure the components are labeled and values are clearly shown.

5. With a 10V supply voltage, we need to find a value of R1 such that the LED would not be damaged. Using KVL from lab 1, calculate the current limiting resistor R1 given that the LED is rated at 2.2V, 20mA. That is the voltage drop across the LED is 2.2V and the recommended current is going through the LED is 20mA. *HINT: the current going through the LED is the same current that goes through R1.*

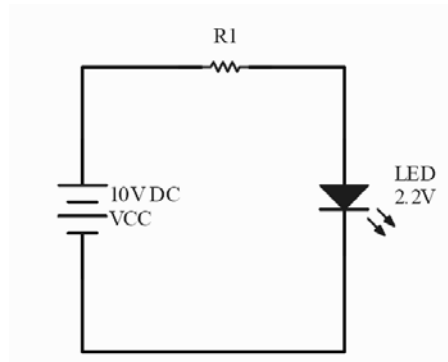


Figure 6 – LED Circuit 1

### Lab Instructions

1. Measure and record the voltage of the battery.
2. Measure and tabulate the actual and nominal value of the two resistors in figure 7. Calculate the voltage across R2 and R3 using the measured values of battery voltage and resistances. Build the resistor circuit and measure the voltage across R2 and R3. Tabulate the measured and calculated values, and comment on the similarities/differences.

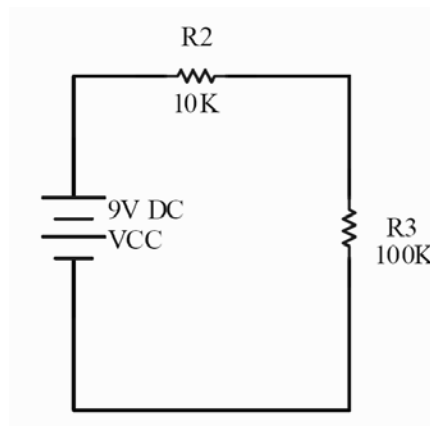


Figure 7 – Resistor Circuit

3. Configure the LED circuit shown in figure 8 onto a protoboard. The exact value of the resistor calculated may not exist. Use the closest resistor value that you can find but be on the safe side. In other words, choose a resistor with value closest to the calculated resistance that will result in no more than 20mA current. Measure the voltage drop across the LED.

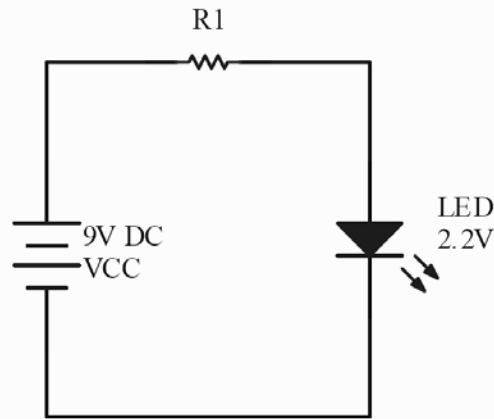


Figure 8 – LED Circuit 2

4. Design a non-inverting op-amp circuit that will yield a gain of 2 ( $A=2$ ). Draw the diagram of the circuit. Build the circuit that you have just designed.
5. Add a potentiometer as a voltage divider to be able to change the input voltage of your circuit in part 4 and observe the change with a DMM. Using an increment of 0.5V, change the input voltage from 0-9V and tabulate the input and output voltage of your circuit. Plot  $V_{out}$  as a function of  $V_{in}$ . In another column, calculate the gain at every input voltage level.
6. Measure and record the resistance range of the CdS cell when exposed to ambient light and when you cover it with your hand (no light).
7. Using an LED, CdS cell, potentiometer, resistors, and LM358 op-amp in non-inverting configuration design an op-amp circuit that will turn on an LED when the room is dark.  
*Hint: You should carefully analyze at the properties of the CdS cell and the gain equation of the op-amp.*

## Questions

1. Give an example (other than a light sensor circuit) and description of where an op-amp may be used.
2. Describe some applications of light sensors in robotic systems.
3. Give a description of how your circuit could be interface with a computer or robotic system.
4. Explain the plot in part 5 and comment on the calculation results.
5. Explain the choices you made in your design of the light sensor circuit and back it up with mathematical analysis.
6. How would you design a circuit that will turn OFF an LED when the room is dark?