# RBE 1001 **Homework #8**: The photoresistor and op-amp

## Introduction

In other homework, you will explore the theory behind the voltage divider and op-amps. Here, you will build a night light to put those concepts into practice and prepare you for the upcoming lab. Be sure to answer the worksheet problems at the end of this handout as you work through the steps.

You will build a circuit that reacts to the amount of light in a space and turns on an LED (the "night light") when the sensor detects that it is dark. For the first part, you will not use a microcontroller, but instead use passive electronics and an op-amp wired as a *comparator*, the simplest configuration for an op-amp.[1] Then you'll use the microcontroller to perform the same function, but with code!

### Resources

- The datasheet for the L272 op-amp can be found <u>here</u> (as well as on canvas).

### The comparator

The operational amplifier, or *op-amp*, gets its name from the fact that op-amps were once commonly used to perform mathematical operations, though much of that functionality is now done using microprocessors. Still, op-amps can be configured to add, subtract, integrate, differentiate, and perform other operations.

In its simplest configuration, an op-amp acts as a *comparator*, where its output depends on the comparison of two inputs. To understand how it works, let's look at a simplified model of an op-amp.

The op-amp shown in Figure 1 has five connections. The power connections, $V_{s+}$ and $V_{s-}$, are referred to as the *rails* – we'll discuss why in a moment. In addition, voltage signals are connected to two inputs: the *non-inverting* input, labelled '+', and the *inverting* input, labelled '–'. The corresponding voltages are referred to as $V_+$ and $V_-$. Finally, the output pin produces a voltage, $V_{out}$, given by:

[1] You won't use a microcontroller for the night light, but you will use one to measure voltages. You'll also use it to supply 3.3 V and ground.

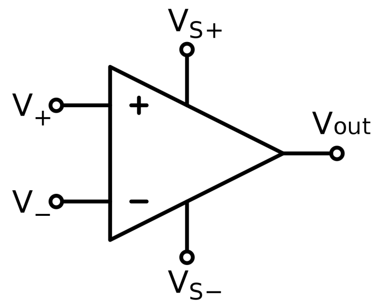


Figure 1: A typical op-amp symbol. Note that the rail connections, $V_{s^+}$ and $V_{s^-}$, are often omitted from schematics, since they're implied.

$$V_{out} = G\left[V_+ \; - \; V_-\right]$$

where $G$ is some *very large* gain, typically in the tens of thousands or more. For the simple model here and subsequent assignments, we'll consider $G$ infinite!

The reason the *output voltage* isn't infinite is that it is constrained by the rails – you can't go outside the rails! In fact, only certain op-amps can reach the rails (and therefore are called "rail-to-rail" op-amps); most produce outputs near, but not at the rails. The end result for our simplified analysis is that the output of the comparator can be described by:

$$V_{out} \approx \begin{cases} V_{s^+} & \text{if} \quad V_+ > V_- \\ V_{s^-} & \text{if} \quad V_+ < V_- \end{cases}$$

That is, it produces a `HIGH` voltage if $V_+ > V_-$ and `LOW` if the opposite is true.

## Building the night light

Consider the circuit shown in Figure 2. Conceptually, what will happen when light shines on the photoresistor? Will the output voltage of the voltage divider go up or down? How will the comparator respond?

### Procedure

Your first task is to determine a good choice of resistor, $R$, for the high-side leg of the voltage divider that contains the photoresistor. You'll want the output of the voltage divider to have a wide range to improve the sensitivity of the night light.

1. For the photoresistor, use a resistance of 600 Ohm in the light, and 2.5 kOhm in the dark.

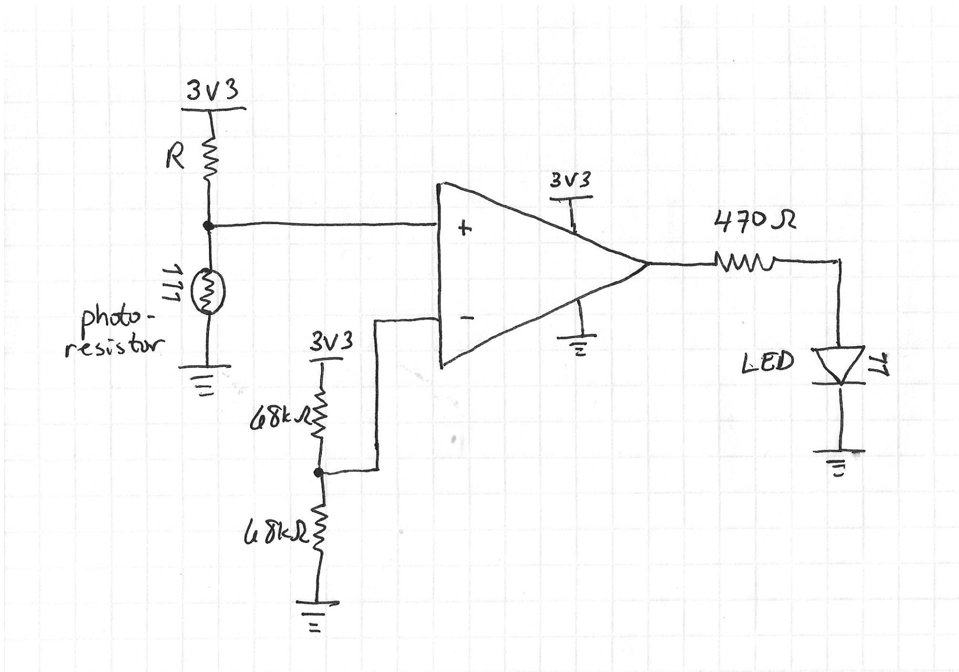


Figure 2: Night light circuit.

2. It can be shown that a resistor that is the *geometric mean* (look it up) of the resistances in light and dark will give the greatest response of the voltage divider. Find a common resistor near this value. **Err on the higher side for your resistor.**

3. Get a properly sized resistor from the Robotics Lab and build the voltage divider circuit. Use your ESP32 board to supply 3.3 V and ground.

4. Connect the junction between the fixed resistor and the photoresistor to pin 26 on your ESP32, which is one of the (many) ADC pins on the ESP32. Open the `adc.ino` program found on canvas and run it (either open it directly or cut-and-paste the code into a new project). The code samples the ADC on pin 26 every 250 ms and prints the result to the screen.

5. Modify the code so that, in addition to the raw ADC value, it also prints the equivalent voltage. $V_{ref}$ for the ESP32's 12-bit ADC is 3.3 V.

6. Using your make-shift voltmeter, measure the voltage of at the junction between the fixed resistor and the photoresistor in both light and dark. Record the values.

7. Complete the circuit shown in Figure 2. The pinout of the op-amp can be found on the datasheet. Note that the 8-pin chip that you are using actually has two independent op-amps in it - pick one and go with it. Walk through the functionality of the comparator to prove to yourself that the LED on the output will light when the photoresistor is dark and vice versa.

8. Test the circuit. Does it work as expected? Note, if the night light stays on or off regardless of the amount of light, you'll need to revisit your resistor selection above.

9. Consider what would happen if you removed the LED and its resistor and connected the output of the comparator to a motor, as shown in Figure 3. Will the motor spin when the photoresistor is in the light or dark? How could you reverse the behavior?

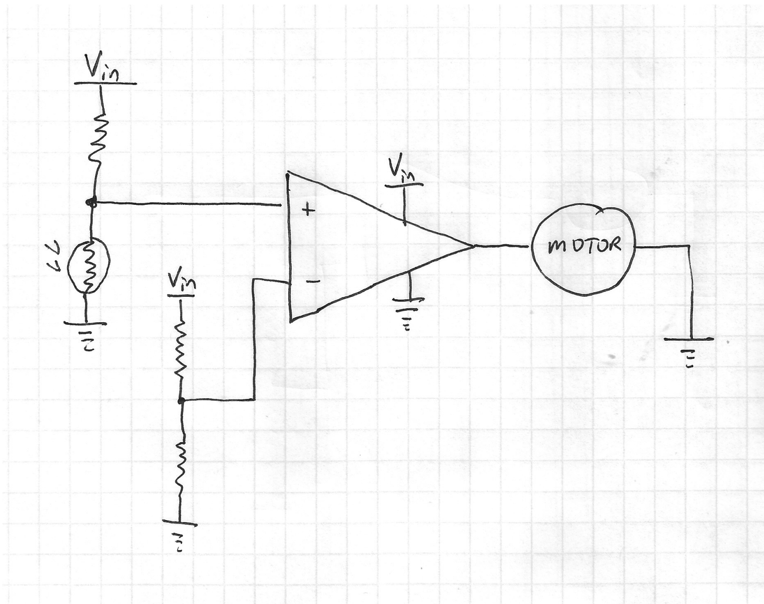


Figure 3: Comparator circuit to power a motor. The resistor sizes are somewhat arbitrary, but you can consider them the same as in the previous exercise.

## A night light with code

You've just built a night light without a microcontroller; now let's build one with a microcontroller.

### Procedure

1. Starting with the skeleton `adc.ino` code above, and using the `blink.ino` program from last week as inspiration, write a program that does the following:
   - Reads the ADC value of the junction between the photoresistor and fixed resistor,
   - Converts that reading to a voltage,
   - Compares the voltage to some threshold of your choosing, and
   - Turns a LED on or off as expected for a night light.
2. Add statements to the `loop()` to output the following to the screen:
   - ADC reading,
   - Equivalent voltage, and
   - "LIGHT" or "DARK", as appropriate.

   Keep the 250 ms delay so that the text is readable. Print the three items on one line, and then start a new line for the next record.

## To turn in

1. Resistance of the photoresistor in light and dark .
   **Solution.** As given: $R_{light} \approx 600\Omega$ and $R_{dark} \approx 2500\Omega$.

2. Your choice for $R$ in Figure 2.

   **Solution.** For the given values,

   $$R = \sqrt{R_{light}R_{dark}} = 1.22k\Omega$$

   so use either $1k\Omega$ or $1.5k\Omega$.

3. Output voltage and ADC value in the light.

   **Solution.** The relevant line to add is

   ```
   float voltage = 3.3 * adcValue / 4096.0;
   ```
   (They can also use the map function)

   Note that the 4096.0 must be written in a way that forces floating point math.

   The voltage in the light should be somewhere in the 0.5 - 0.9 V range, though it can vary. It should definitely be less than 1.65 V.

4. Output voltage and ADC value in the dark.

   **Solution.** The voltage in the dark should be somewhere in the 2.5 - 2.9V range. Definitely greater than 1.65 V.

5. Describe the behavior of the motor in light and dark for the configuration in Figure 3.

   **Solution.** Like the "night light," the motor will turn on (full power) in the dark and off (zero power) in the light.

6. Describe what you would do to the circuit to reverse the behavior of the motor.

   **Solution.** A few options here: the easiest is invert the photoresistor circuit (i.e., put the photoresistor on the high side. You could also swap the +/- terminals. Finally, you could connect the other side of the motor to $V_{in}$.

7. If you used either circuit to drive a motor in a Braitenberg vehicle, do you think it would perform well? What might some of the problems be?

   **Solution.** The motion would likely be jerky – motor on, motor off, but no smooth transition in between.

8. Submit your night light program and a picture of your night light circuit separately.