Experiment: Design a Night Light

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Objectives The objectives of this experiment are (a) to apply the concept of voltage division to control the voltage supplied to two light-emitting diodes (LEDs), (b) to demonstrate the operation of an op amp as a voltage comparator, and (c) to determine the resistance of a photocell over a wide range of illumination conditions.

Preparation Read the sections on op amp circuits in your textbook. Also, refer to Section 3.12 and 3.13 on op amps and diodes in this text. Download and read the LM324 op amp data sheet from National Semiconductor (2008). Review Experiment 4 on voltage dividers.

Background In introductory analyses of operational amplifier (op amp) circuits, a simple model of an op amp is used as its equivalent circuit (Fig. 1). The output voltage of the op amp, v_o, is proportional to the difference in the voltage between the positive and negative input terminals. $v_o = A(v_1 - v_2)$ where $v_1 - v_2 = v_d$ the voltage drop across the input resistance, R_{in}, between the two input terminals. R_{in} has a very high resistance, generally in the range of 1-100 MΩ so little current flows across R_{in} when the magnitude of v_d is small.

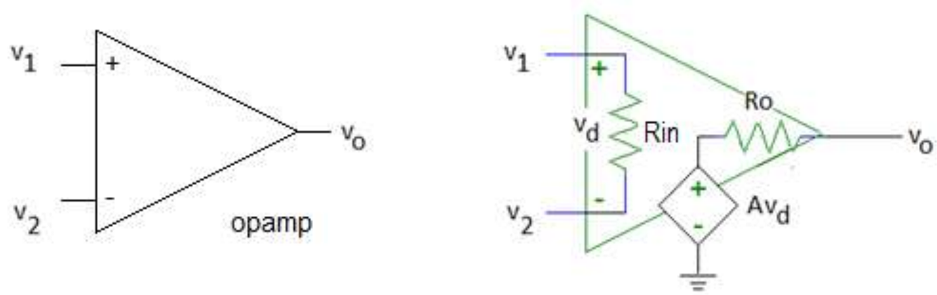

Figure 1: Symbol for a simple ideal op amp and its equivalent circuit.

The proportionality constant, or open loop gain, A, which is usually very large. In the National Semiconductor datasheet for the LM324, the typical value for A is specified as a 100dB large dc voltage gain on the first page and in a table on electrical characteristics later in the datasheet as the large signal voltage gain of 100V/mV where

$$A = 10^{100dB/20dB} = \frac{100V}{0.001V} = 100{,}000 \qquad (1)$$

However the maximum output voltage of an op amp is limited a value slightly less than the voltage used to power the device, usually called V^+ or V_{cc+} for the power supply with a positive magnitude and V^- or V_{cc-} for the power supply with the negative magnitude. Given the value of *A* and that the maximum value of V^+ and V^- for the LM324 is +/-16V, it is easy to see that the difference between the two input voltages v_d need only be a fraction of 1mV before the output voltage of the op amp is equal to the voltage of its power supply. A voltage comparator circuit uses this behavior as a means to determine when one input voltage is larger than the other. For example, when $v_1 > v_2$ and v_d is positive, the output voltage v_o saturates to a value close to V_{cc+}. When $v_2 > v_1$ and v_d is negative, $v_o \sim V_{cc-}$.

A CdS photocell is used in a circuit to switch on a night light. The resistance of the CdS photocell varies over several orders of magnitude depending on the intensity of light that illuminates its surface. In the dark, the photocell resistance can be in the MΩ and will drop to less than 10 kΩ when the photocell surface is brightly lit. If the photocell is used as a resistor in a two resistor voltage divider, the voltage at the node between the two resistors will be a function of the amount of light sensed by the photocell. For example, the voltage at Node A in Figure 2a will be close to V1 when the photocell is in the dark and $R_{Photocell} >> R$ and will decrease towards 0V as the intensity of the light shining on the active surface of the photocell increases, causing $R_{Photocell}$ to decrease. If one of the inputs of the op amp is connected to Node A and the other input is connected to a reference voltage as shown in Figure 2b, the output of the op amp will switch between V_{cc-} and V_{cc+} when the amount of light illuminating the photocell causes the voltage at Node A to be greater than V_{ref}.

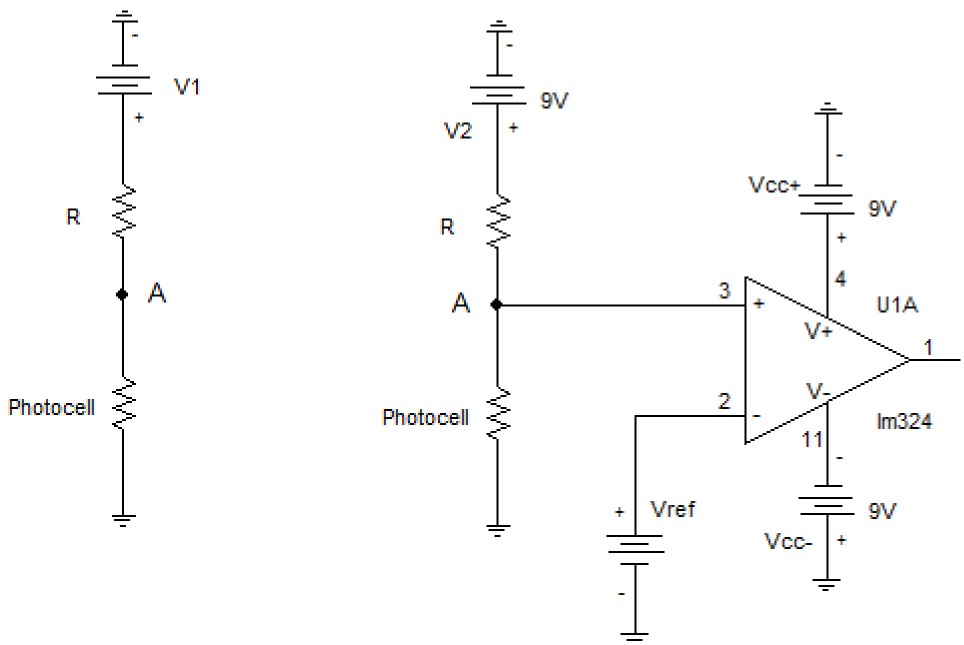

Figure 2: In a, the voltage a Node A can be determined by an equation for a simple 2-resistor voltage divider. In b, the input voltage v_1 of the LM324 is the voltage at Node A. The output voltage of the op amp is dependent on the voltage at Node A as compared to V_{ref}.

In this experiment, a light-emitting diode (LED) will be used as the light that is switched on by the night light circuit when the natural light in a room becomes too dim. A LED will emit light when current begins to flow through the diode. To force current through a diode, the LED must first be turned-on – i.e., a positive voltage equal to the LED's built-in voltage must be applied from the anode to the cathode of the diode (see Figure 30 in Section 3.13). Additional voltage is supplied to drive current through the LED, which has a small internal resistance of 10-150 Ω. The output of the LED will be proportional to the current flowing through the forward-biased LED up to a maximum current level. Since the maximum currents that should flow through the LEDs in the LiaB kit are 30mA, this means that the voltage supplied to the LED should be no more than ~2V.

However, we would like to use the output voltage of the op amp to forward bias the LED when the resistance of the CdS photocell has increased to or above a specified value as the light in the room becomes too low. To insure that the current through the LED is not greater than the maximum specified value, a current limiting resistor is included in the circuit (Figure 29 in Section 3.13 or Figure 3 below). Assume that the voltage required to drive current through the forward-biased LED is 2V for a red or green LED. [It will be about 3.5V for a blue LED.] If the output resistance R_o of the op amp is very small, it can be neglected in the analysis.

The value of the current-limiting resistor can be determined from the following equation:

$$R_{limit} = \frac{v_o - 2V}{I_{LED}} \qquad (2)$$

Due to the semiconductor physics associated with the operation of the light-emitting diode, no current will flow through the LED when v_o is less than 2V.

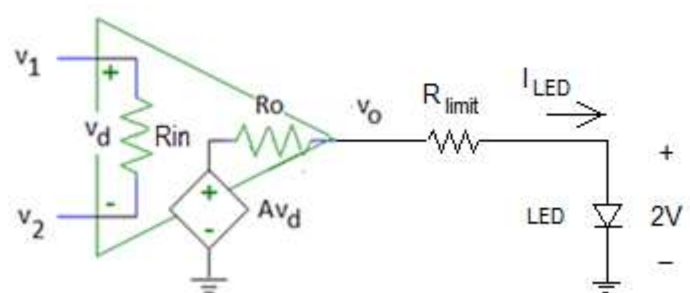

Figure 3: A schematic diagram of ideal op amp in which the output terminal is tied to an LED and current-limiting resistor.

In this experiment, you will design a two-resistor voltage divider where one of the resistors is a CdS photocell. A voltage comparator circuit will be used to monitor the voltage at the node between the two resistors. As the room light is decreased, the resistance of the CdS photocell will increases. When the resistance reaches a specified value, the output of the voltage comparator will change and approximately 10 mA will flow through a green LED, causing it to emit light. An example of the night light circuit as implemented in PSpice is shown in Figure 4.

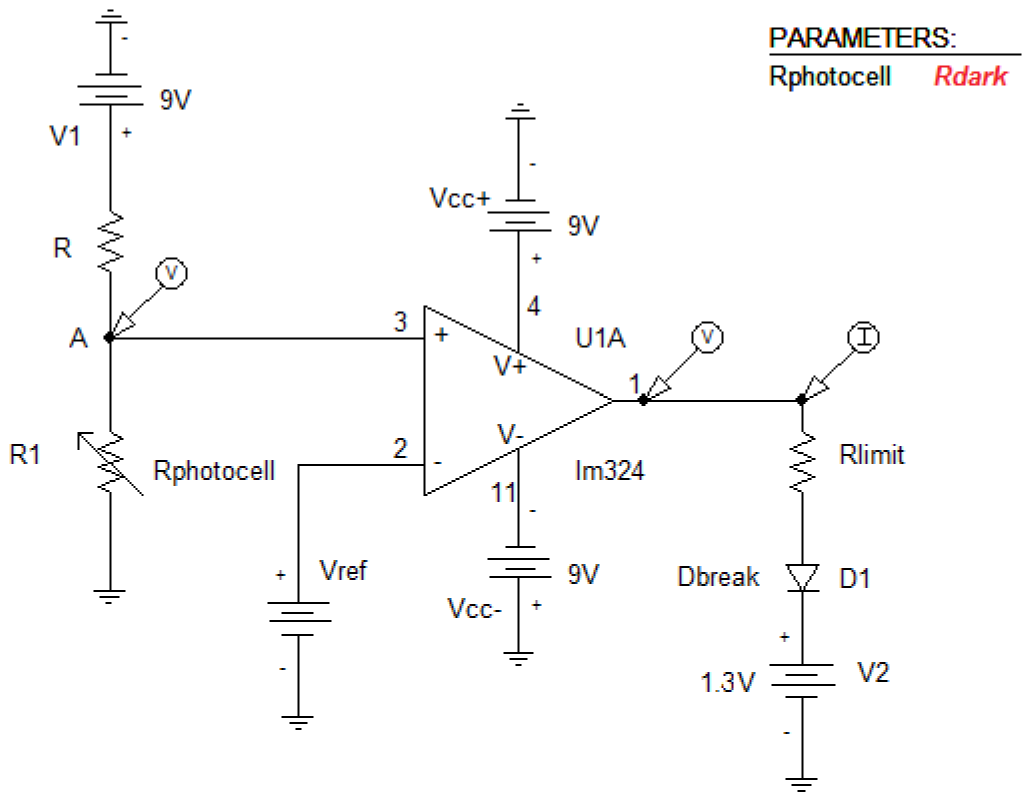

Figure 4: Schematic of night light circuit implemented in PSpice.

Caution: Note that several wiring errors can cause excessive heating of the op amp, which will eventual damage the op amp as well as damage the ANDY board. These include (1) connecting -9V to the pin labeled V+ and +9V to the pin labeled ground on the LM 324 datasheet (the two pins used to power the op amp) and (2) connecting the output of the op amp directly to ground, V+, or V-. The temperature increase of the op amp package is sufficient to melt the breadboard under the package. Take care and do not touch the op amp dip package when hot. Remove the power supply to the ANDY board and wait until the package has cooled before replacing the op amp.

References

National Semiconductor, (2000). "LM124/LM224/LM324/LM2902 Low Power Quad Operational Amplifiers." 6 March 2011 <http://www.national.com/ds/LM/LM124.pdf>

Materials

The equipment and components required to perform this experiment are:

- ANDY board
- Digital multimeter
- USB oscilloscope
- 1 ea LM 324 op amp

- 2 resistors, values to be determined by student

Procedure

Analysis:

1. Because the resistance of the CdS photocells vary considerable, it is important that the resistance of the photocell be measured before the analysis of the circuit is performed. Using the DMM, measure the resistance of the CdS under normal room light. Measure its resistance again when there is no light on the active surface of CdS photocell (e.g., the photocell is covered – but not by placing your finger over the active surface as you are too transparent). Record these values.

2. Assume that the resistance of the photocell changes linearly with the intensity of light illuminating its surface. Determine the value of the CdS photocell when the light intensity has decreased by 75%.

3. Determine the value for a resistor, R, for the voltage divider show in Figure 1 such that the voltage at Node A will equal to 5V when the resistance of the CdS photocell is equal to the value calculated in Step 2.

4. Calculate the value of R_{limit} in Figure 3 such that the current through the LED I_{LED} = 10 mA when the output voltage of the op amp v_o = 9V.

Modeling:

5. Perform a DC Sweep in PSpice on the circuit using the values for the resistors *R* and R_{limit} calculated in Steps 3 and 4. The range of values for R_var should be the maximum and minimum values of resistance measured in Step 1. Set the value of V_{ref} to 5V.

6. Plot the voltage at Node A, the output voltage of the op amp, and the current through the current limiting resistor as a function of the resistance of the CdS photocell. Scale the magnitude of the current by a factor of 1000.

7. Using the cursors, determine the values of maximum and minimum output voltages of the op amp, the maximum and minimum current through the current limiting resistor, and the resistance of the *R_var* at which the voltage at Node A equals V_{ref}.

8. Perform a second DC Sweep in PSpice where R_var is replaced with a resistor with a value equal to that calculated in Step 2. Sweep the value of V_{ref} from 0V to 9V. Plot the output voltage of the op amp, and the current through the current limiting resistor as a function of V_{ref} and show that the output voltage switches when V_{ref} = 5V.

Measurements:

9. Measure the + 9 V, +5 V, and - 9 V power supplies.

10. Measure the resistance of *R* and R_{limit}.

11. Download the LM 324 datasheet from the National Semiconductor website. Identify the pins on the op amp dip package after looking at the **Connection Diagram** for the dual in-line package on the datasheet. The pin labeled ground

on the datasheet will not be connected to ground and is V- in schematic shown in Figure 1.

12. Construct the circuit shown in Figure 4 where D1 (Dbreak) and V2 are replaced with a green LED. Be sure to connect the polarities of the ± 9 V power supplies correctly and that the cathode of the green LED is connected to ground.
13. With the active area of the CdS photocell illuminated, measure the voltage at Node A, the output voltage of the op amp, and the current flowing through the current limiting resistor.
14. With the active area of the CdS photocell not illuminated, measure the voltage at Node A, the output voltage of the op amp, and the current flowing through the current limiting resistor.
15. Compute the percent deviation* of the current through the current limiting resistor measured when the green LED is on.
16. Replace the 5V supply for Vref with the Velleman arbitrary function generator. Set the function generator to a triangular wave with a 4.5V offset and 9V amplitude. Set the frequency to 5 Hz.
17. With the active area of the CdS photocell in the dark, measure the output voltage of the op amp and the voltage from the arbitrary function generator as a function of time. Determine the value of V_{ref} at the point of time the green LED first turns on.
18. From the measurement of R and the value of V_{ref} found in Step 17, estimate the resistance of the unilluminated CdS photocell.
19. Comment on the performance of the circuit. Explain any discrepancies.

* The formula used to calculate the percent deviation is:

$$\%\,\text{deviation} = \frac{\text{Ideal Value} - \text{Measured Value}}{\text{Ideal Value}} \times 100\%$$

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