EECS 16A Designing Information Devices and Systems I
Fall 2022 Homework 11

This homework is due November 11, 2021, at 23:59.
Self-grades are due November 14, 2021, at 23:59.

Submission Format
Your homework submission should consist of **one** file.

- `hw11.pdf`: A single PDF file that contains all of your answers (any handwritten answers should be scanned)

Submit each file to its respective assignment on Gradescope.

1. **Reading Assignment**

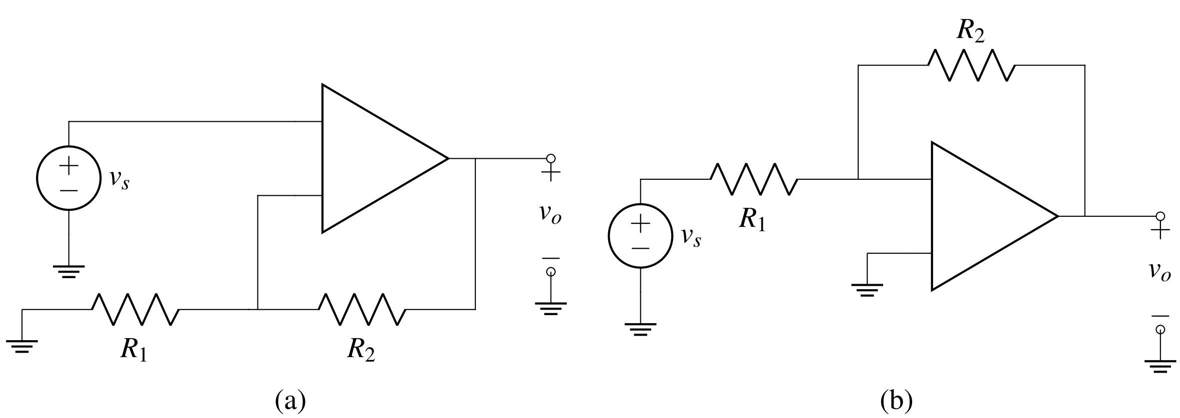
For this homework, please read Notes 18 and 19. They will provide an overview on operational amplifiers (op-amps), negative feedback, the "golden rules" of op-amps, and various op-amp configurations (non-inverting, inverting, buffers, etc). You are always encouraged to read beyond this as well.

(a) What are the two "golden rules" of ideal op-amps? When do these rules hold true?

(b) What does the internal gain of an op-amp, A, mean? What is its value for an ideal op-amp? What about for a non-ideal one?

2. **Basic Amplifier Building Blocks**

The following amplifier stages are used often in many circuits and are well known as (a) the non-inverting amplifier and (b) the inverting amplifier.



(a) Label the input terminals of the op-amp with $(+)$ and $(-)$ signs in Figure (a), so that it is in negative feedback. Then derive the voltage gain ($G = \frac{v_o}{v_s}$) of the non-inverting amplifier in Figure (a) using the Golden Rules. Why do you think this circuit is called a non-inverting amplifier?

(b) Label the input terminals of the op-amp with $(+)$ and $(-)$ signs in Figure (b), so that it is in negative feedback. Then derive the voltage gain ($G = \frac{v_o}{v_s}$) of the inverting amplifier using the Golden Rules. Can you explain why this circuit is called an inverting amplifier?

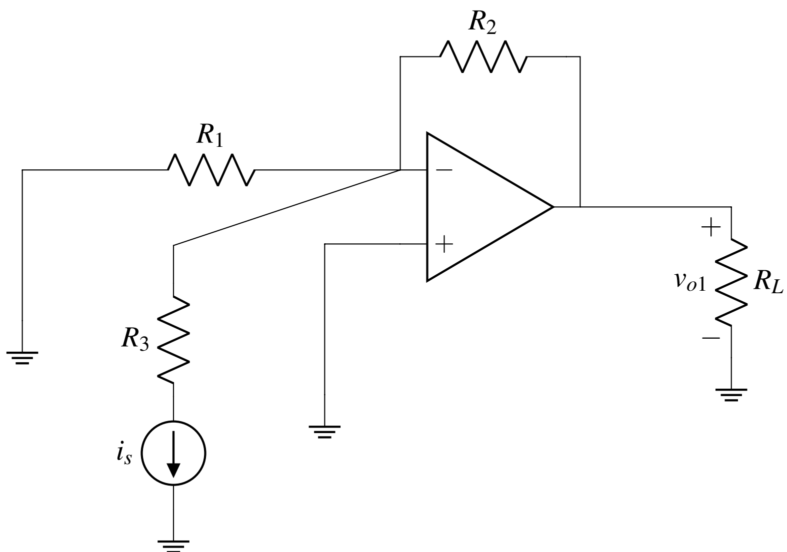
(c) Using your toolkit of circuit topologies, design blocks that implement the following equations. Feel free to reference Discussion 11B for circuit topologies:

i. $v_o = 2v_s$

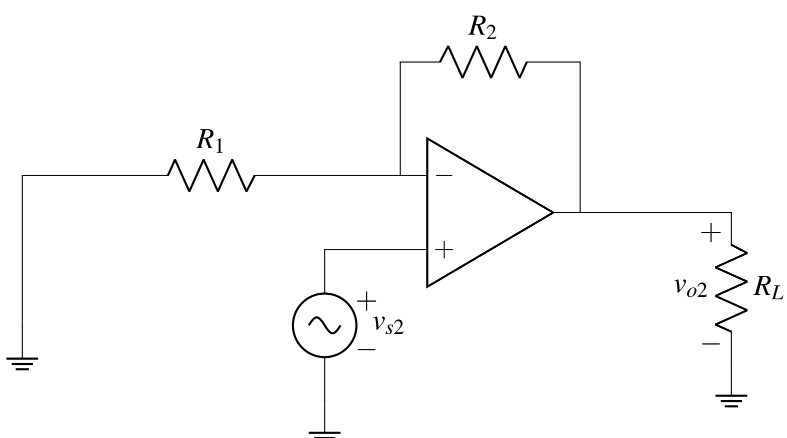
ii. $v_o = -3v_s + 8$

3. Amplifier with Multiple Inputs

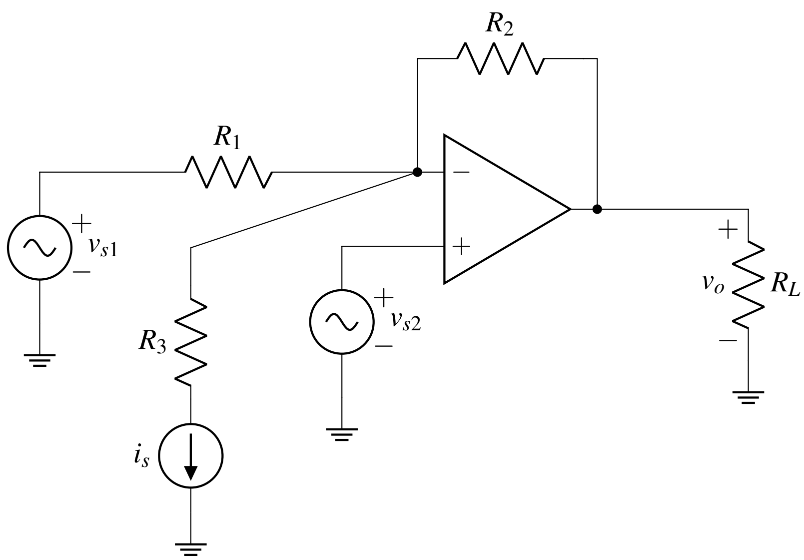
(a) Use the Golden Rules to find v_{o1} for the circuit below.



(b) Use the Golden Rules to find v_{o2} for the circuit below.

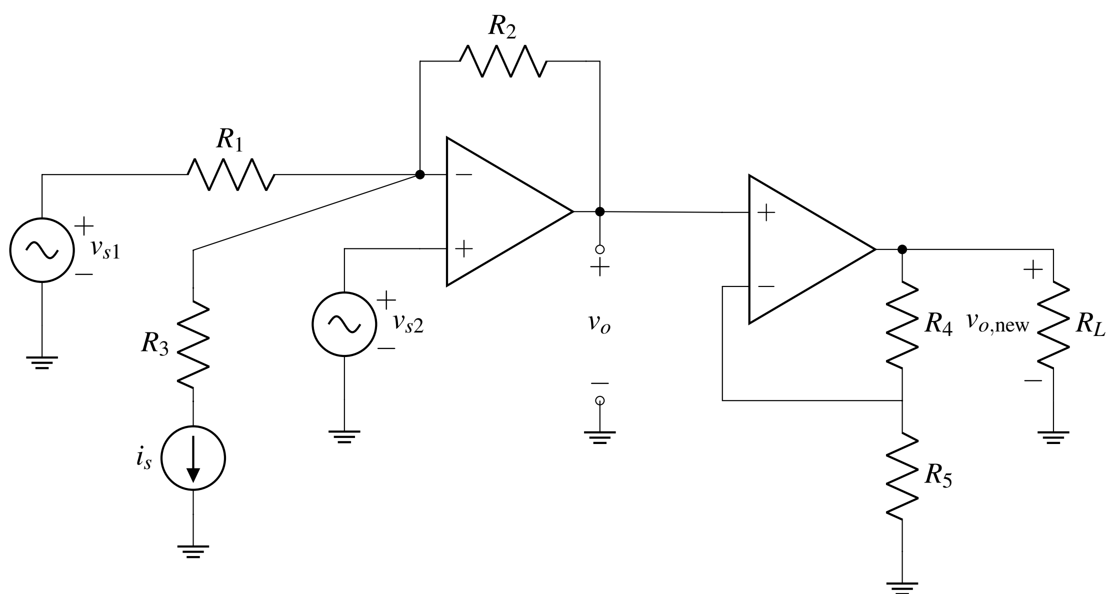


(c) Use the Golden Rules to find the output voltage v_o for the circuit shown below.



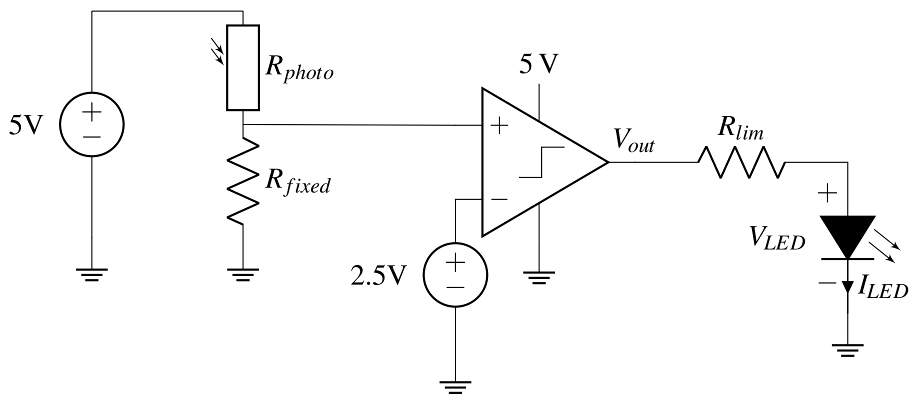
(d) Use superposition and the answers to the first few parts of this problem to verify your answer to part c. *Hint: See if you can generate some combination of the circuits in a & b that is equivalent to the one in c.*

(e) Now add a second stage as shown below. What is $v_{o,\text{new}}$? Does v_o change between part (c) and this part? Does the voltage $v_{o,\text{new}}$ depend on R_L?



4. LED Alarm Circuit

One day, you come back to your dorm to find that your favorite candy has been stolen. Determined to catch the perpetrator red-handed, you decide to put the candy inside a kitchen drawer. Using the following circuit design, you would like to turn on a light-emitting diode (LED) "alarm" if the kitchen drawer is opened.



Note R_{photo} is a photoresistor, which acts like a typical resistor but changes resistance based on the amount of light it is exposed to. This photoresistor is located inside the kitchen drawer, so we can tell when the drawer is opened or closed.

V_{LED} indicates the voltage across the LED; we will guide you through the IV behavior of this element later in the problem. The LED is located in your room (and connected to a long wire going to the kitchen), so that you can remotely tell when the kitchen drawer has been opened.

(a) What is V_+, the voltage at the positive voltage input of the comparator? Your answer should be written in terms of R_{photo} and R_{fixed}.

(b) We now want to choose a value for R_{fixed}. From the photoresistor's datasheet, we see the resistance in "light" conditions (i.e. drawer open) is $1\,\text{k}\Omega$. In "dark" conditions (i.e. drawer closed), the resistance is $10\,\text{k}\Omega$.

To ensure the comparator detects the light condition with more tolerance, we decide to design R_{fixed} so that V_+ is $3\,\text{V}$ under the "light" condition. Solve for the value of R_{fixed} to meet this specification.

(c) Write down V_{out} with any conditions in terms of V_+. For simplicity, consider the case when $V_+ \neq V_-$ and assume the comparator is ideal.

(d) Using your answers to the previous parts, write down V_{out} with the conditions on its output **in terms of** R_{photo}. You can substitute the value of R_{fixed} you found in part (b). As before, you can assume that $V_+ \neq V_-$ and the comparator is ideal.

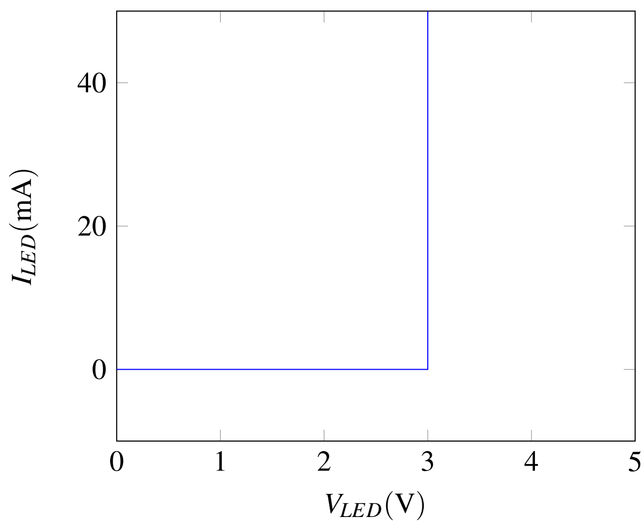
(e) From the design steps in the previous parts, we have designed a circuit that outputs non-zero voltage when the photoresistor is exposed to light (i.e. kitchen drawer open). We now want to design the LED portion of the circuit, so we get a visual alarm when the drawer is open.

From the LED's datasheet, the forward voltage, V_F is $3\,\text{V}$. Essentially, if V_{LED} is less than this voltage, the LED won't light up and I_{LED} will be $0\,\text{A}$.

Here is an idealized IV curve of this LED. The LED behaves in one of the following two modes:

i. If the voltage across the LED is less than $V_F = 3\,\text{V}$ or if $I_{LED} < 0\,\text{A}$, then the LED acts like an open circuit.

ii. If the voltage across the LED is $V_F = 3\,\text{V}$, then the LED acts like a voltage source, except that it only allows positive current flow (i.e. only in the direction of current marked on the circuit diagram).



To avoid exceeding the power rating of the LED (and having it burn out), the recommended value for I_{LED} is 20 mA.

Find the value of the current-limiting resistor, R_{lim}, such that when the photoresistor is in the "light" condition, $I_{LED} = 20\,\text{mA}$.

5. Homework Process and Study Group

Who did you work with on this homework? List names and student ID's. (In case you met people at homework party or in office hours, you can also just describe the group.) How did you work on this homework? If you worked in your study group, explain what role each student played for the meetings this week.