EECS 16A Designing Information Devices and Systems I
Summer 2020 Homework 5A

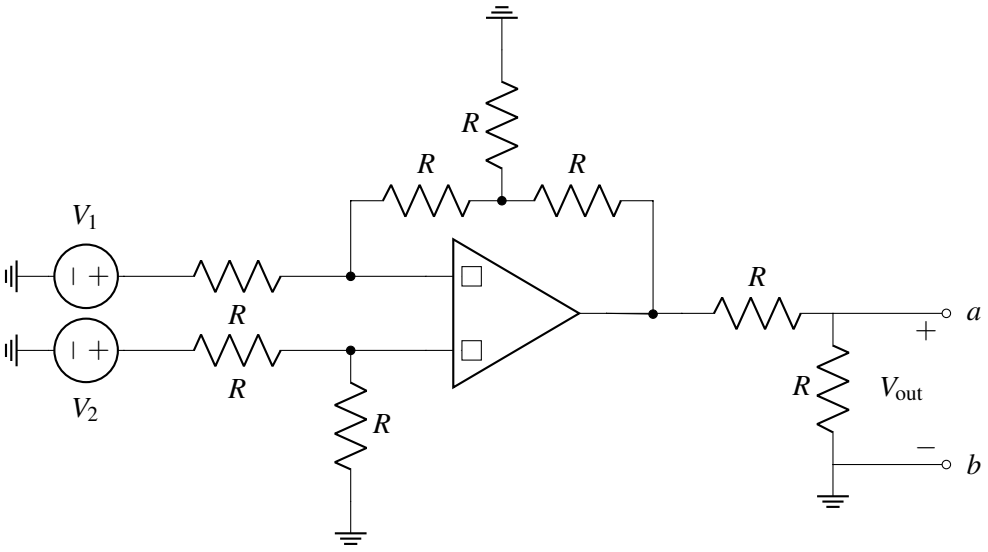
This homework is due Wednesday, July 29, 2020, at 23:59.
Self-grades are due Sunday, August 2, 2020, at 23:59.

Submission Format
Your homework submission should consist of a single PDF file that contains all of your answers (any hand-written answers should be scanned).

Homework Learning Goals: *The objective of this homework is to introduce Node Voltage Analysis for Op-Amps and reinforce your circuit modeling and design skills using Op-Amps in negative feedback.*

1. Op Amp Nodal Analysis

Consider this Op Amp circuit below:



We are interested in analyzing its input-output relationship.

(a) Redraw the circuit with a choice of $+$ and $-$ terminal labelings to guarantee that the circuit is in negative feedback.

Our goal in the succeeding parts will be to find the Thevenin equivalent of this op amp circuit, and make some observations about the resulting equivalent.

(b) Find the open circuit output voltage, V_{out} as a function of the input voltages V_1 and V_2. This will be the Thevenin Voltage, V_{Th}.

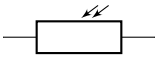
(c) Turn off all independent sources ($V_1 = V_2 = 0V$). What is the equivalent resistance as seen between terminals a and b? This will be your Thevenin resistance, R_{Th}. (Hint: Consider what the voltage at the output of the op amp becomes and use a test source, or replace the op amp with its internal model where it has a dependent source.)

(d) Use what you found in parts b and c to draw the Thevenin equivalent.

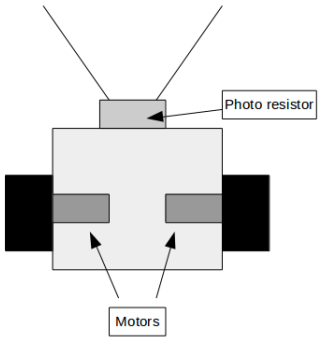
(e) **Practice (Optional)**: Does the Thevenin resistance depend on all the resistors or a strict subset? What might explain this?

2. PetBot Design

In this problem, you will design circuits to control PetBot, a simple robot designed to follow light. PetBot measures light using photoresistors. A photoresistor is a light-sensitive resistor. As it is exposed to more light, its resistance decreases. Given below is the circuit symbol for a photoresistor.

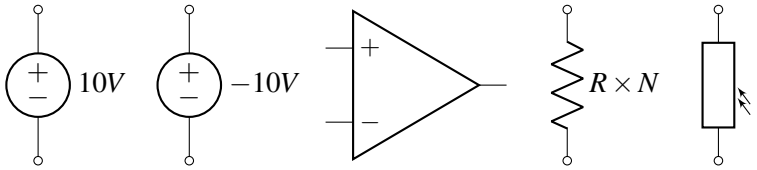


Below is the basic layout of the PetBot. It has one motor on each wheel. We will model each motor as a $1\,\Omega$ resistor. When motors have positive voltage across them, they drive forward; when they have negative voltage across them, they drive backward. At zero voltage across the motors, the PetBot stops. The speed of the motor is directly proportional to the magnitude of the motor voltage. The light sensor is mounted to the front of the robot.



(a) **Speed control** – Let us begin by first having PetBot decrease its speed as it drives toward the flashlight. Design a motor driver circuit that outputs a decreasing positive motor voltage as the PetBot drives toward the flashlight. The motor voltage should be at least $5\,\text{V}$ far away from the flashlight. When far away from the flashlight, the photoresistor value will be $10\,\text{k}\Omega$ and dropping toward $100\,\Omega$ as it gets closer to the flashlight.

In your design, you may use any number of resistors with any value and just 1 op-amp. You also have access to voltage sources of $10\,\text{V}$ and $-10\,\text{V}$. Based on your circuit, derive an expression for the motor voltage as a function of the circuit components that you used.



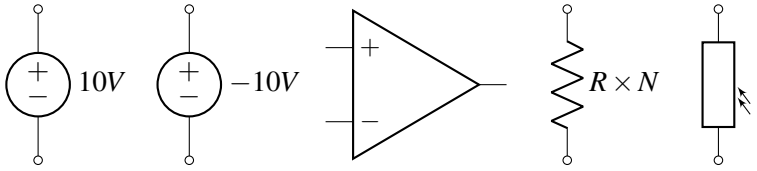
Hint 1: You should consider the loading effect of connecting this circuit to your motor, which has resistance. A buffer may help solve this problem.

Hint 2: If you're not sure where to start, try playing around with connecting the circuit elements in different ways, and think about circuits you have seen before.

(b) **Distance control** – Let us now have PetBot drive up to a flashlight (or away from the flashlight) and stop at distance of 1 m away from the light. At the distance of 1 m from the flashlight, the photoresistor has a value 1 kΩ.

Design a circuit to output a motor voltage that is positive when the PetBot is at a distance greater than 1 m from the flashlight (making the PetBot move toward it), zero at 1 m from the flashlight (making the PetBot stop), and negative at a distance of less than 1 m from the flashlight (making the PetBot back away from the flashlight.)

In your design, you may use any number of resistors of any value and just 1 op-amp. You also have access to voltage sources of 10 V and −10 V. Based on your circuit, derive an expression for the motor voltage as a function of the values of circuit components that you used.



3. Homework Process and Study Group

Who else did you work with on this homework? List names and student ID's. (In case of homework party, you can also just describe the group.) How did you work on this homework?