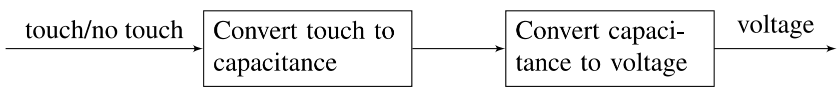
EECS 16A Designing Information Devices and Systems I
Fall 2021 Discussion 11B

When faced with a design problem, a good place to start is to follow the *design procedure* outlined here (from Note 20):

Step 1 (Specification): Concretely restate the goals for the design.
Frequently, a design prompt will include a lot of text, so we'd like to restate all of the most important features of our design. We'll refer to these specifications later to determine if our design is complete.

Step 2 (Strategy): Describe your strategy (often in the form of a block diagram) to achieve your goal.
To do this, start by thinking about what you can measure vs. what you want to know. For example in our capacitive touchscreen, we want to know if there is a touch and we can measure voltage. Since we know that a touch can change the capacitance, we break this down into the following block diagram:



Step 3 (Implementation): Implement the components described in your strategy.
This is where pattern matching is useful: remind yourself of blocks you know, (ex. voltage divider, inverting amplifier) and check if any of these can be used to implement steps of your strategy. If you don't know of a block that does what you want, think about how to modify or extend the blocks you know.

Step 4 (Verification): Check that your design from Step 3 does what you specified in Step 1.
It's tempting to think that you're done after implementation, but verification is critical! In particular, check block-to-block connections, as these are the most common point for problems. Does one block load another block causing it to behave differently than expected? Are there any contradictions (ex. a voltage source with both ends connected by a wire, or a current source directed into an open circuit)? Repeat previous steps if necessary to make sure that your final circuit meets the specifications.

1. PetBot Design (from Fall 2016 Final Exam)

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

The PetBot is driven by one motor that will be modeled as a resistor. PetBot drives forward (towards the said light source) when a positive voltage is applied across the motor, and conversely a negative applied voltage drives PetBot backward (away from the light source). In this system the light sensor is mounted to the front of the robot, and the speed of PetBot is proportional to the applied voltage to the motor.

(a) **Speed control**
In our first circuit design, we will begin by making PetBot decrease speed as it drives towards light. **Design a motor-driving circuit that outputs a decreasing positive motor voltage as PetBot drives toward the light source.** The motor voltage should be at least 5 V when far away from the light. At this far away from the light source, the photoresistor value will be $10\,k\Omega$, and then drop towards $100\,\Omega$ as it approaches the light.

In your design, you may use any number of resistors and op-amps. 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 circuit components that you used.**

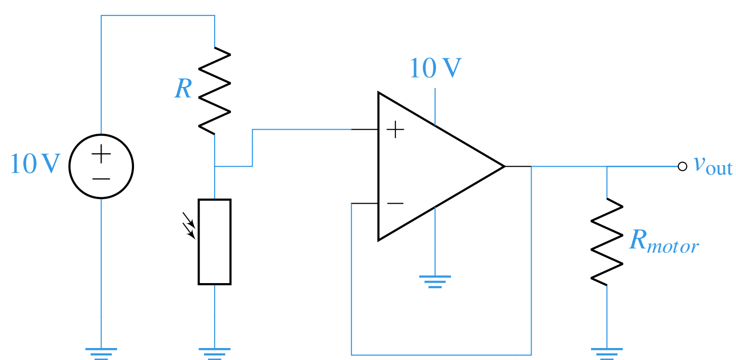
NOTE! Since the motor is a resistor, the circuit design MUST have a buffer so that the applied voltage to the motor does not depend on its resistance.

Follow the design procedure introduced before:

Step 1(Specification) For this problem, we specify it as "We want to design a circuit such that when the PetBot gets closer to the light, the circuit outputs an decreasing voltage."

Step 2(Strategy) As introduced in the context, the resistance of a light-sensitive resistor decrease when PetBot gets closer to the light. So we can break down the problem into: 1)Convert distance to light exposure; 2)Convert light exposure to resistance of a light-sensitive resistor; 3)Convert decreasing resistance to decreasing voltage output.

Step 3(Implementation) We can use voltage divider to covert resistance to voltage output, and use an op-amp buffer circuit to drive the motor. A natural choice for our design is to combine a voltage divider with a buffer circuit, as depicted below.



Step 4(Verification) The output of the above circuit is:

$$v_{out} = \left(\frac{R_p}{R_p + R}\right) 10\,\text{V}$$

R_p represents the photoresistor, and $R \leq 10\,k\Omega$.

Since we require $v_{out} \geq 5$V when far from light ($R_p = 10\,k\Omega$), the maximum allow value for R is $R = R_p$ as stated.

(b) **Distance control**

When the PetBot stops at a distance of 1 m away from the light, the photo-resistor has a value 1 kΩ. We would like to have the PetBot drive away when closer than 1m from the light (so for lower R_p), and drive towards the light when exceeding 1m (so for greater R_p).

Design a comparator circuit that outputs a positive motor voltage when the PetBot exceeds 1 m in distance from the flashlight (making the PetBot move toward it), and a negative voltage when PetBot is within 1 m of flashlight (making the PetBot back away from the flashlight).

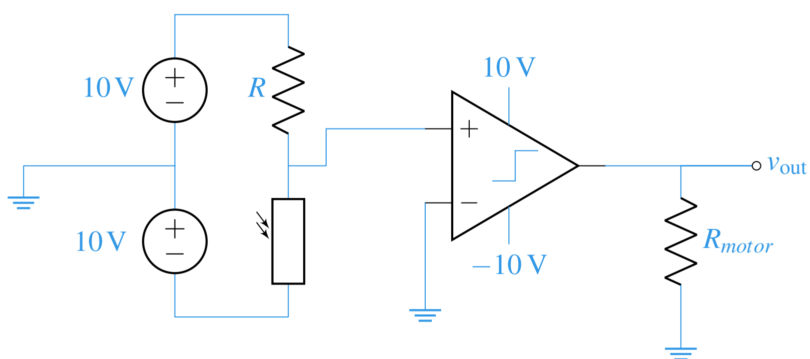
In your design, you may use any number of resistors along with the comparator. You also have access to voltage sources of 10 V and −10 V.

Step 1(Specification) For this problem, we specify it as "We want to design a circuit such that when the PetBot exceeds 1 m closer from the flashlight, the circuit outputs an negative voltage."

Step 2(Strategy) As introduced in the context, the resistance of a light-sensitive resistor decrease when PetBot gets closer to the light. So we can break down the problem into: 1)Convert distance to light exposure; 2)Convert light exposure to resistance of a light-sensitive resistor; 3)Convert decreasing resistance to either positive or negative constant voltage output.

Step 3(Implementation) We can combine a voltage divider and a comparator to achieve the goal.

One possible comparator circuit design is shown below:



Since we have grounded the negative input terminal (and there is no feedback in the circuit), we realize the comparator rails high (positive $v_{out} = +10V$ when the input to the positive op-amp terminal has positive voltage.

Step 4(Verification) Using our voltage-divider knowledge (and recognizing this divider is analogous to a simple divider with $V_s = 20V$ and then shifted by 10V) we find the positive node voltage:

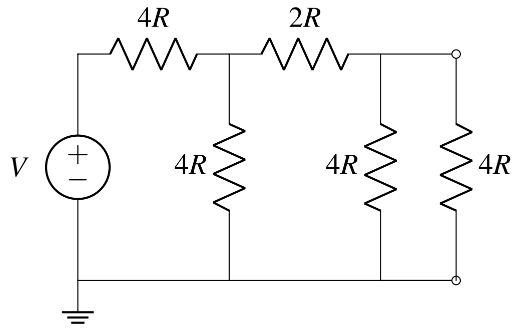
$$u_+ = 20\left(\frac{R_p}{R_p+R}\right) - 10 \;=\; 10\left(\frac{R_p - R}{R_p+R}\right).$$

Notice for $R_p > R$, the node u_+ has positive voltage and so $u_+ > u_-$, thus $v_{out} > 0$. Conversely when $R_p < R$, the u_+ node goes below zero and renders a negative v_{out} on the motor.

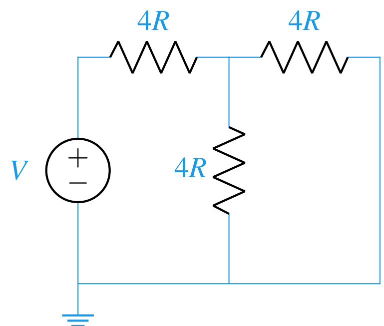
This means our circuit successfully applies positive motor voltage (drives PetBot forward) when far away from the light source with large R_p, and applies negative voltage when too close to the light. Our exact design criteria are met when $R = R_p = 1\,\text{k}\Omega$.

2. OPTIONAL: Power to Resist (from Spring 2018 midterm 2)

Find the power dissipated by the voltage source in the circuit below. Be sure to use passive sign convention.



Answer: We want to find the equivalent resistance across the voltage source in Figure 6.2. Start by reducing the two resistors on the right to $4R \parallel 4R = 2R$. Then combine the other $2R$ resistor with this to get a new resistor of value $4R$ as in the circuit below.



Once again we have $4R \parallel 4R = 2R$. This is finally in series with $4R$ giving us a total resistance of $4R + 2R = 6R$

$$P = VI = V\frac{-V}{6R} = -\frac{V^2}{6R}$$

The negative sign is present because the voltage source actually provides power, which can also be seen by using passive sign convention.