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# EECS 16A      Designing Information Devices and Systems I      Homework 8

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**This homework is due Friday, March 17, 2023 at 23:59. Self-grades are due Monday, March 20, 2023, at 23:59.**

## Submission Format

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

- `hw8.pdf`: A single PDF file that contains all of your answers (any handwritten answers should be scanned).

Submit the file to the appropriate assignment on Gradescope.

## Mid Semester Survey

Please fill out the mid semester survey: <https://forms.gle/oG9GW9odcW78Nz839>.

We highly appreciate your feedback!

## 1. Reading Assignment and Midterm Survey

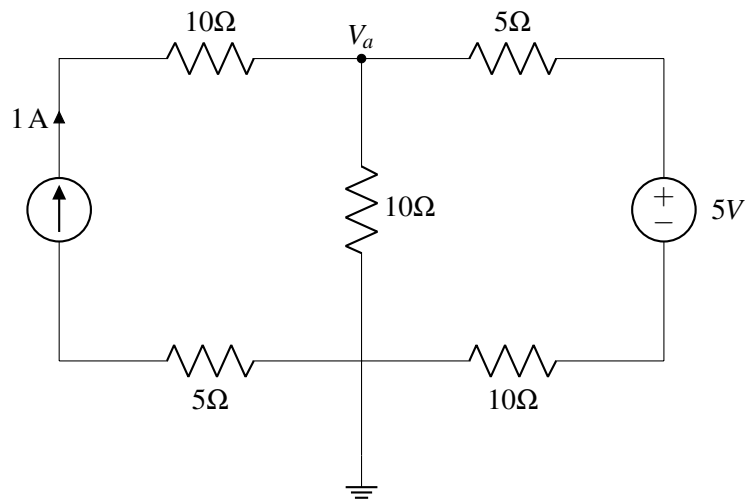
For this homework, please read Notes [14](#) and [15](#). Note 14 introduces better, but more complex models for the resistive touchscreen. Note 15 covers superposition and equivalence, two techniques to simplify circuit analysis.

- Please fill out [this survey](#) regarding the first midterm.
- For the touch screen model introduced in Note 14, why can't we simultaneously get the horizontal and vertical position of the touch with a single measurement? *Think about how many unknowns there are.*
- Explain the connection between the "superposition" you learned about in Note 15 with the "superposition" you learned back in module 1 in the context of linear functions.

## 2. Superposition

**Learning Goal:** *The objective of this problem is to help you practice solving circuits using the principles of superposition.*

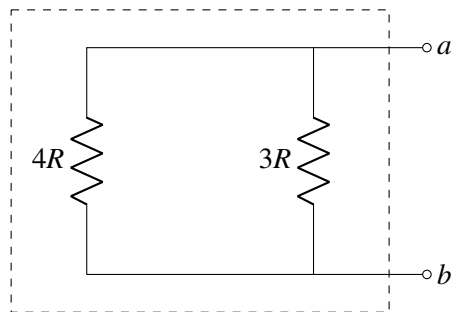
Find the node potential  $V_a$  indicated in the diagram using superposition. Be careful when solving to take into account where the reference potential is.



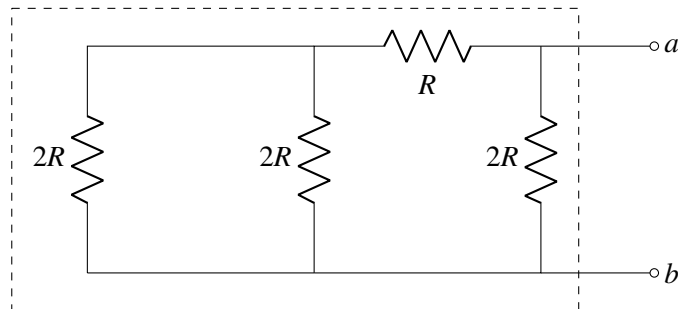
### 3. Equivalent Resistance

**Learning Goal:** The objective of this problem is to practice finding the equivalent to a series/parallel combination of resistors.

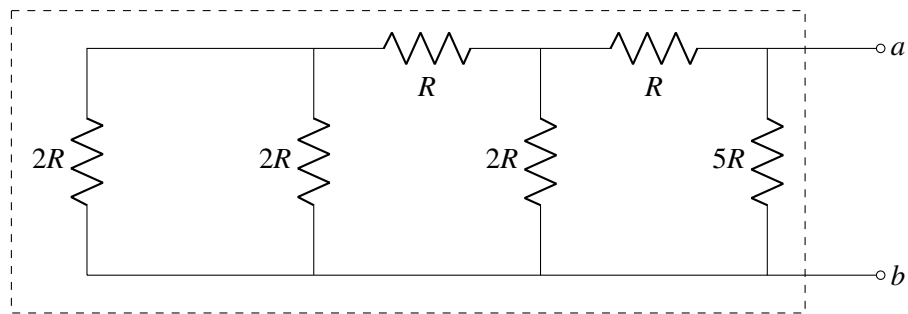
- (a) Find the equivalent resistance looking in from points  $a$  and  $b$ . In other words, express the resistive network in the dashed box as one resistor.



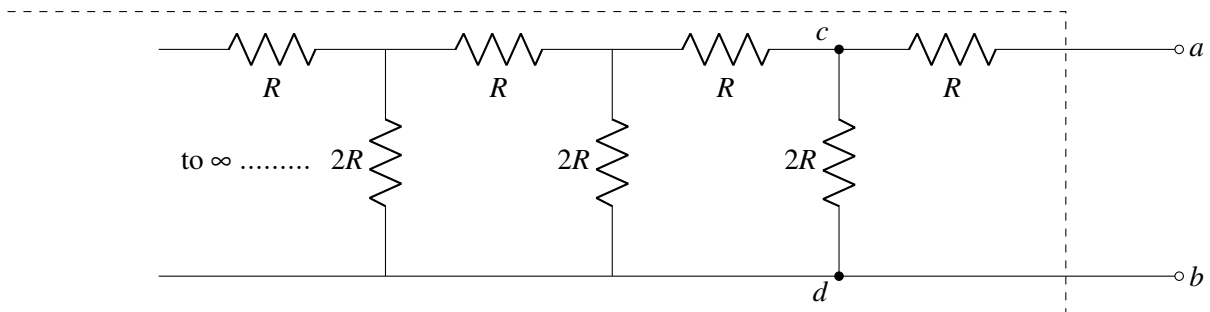
- (b) Find the equivalent resistance looking in from points  $a$  and  $b$ . In other words, express the resistive network in the dashed box as one resistor.



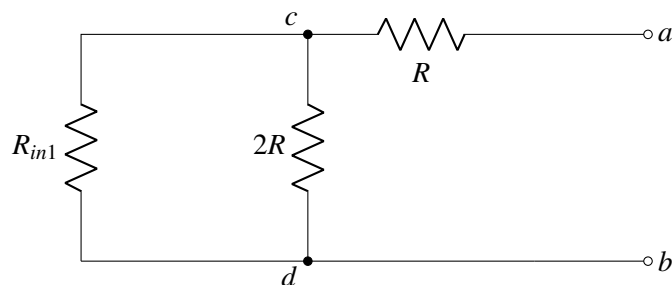
- (c) Find the equivalent resistance looking in from points  $a$  and  $b$ . In other words, express the resistive network in the dashed box as one resistor.



- (d) Find the equivalent resistance for the infinite ladder looking in from points  $a$  and  $b$ . In other words, express the resistive network in the dashed region as one resistor. (Hint: Let's call the resistance looking in from  $a$  and  $b$  as  $R_{in}$ , and the resistance looking to the left from points  $c$  and  $d$  as  $R_{in1}$ . Replace the entire circuit to the left of points  $c$  and  $d$  with a resistor whose value is given by  $R_{in1}$ . Find the relationship between  $R_{in}$  and  $R_{in1}$  using this circuit. Find another relationship between  $R_{in}$  and  $R_{in1}$  using the fact that the ladder is infinite. For an infinite ladder, adding another branch does not change the equivalent resistance. Think of this as a convergent infinite series.)

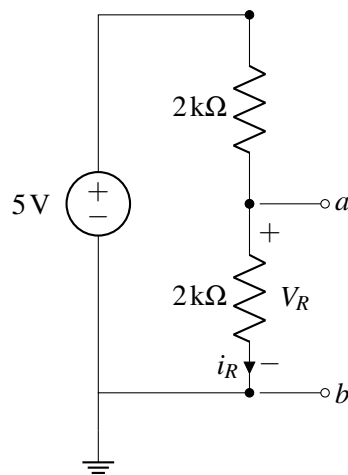


As a first step you can replace the circuit looking to the left from  $c$  and  $d$  by  $R_{in1}$ .

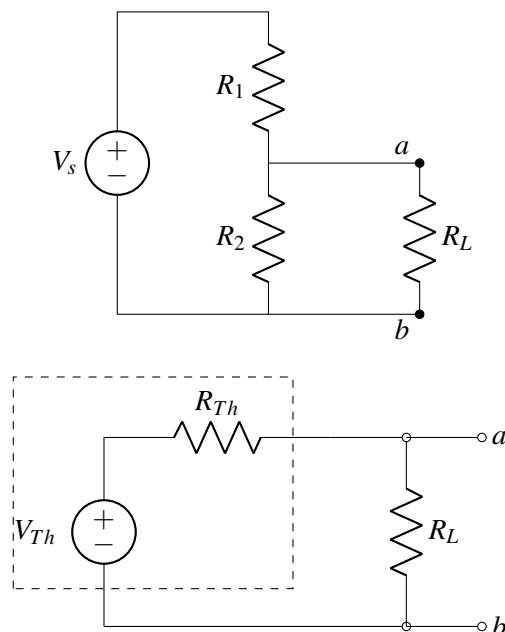


#### 4. Why Bother With Thévenin Anyway?

- (a) Find a Thévenin equivalent for the circuit shown below looking from the terminals  $a$  and  $b$ . (Hint: That is, find the open circuit voltage  $V_R$  across the terminals  $a$  and  $b$ . Also, find the equivalent resistance looking from the terminals  $a$  and  $b$  when the input voltage source is zeroed.)

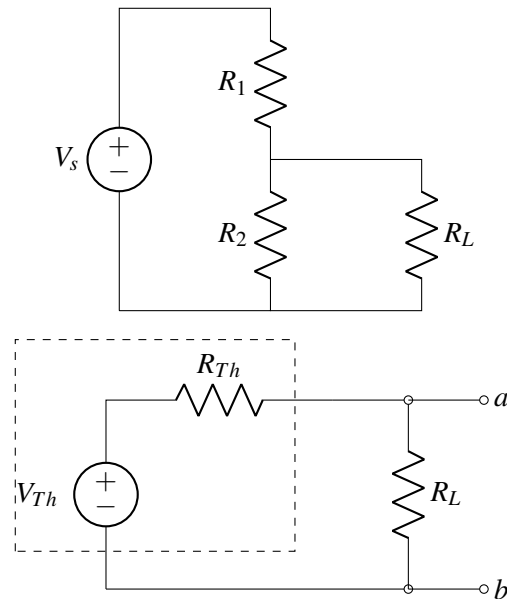


- (b) Now consider the circuit shown below where a load resistor of resistance  $R_L$  is attached across the terminals  $a$  and  $b$ . Such a load resistor is often used to model a device that we want to plug our circuit into, like an audio speaker. Compute the voltage drop  $V_R$  across the terminals  $a$  and  $b$  in this new circuit with the attached load. Express your answer in terms of  $R_L$ . *Hint: We have already computed the Thévenin equivalent of the unloaded circuit in part (a). To analyze the new circuit, attach  $R_L$  as the load resistance across the Thévenin equivalent computed in part (a), as shown in the figure below. One of the main advantages of using Thévenin (and Norton) equivalents is to avoid re-analyzing different circuits which differ only by the amount of loading (which depends on the device we are connecting!).*



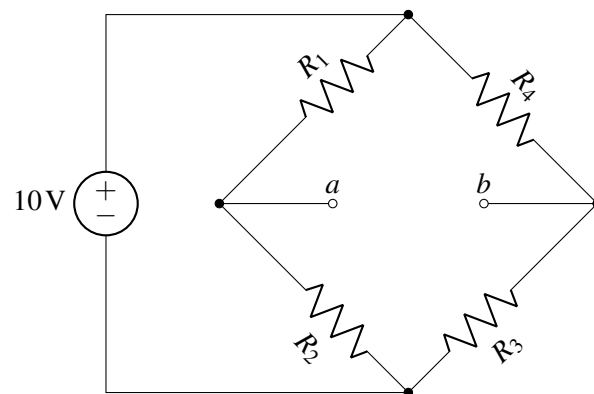
- (c) Now compute the voltage drop  $V_R$  for three different values of  $R_L$  equal to  $5/3 \text{ k}\Omega$ ,  $5 \text{ k}\Omega$ , and  $50 \text{ k}\Omega$ ? What can you comment on the value of  $R_L$  needed to ensure that the loading does not reduce the voltage drop  $V_R$  compared to the unloaded voltage  $V_R$  computed in part (a)?
- (d) Thus far, we have seen how to use Thévenin equivalents to compute the voltage drop across a load without re-analyzing the entire circuit. We would like to see if we can use the Thévenin equivalent for power computations. Consider the case where the load resistance  $R_L = 8 \text{ k}\Omega$ ,  $V_S = 5 \text{ V}$ ,  $R_1 = R_2 = 2 \text{ k}\Omega$ . Compute the power dissipated across the load resistor  $R_L$  both using the original circuit and the

Thévenin equivalent. Are they equal? Now, compute the power dissipated by the voltage source  $V_s$  in the original circuit. Also, compute the power dissipated by the Thévenin voltage source  $V_{Th}$  in the Thévenin equivalent circuit. Is the power dissipated by the two sources equal?

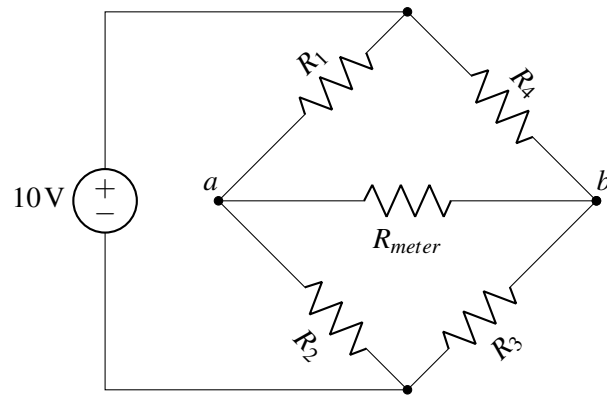


## 5. Wheatstone Bridge

Thévenin equivalence is a powerful technique we can use to analyze the Wheatstone bridge circuit shown below. This circuit is used in many sensor applications where resistors  $R_1, R_2, R_3, R_4$  are varying with respect to some external actuation. For example, it can be used to build a strain gauge or a scale. In that case the resistors  $R_1, R_2, R_3, R_4$  would vary with respect to a strain caused by a force, and the Wheatstone Bridge circuit would translate that variation into a voltage difference across the “bridge” terminals  $a$  and  $b$ . Assume that  $R_1 = 2\text{ k}\Omega$ ,  $R_2 = 2\text{ k}\Omega$ ,  $R_3 = 1\text{ k}\Omega$ ,  $R_4 = 3\text{ k}\Omega$



- Calculate the voltage  $V_{ab}$  between the two terminals  $a$  and  $b$ .
- Next, draw the Thévenin equivalent of the Wheatstone bridge circuit.
- Now assume that you are trying to measure the voltage  $V_{ab}$  using a voltmeter, whose resistance is  $R_{meter}$ , so you end up with the circuit below.



Unfortunately, your voltmeter is far from ideal, so  $R_{meter} = 4k\Omega$ . Is the voltage  $V_{ab}$  you found in part (a) equal to the new voltage  $V_{R_{meter}}$  across the voltmeter resistor? Why or why not? Calculate the current  $I_{R_{meter}}$  through the voltmeter resistor and the voltage  $V_{R_{meter}}$  across the meter resistor.

## 6. 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.