

Name:

# Experiment 2: Resistor Networks for Speed Control

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NetID:

## Laboratory Outline

This week, you will use resistors to control the speed of each motor on your car. You are going to do this in a fairly direct, brute-force, manner by placing resistance between the battery supply and the motors to limit the current supplied to each. Because the battery is capable of supply high power to the resistors (in excess of their  $\frac{1}{4}$ -watt rating), we will use “networks” of resistors such that the effective rating of the resistance created by the combination of resistance is much higher than that of a single resistor.

Today’s bench partner:

Section AB/BB:

0	1	2	3	4	5	6	7
8	9	A	B	C	D	E	F

## Learning Objectives

- Learn to pulse wheels for control of motor speed and car direction.
- Investigate power rating and equivalent resistance to implement a simple method of motor speed control.
- Measure the equivalent resistance of multiple resistors in parallel to determine a descriptive formula for equivalent resistance.

## Introduction...Meet in 1005 ECEB

In 1005 ECEB, your TA will check that you have completed your prelab assignment and answer any questions you may have about last week’s lab or today’s prelab. You will also receive a quick rundown of what is planned for today.

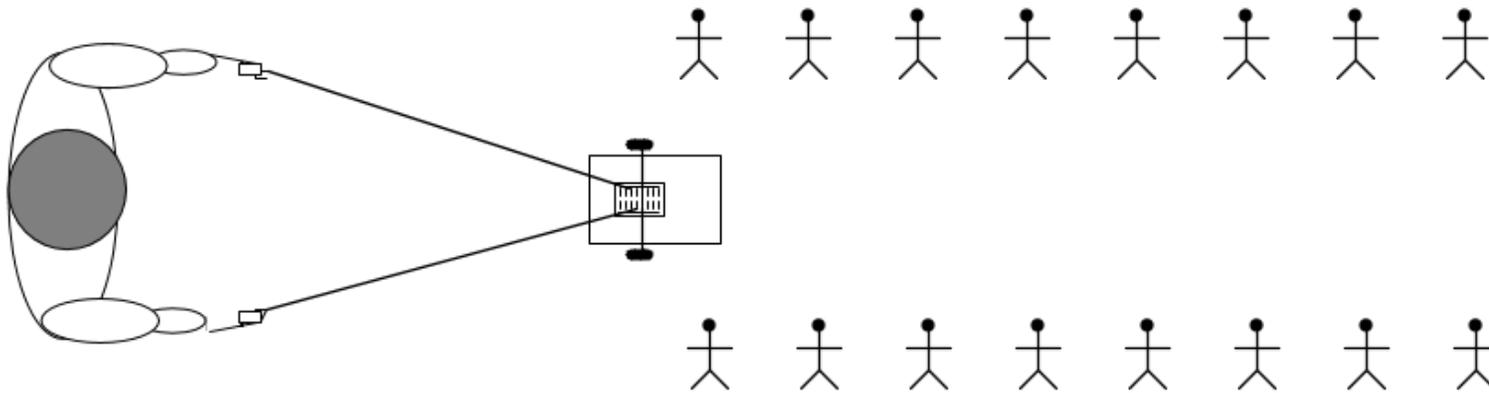
## In the Lab...Move into 1001 ECEB

When we transition from 1005 to 1001 ECEB, we will first meet (in two groups) at the center tables. Generally, this first “breakout” session is where students will discuss and perfect their prelab assignments which often involve a circuit built at home or other group discussion. Today, you will work with the snap-action switches.

## Breakout Session #1

Set up two rows of figurines (we'll use wooden blocks this semester) about 30 cm away from each other and about 1.5 meters in length. Using the longer wires provided by your TA, take turns racing your car through the setup using the snap-action switches as controllers for the two wheels while someone keeps times. If you knock down a figurine, you are eliminated. The person with the best time and no persons knocked down is your winner!

East vs. West: Have the winner of the East side of the room compete in a head-to-head against the winner of the West side.



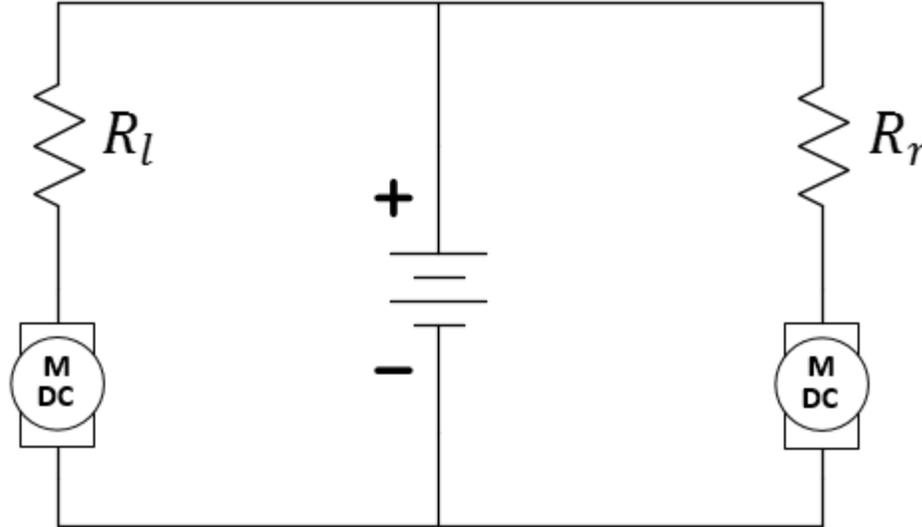
*Figure 1: Car race using snap-action switches for wheel control (not to scale).*

## At your Bench

Circle the bench you are working at today:

A B C D E F G H I J K L M N O P

While it was fun to control your car and make it move in a straight line, it should also be possible to build a type of “cruise control” to make your car go in a straight line as well. To do so, we might consider placing a resistor in series with each motor in order to limit the current flow and slow the motors. To match wheel speeds (compensating for differences in the motors due to loose specifications), a different resistance would be necessary for each wheel. See Figure 2.



**Figure 2:** The grand idea! Use two different resistances to make the speeds of the left and right motors match.

The problem with this plan is that the resistors in our pack are only rated at  $\frac{1}{4}$ -watt. Let's crunch some numbers and see why this is an issue.

**Question 1:** When modeling your wheel as an Ohmic device (a resistor) last week, what value did you determine would represent it?  $R_m =$  \_\_\_\_\_

**Question 2:** Assuming you want most of the battery voltage to appear across the motor,  $R_l$  and  $R_r$  should be no larger than the resistance of the motor. Again, measure the open circuit voltage of your rechargeable battery (you may have a different battery than last time). Now, assuming we choose  $R_l = R_r = R_m$ , estimate how much current might flow through each resistor and, therefore, each motor?

$$V_{\text{battery,oc}} = \text{_____}$$

$$I_m = \text{_____}$$

**Question 3:** Again, continuing with this model for the motors, how much power will be dissipated by each of the resistors?  $P_R =$  \_\_\_\_\_

Therefore, we have established that simple resistors used in this manner are attempting to dissipate power well beyond their rated values and bound to 1) get hot, 2) burn your fingers when you touch them, and 3) eventually fail. What can we do? Use your understanding of cylindrical conductors to think about this...

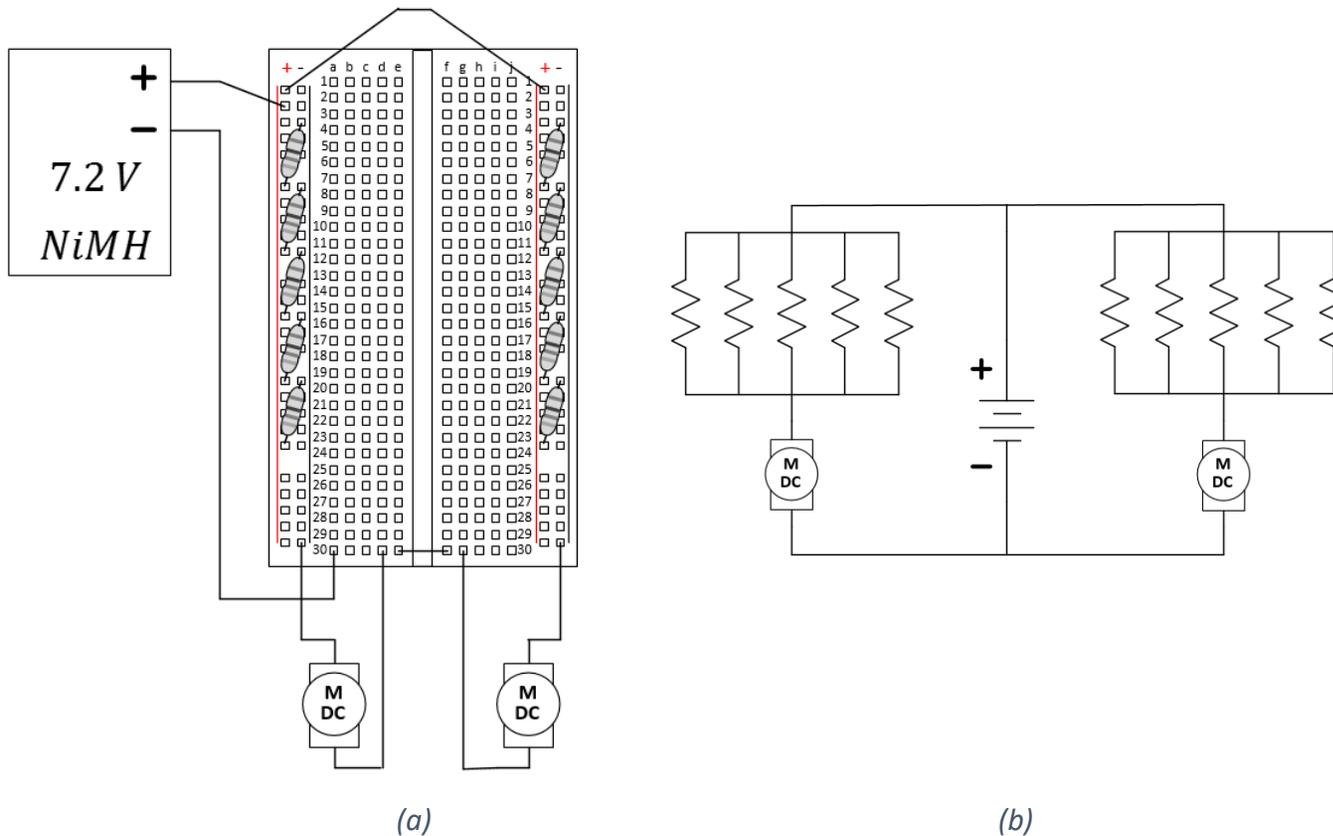
**Question 4:** If a  $20\ \Omega$  resistor is dissipating  $1\ \text{W}$ , how much power would be dissipated by each of five  $100\ \Omega$  resistors used in parallel to replace the single  $20\ \Omega$  resistor?

Let's not use a single value for  $R_l$  and  $R_r$ , but rather use a network of parallel resistors to build an equivalent resistance with an effective higher power rating. Please follow the following procedures carefully...

With your battery turned OFF, construct the circuit of Figure 3. Note how we are using the "power rail" of the breadboard to facilitate the placement of multiple resistors. Use  $100\ \Omega$  for each resistor. Five such resistors in parallel will provide the equivalent of around  $20\ \Omega$ , but with a higher power rating. Carefully clip the wires of each  $100\ \Omega$  resistor so that there is less chance of creating a "short circuit" across the desired resistive network. Leave space for more resistors to be added. Don't miss adding the two "jumper" wires that connect one side of the board to the other.

Make sure your battery is initially OFF.

We don't want current flowing through our circuit until we are confident it can handle it!

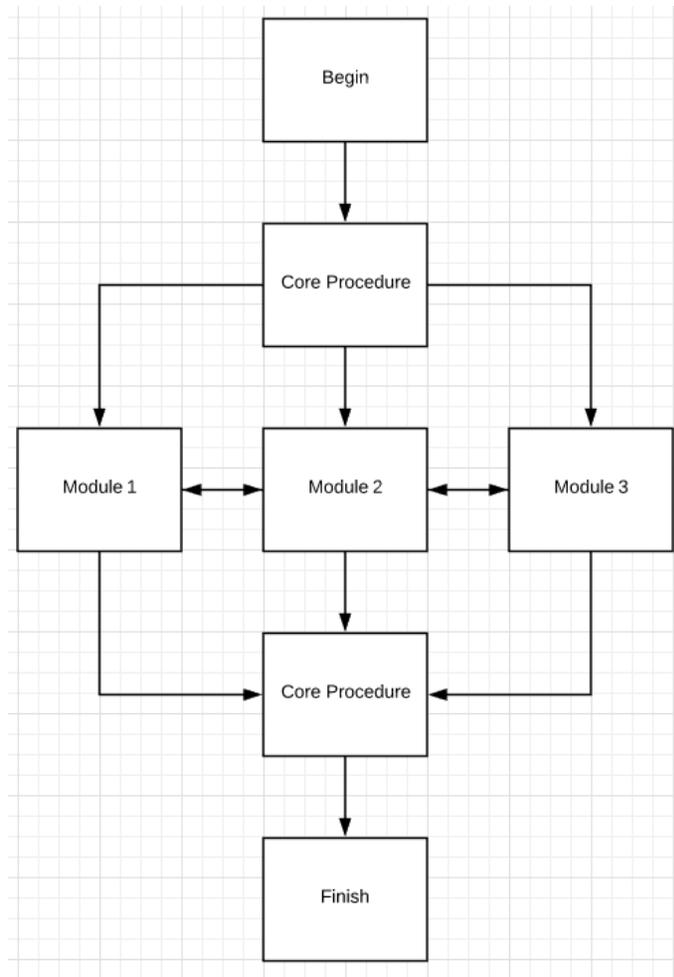


**Figure 3:** The breadboard circuit you are to build (a) the physical diagram and (b) the schematic of the same circuit.

Now, with your car sitting on a wooden block (so it doesn't run away from you), turn on the battery. Both wheels should spin, but you might note that one wheel is faster than the other. Attempt to speed a slow wheel by adding another resistor in parallel with the network on that side of the car. Alternately, attempt to slow a wheel by removing a resistor. **BUT DO NOT USE LESS THAN FIVE RESISTORS PER NETWORK** or you may go beyond the power rating and burn your fingers!

Make final adjustments by setting your car on the floor until it runs straight. Set your car aside until the breakout session. Until then, continue with one or more of the following **Explore More! Modules**.

## Explore More! Modules



**Figure 9:** Explore More! Modules provide students with options to investigate new concepts! As time allows, do one or more of the modules before returning to the laboratory's core procedure.

This week, we highly recommend the following *Explore More! Modules*:

<i>Explore More! Python for Plotting</i>	<i>Explore More! Making Batteries (may not be ready in time)</i>	<i>Explore More! Inside the Arduino (may not be ready in time)</i>
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At the end of the semester, you will earn points towards your total semester lab score by having completed a minimum of 8 modules. If you wish to be eligible for a Course Aide position in the future, please consider doing more and impressing us with your command of the material and your ability to aid your classmates.

## Breakout Session #2

Return to the breakout session when instructed by the TA. Set up again the two rows of figurines. Have each person attempt to navigate the straight path quickly without hitting a figurine, now *without* any physical control! Have the best car of the East race the best car of the West!

## At your Bench

As an aspiring engineer, we would like to not only follow a procedure, but to also analyze the results and consider alternatives to our design. Let's spend a little time decomposing the circuit we just built. Carefully follow these instructions.

Remove the battery, the motors, and the two "jumper wires" from your circuit leaving ONLY the two resistor networks on either side.

**Question 5:** Beginning with the left resistor network circuit, attach the Ohmmeter to the two rails and record the resistance. Continue to remove resistors and record the measurement until all resistors have been removed from the left-side resistor network.

Number of resistors	Resistance (measured, in $\Omega$ )	Comments:
		With all resistors, this is $R_l$ .

*Table 1: Left-side resistor network decomposition*

Think about it...

While ECE110 doesn't require a "professional" lab notebook, you should learn to start good habits now. Never erase mistakes or remove "bad" data. Cross out mistakes with a simple line and make the correction nearby. If you can explain an "outlying" data point, do so, but never arbitrarily choose to remove an outlier to improve your data set.

Notes:

**Question 6:** Repeat this procedure with the right-side resistor network.

Number of resistors	Resistance (measured, in $\Omega$ )	Comments:
		With all resistors, this is $R_T$ .

*Table 2: Right-side resistor network decomposition*

**Question 7:** Provide a formula for the resistance of  $n$   $100 \Omega$  resistors in parallel.

**Question 8:** Using your resistive model,  $R_m$ , for both motors and the resistor networks you designed above, predict how long a NiMH rechargeable battery rated at 1200 mAh would operate both wheels of the car continuously before going dead (depleting its charge). Show your work.

## Lab 2 Summary (To be submitted at the end of the laboratory session)

**For TA use only:**

Student was prompt, participated in Breakout Session #1. Points earned: **0, 1, 2** (TA circle one) TA initials: \_\_\_\_\_

**Question 9:** Explain in your own words why we needed a resistive network (instead of a single resistor) to slow the wheels.

**Question 10:** What is the equivalent power rating of your left-side resistive network?

**Question 11:** Did this seem to be an effective method of wheel-speed control? What pros and what cons do you see in this method?

**For TA use only:**

Student was engaged throughout the lab, without distractions like cell phone, homework non-course-related videos, etc.

Points earned: **0, 1, 2** (TA circle one)

TA initials: \_\_\_\_\_

Modules submitted today: \_\_\_\_\_

Notes: \_\_\_\_\_

Name: \_\_\_\_\_

NetID: \_\_\_\_\_

Section AB/BB:

**0 1 2 3 4 5 6 7**

**8 9 A B C D E F**

**(circle one)**