

Name:

NetID:

Today's bench partner:

Section AB/BB:

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

Experiment 3: Switched-Resistor Speed Control

Laboratory Outline

This week, we will continue to use networks of resistors in series with the motors for speed control of the wheels. As we observed before, the resistive networks allow us to create smaller resistive values with higher power ratings. In the prelab, we use switches to alter the wheel speeds by small amounts for fine-tuning of the wheel speeds by tuning resistor networks without completely stopping the wheels. In lab, we will be able to do analysis considering Kirchhoff's Voltage Law and Kirchhoff's Current Law using the DC V option of the voltmeter. As we use the switches to alter the resistive network, we are actually using a time-varying circuit. The tool of choice for analyzing time-varying signals is the *oscilloscope*. Also, we have a tool called the *function generator* that will enable us to generate time-varying voltage signals for test-and-analysis. We'll save the function generator for next week.

Learning Objectives

- Learn to pulse wheels for *fine-tuned* control of motor speed and car direction.
- Investigate and confirm Kirchhoff's laws for DC analysis of our car.
- Gain an introduction to benchtop equipment designed for time-varying signals; the function generator and oscilloscope.

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 instructed, move into the breakout session of the lab. Today, you will compete in navigating a straight line, but with small adjustments in the motor speed.

Breakout Session #1

Set up two rows of figurines 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! In lab 2, the car wheels would start and stop. Now, you will just be causing them to change speeds.

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.

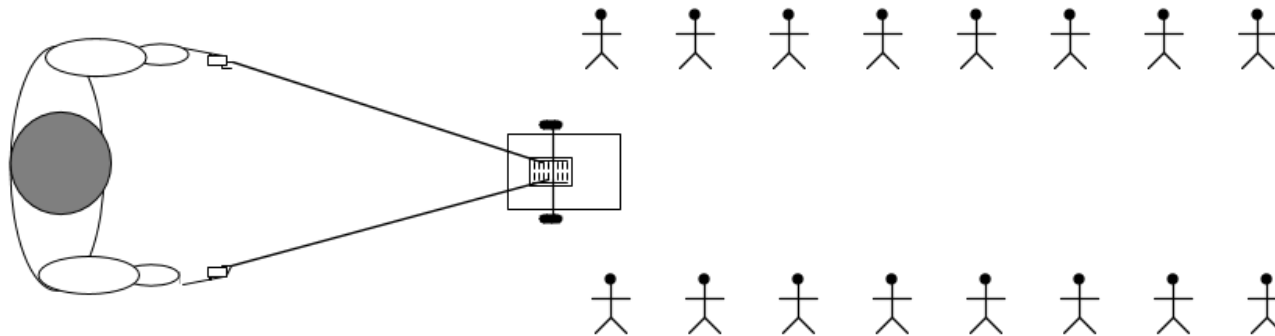


Figure 1: Car race using snap-action switches for wheel control (not to scale).

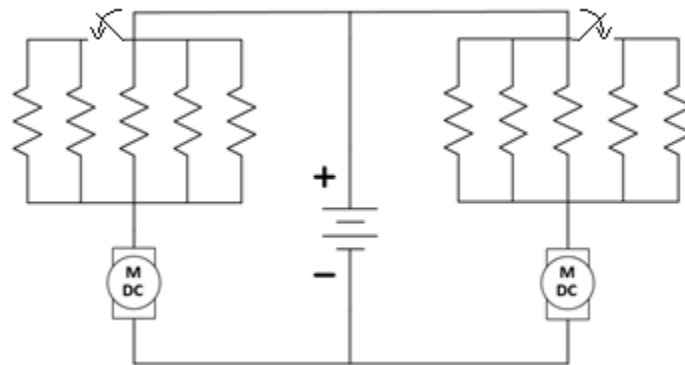


Figure 2: Example circuit using snap-action switches to fine tune the wheel speed without stopping. Figure is intended only as a conceptual idea, not to suggest numbers and orientation of resistors.

At your Bench

Circle the bench you are working at today: moved to the Summary page. Please do this now. Thanks!

Today, we will focus on engineering *analysis*. Hobbyists are able to follow instructions and even make small adjustments to a design to alter the results. It takes engineering expertise, however, to fully understand, make significant improvements, and even create fresh designs.

Oscilloscope Viewing of Time-Varying Signals

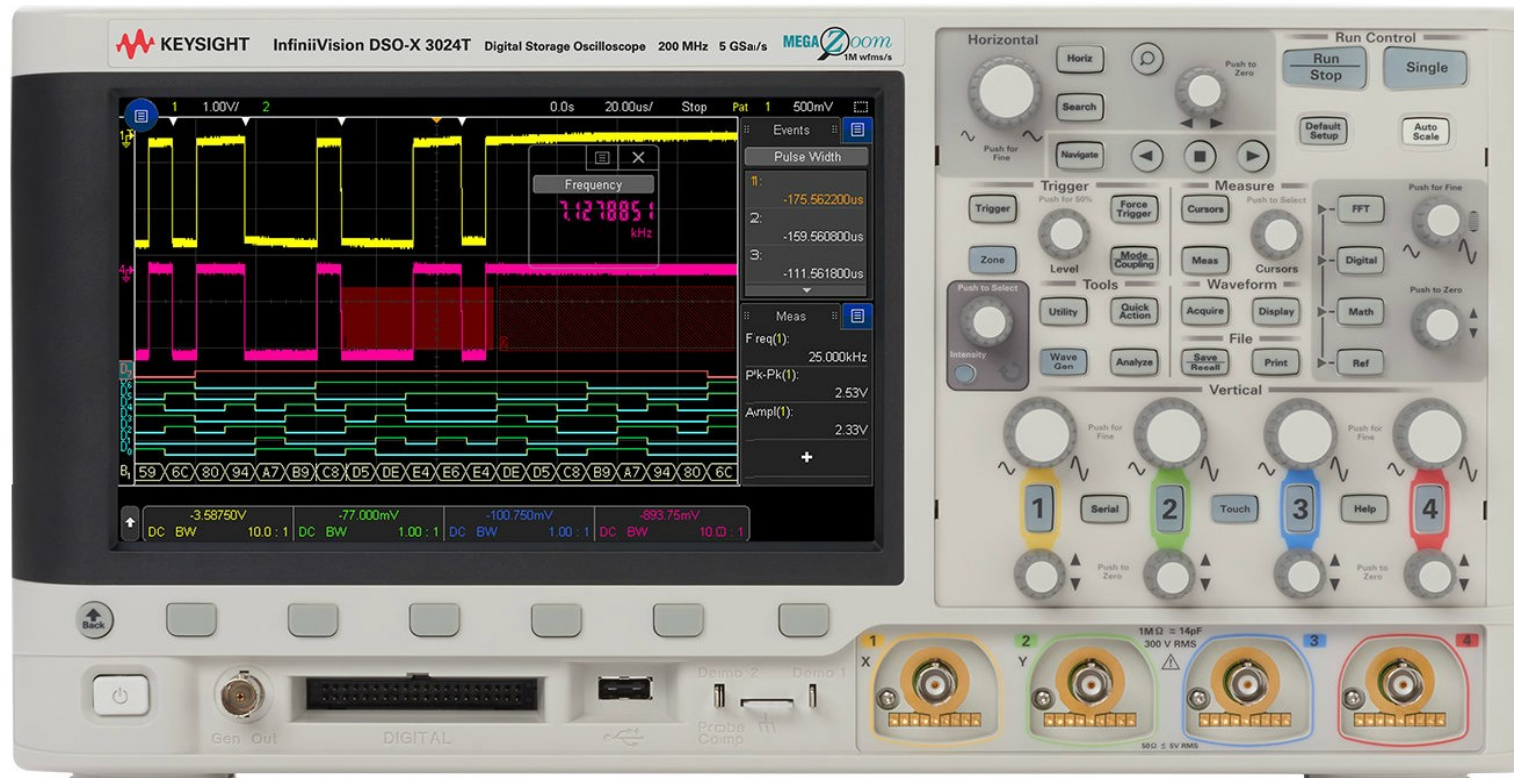


Figure 3: A KEYSIGHT Technologies oscilloscope similar to that used in the lab. Image Source: KEYSIGHT

When the instrument has finished powering up, press the Default Setup button near the upper-right corner of the instrument. This button will remove any unusual settings done by the previous user and put us into a known state.



Figure 4: The oscilloscope's Default Setting.

Next, connect a coaxial-to-banana cable to the Channel 1 input.

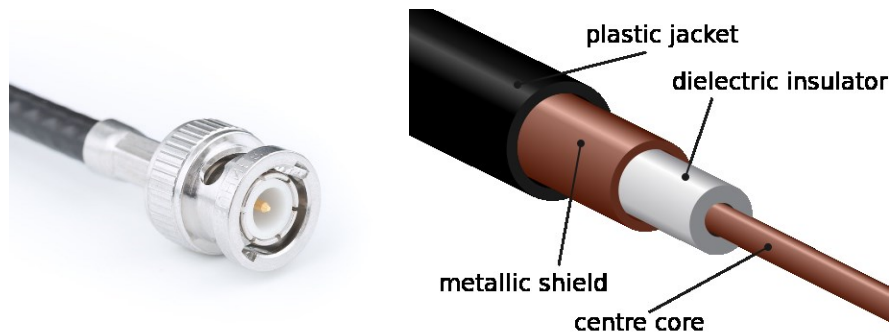


Figure 5: A coaxial cable with a BNC connector appropriate for use with the KEYSIGHT oscilloscope. Note that although the cable on the left would seem to be a single wire, the actual construction has two conductors, a core and a shield.

Image Source: Wikipedia

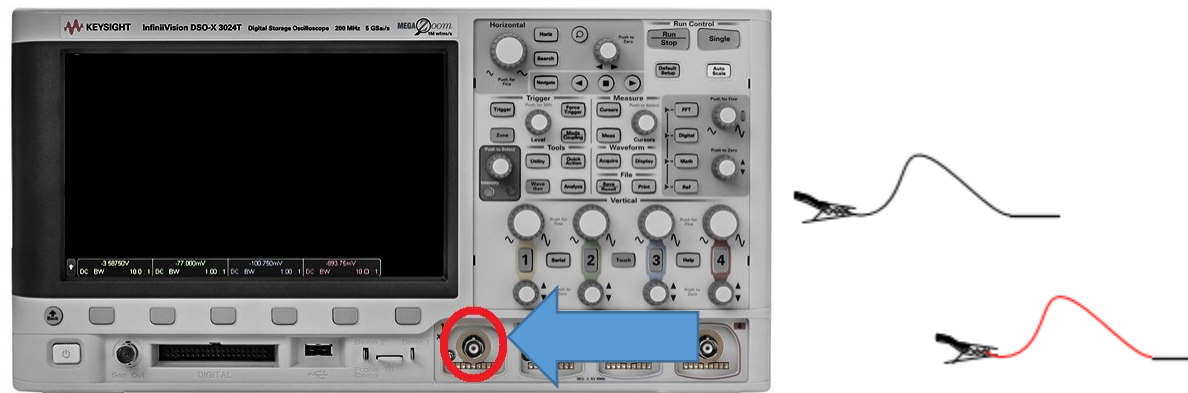


Figure 6: The oscilloscope's Channel 1 input.

Place alligator clips with wires onto the banana ends of this cable for monitoring the voltage across your left motor as shown in the figure below. Use the black probe where the negative polarity is indicated and the red probe where the positive polarity is indicated.

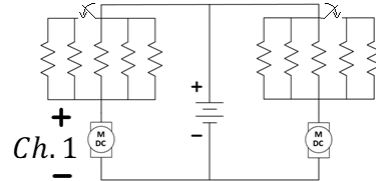


Figure 7: Using the oscilloscope to monitor the voltage on the left motor.

Very quickly, toggle your left motor's speed using the snap action switch. You will primarily use two controls on the oscilloscope to improve your view...the vertical scale adjust and the horizontal scale adjust. If the display appears to be “untriggered” (ie. scrolling past), try turning the triggering threshold knob (Figure 9), first counter-clockwise, until the horizontal triggering line *slices* through the signal.

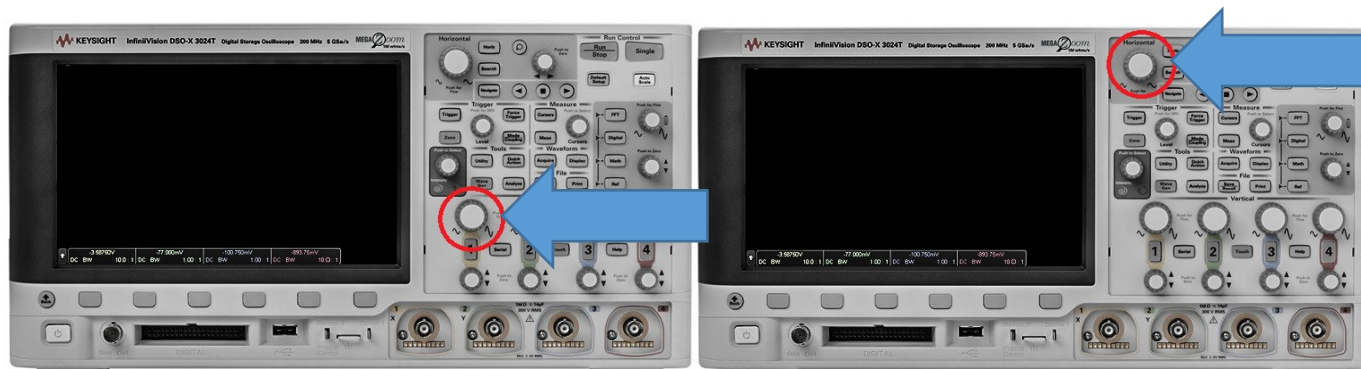


Figure 8: Adjust the view using the vertical scale adjust (visible height of the signal) and the horizontal scale adjust (amount of time shown on the screen).

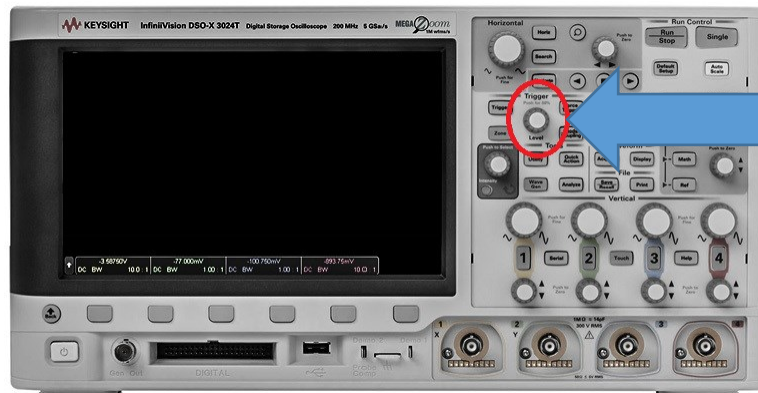


Figure 9: Adjust the trigger such that the horizontal trigger line that appears sits between the two voltage values across the motor.

Question 1: Briefly discuss the function of each the vertical scale and the horizontal scale adjustments.

Question 2: Adjust the time scale to estimate the maximum frequency at which you are able to vary between the two motor speeds. Record below the rate (or the *period*) at which you can toggle between the two speeds and discuss any challenges you had in determining this measurement.

Kirchhoff's Laws

Now, let's use the voltmeter to validate Kirchhoff's Laws for our circuit.

Remove the switches and the four $47\text{ }\Omega$ resistors from the circuit. Set the car on the stand (wooden block, so it doesn't run away). **Turn on the battery** so that the wheels are turning.

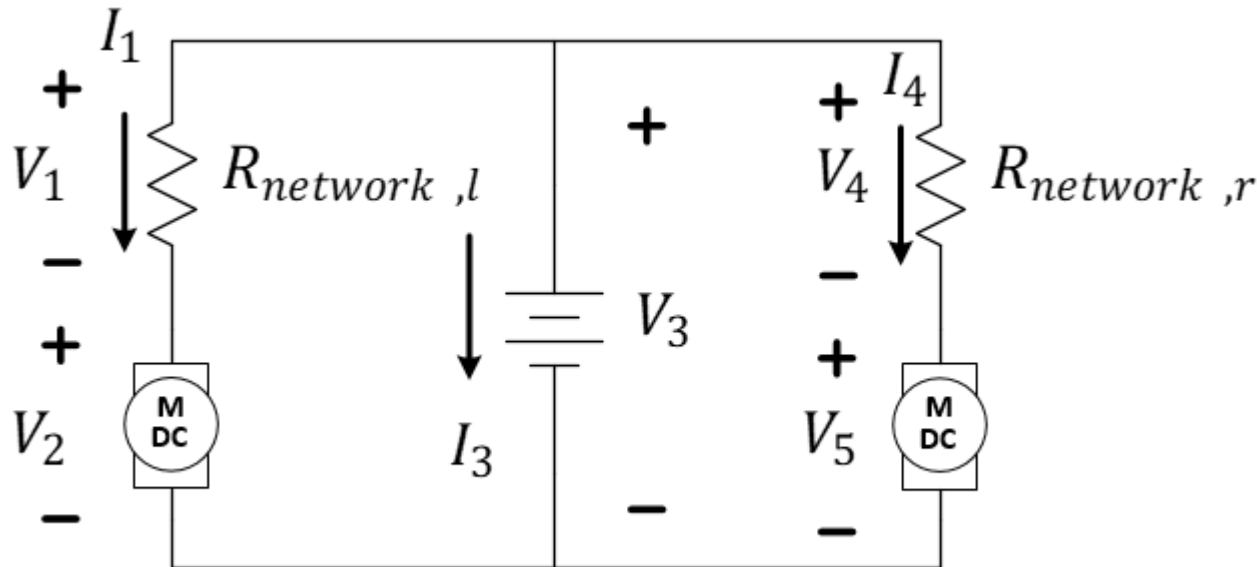


Figure 10: Voltage measurements to be recorded. Note that the $-$ symbol represents the location of the black (COM) wire of the multimeter and the $+$ symbol the location of the red ($V - \Omega$) wire for each measurement.

Question 3: Beginning with the left resistor network circuit, attach the voltmeter to measure each of the five voltages above and report them in Table 1. Note that the $-$ symbol represents the location of the black (LO) wire of the multimeter and the $+$ symbol the location of the red (HI) wire for each measurement.

Voltage Symbol	Voltage (measured, in V)	Comments:
V_1		
V_2		
V_3		
V_4		
V_5		

Table 1: Voltage measurements of Figure 3.

With these measurements, we can determine the validity of Kirchhoff's Voltage Law.

Question 4: For the loop indicated below, write the KVL expression using first the symbols for the voltages, then solve using the actual voltages to determine if the equation is approximately correct. Start by writing the voltage labels and polarities on the schematic (ref. Figure 10).

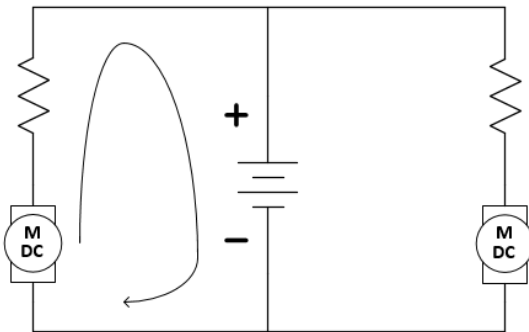


Figure 11: Loop 1.

Question 5: For the loop indicated below, write the KVL expression using first the symbols for the voltages, then solve using the actual voltages to determine if the equation is approximately correct.

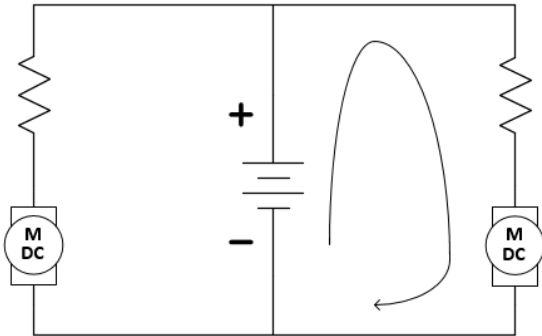


Figure 12: Loop 2.

Question 6: For the loop indicated below, write the KVL expression using first the symbols for the voltages, then solve using the actual voltages to determine if the equation is approximately correct.

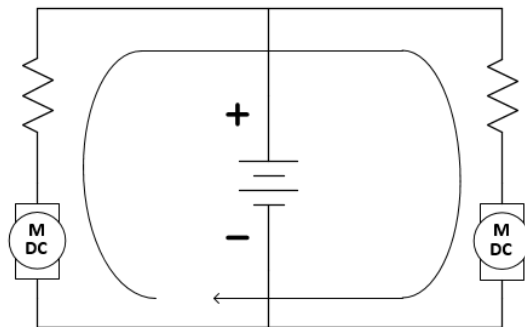


Figure 13: Loop 3.

Question 7: The resistance of each resistive networks were measured last time (if they were unchanged). Reference the previous lab and report them here. Alternately, remove the battery and motors and measure each again using the ohmmeter. $R_{network,l} = \underline{\hspace{2cm}}$, $R_{network,r} = \underline{\hspace{2cm}}$

Question 8: Use Ohm's Law and your measurements to determine the values of I_1 and I_4 (ref Figure 10).

Question 9: Use Kirchhoff's Current Law to determine the value of I_3 (ref Figure 10). Start by circling the node being evaluated in the circuit below and drawing your current labels and assumed polarities (see Figure 3) on the schematic. Show your work. Briefly explain why I_3 takes on a negative value.

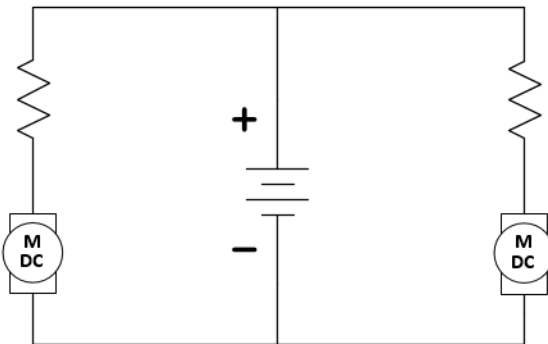


Figure 11: Please circle your node and label the currents.

Set your car aside until the breakout session. Until then, continue with one or more of the following **Explore More! Modules**.

Explore More! Modules

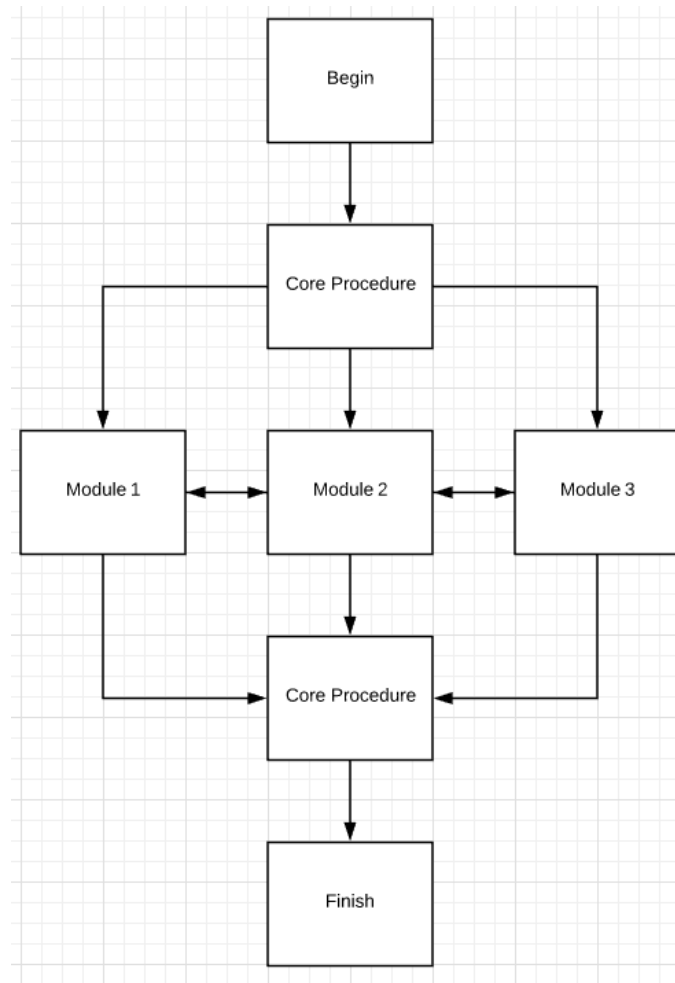


Figure 12: Explore More! Modules provide students with options to investigate new concepts! As time allows, do one or more of the modules before returning to the laboratory's core procedure.

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

Explore More!	Explore More!	Explore More! Engineering Ethics: Case Studies (can be done at home!)
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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

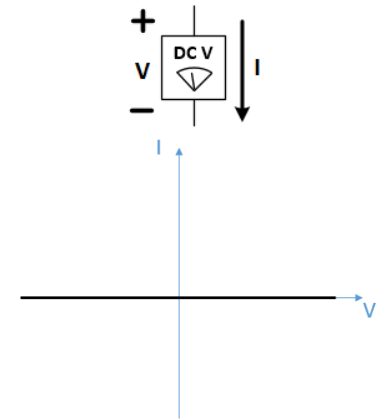
Return to the breakout session when instructed by the TA. As a group, read the following statements and answer the corresponding questions.

Any equipment used in the lab to analyze a circuit should have a minimal effect on the circuit's behavior. For instance, the use of a voltmeter should not alter the voltage it was intended to measure. An ammeter (current meter) should have minimal effect on the current it is to measure.

Question 10: The voltmeter is placed in parallel with a circuit component to measure the voltage potential across it. What must be true about the effective resistance of the voltmeter?

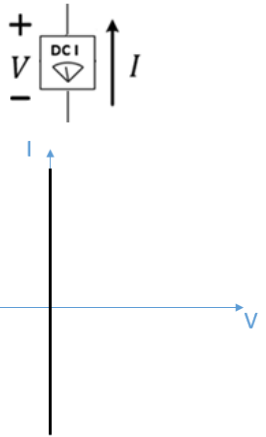
Think about what the oscilloscope measures and how channel 1 of the oscilloscope was inserted into the circuit.

Question 11: What must be true about the effective resistance of the oscilloscope's Channel 1?



The ideal voltmeter carries no current regardless of the voltage it measures.

Notes:



An ideal ammeter incurs no voltage drop across its terminals regardless of the current flowing through it.

Question 12: An ammeter is placed in series with the branch for which current is to be measured. What must be true about the effective resistance of the ammeter?

At Your Bench

Let's use the ammeter to measure the current flowing through your motors. Note the change in the location of the red wire on the figure below.

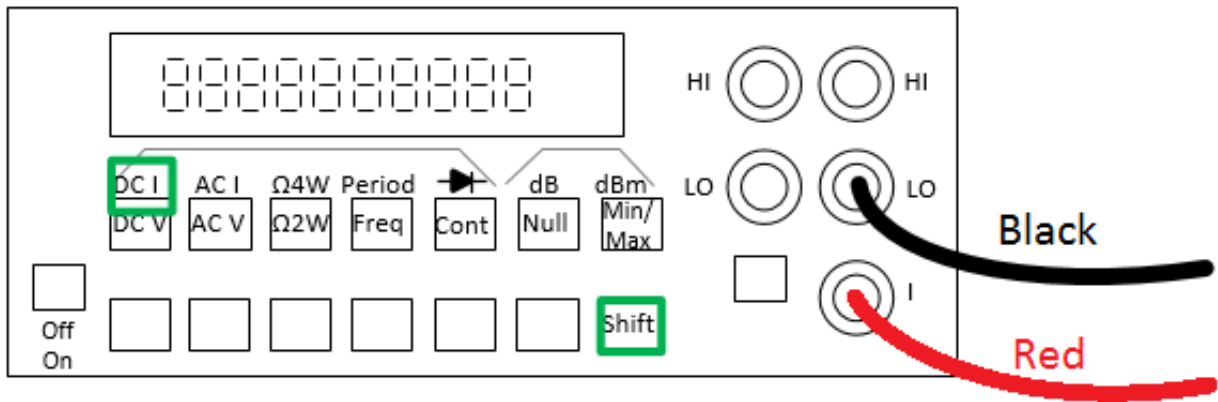


Figure 13: Use Shift-DCI to measure DC current.

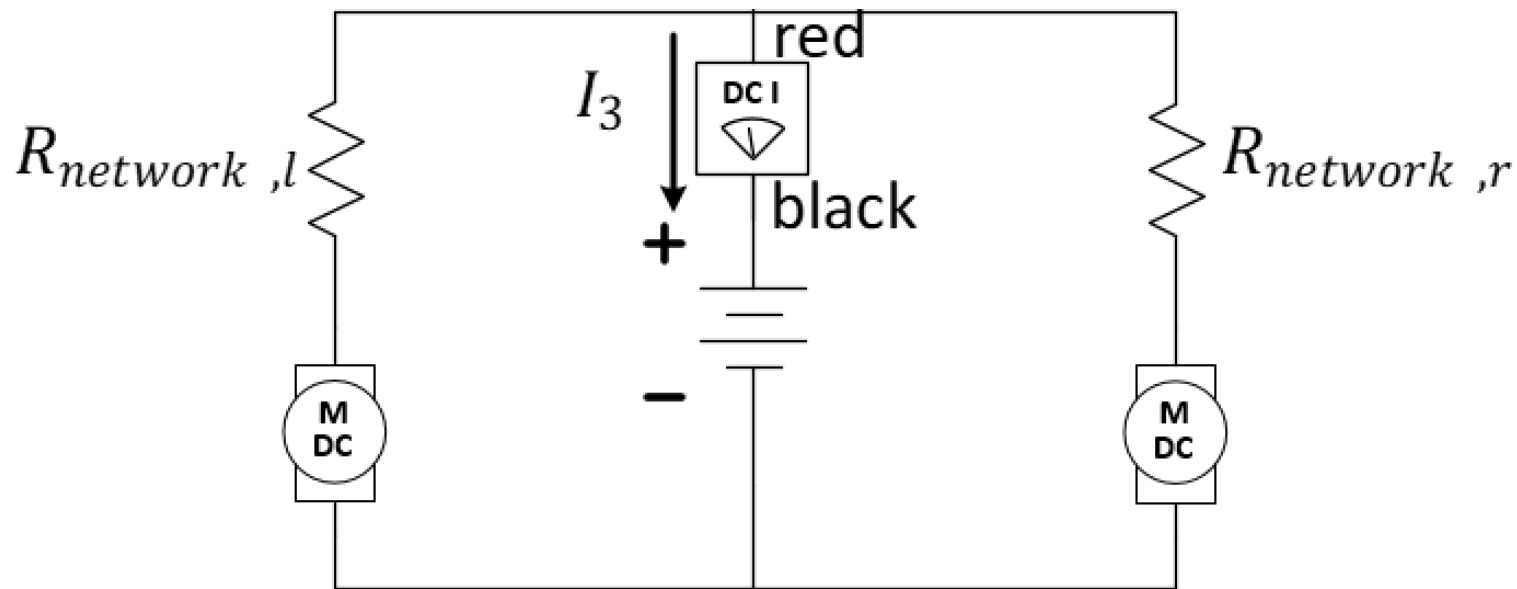


Figure 14: Insert the ammeter to measure the current supplied by the battery, I_3 . The connections of the physical ammeter are shown in the previous figure.

Question 13: Measure I_3 using the ammeter and compare to the calculation using KCL done earlier.

Return your borrowed equipment, clean up your benchtop, and submit your lab summary before leaving for the day. Thank you!

Notes:

Lab 3 Summary (To be submitted at the end of the laboratory session)

For TA use only:

Prelab Score: **0, 1, 2**

Student was prompt, participated in Breakout Session #1. Points earned: **0, 0.5, 1** (TA circle one) TA initials: _____

Question 14: Discuss: Do you feel that the incremental change in wheel speed is better or worse than turning the motors fully on and off like we did last week? Explain.

Question 15: What did the oscilloscope offer that the voltmeter did not?

Question 16: What is always an important requirement of the equipment we use to measure voltage and current? Think about how it must not affect the circuit to be measured.

For TA use only:

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

Points earned: **0, 0.5, 1** (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)

Bench:

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

(circle one)