Assignment # 1
ENGN/PHYS 207—Fall 2018
DC circuit fundamentals

Circuits You'll Build

1. The classic ***voltage divider*** (because it appears everywhere)
2. Series-parallel circuit model of stove top temperature control and/or robot motors
3. Audio volume control

Lab Skills You'll Learn

1. Basic breadboard prototyping
2. Working with lab power supply
3. Making DC voltage and resistance measurements
4. How a potentiometer works, and applications thereof

1 Voltage Divider—and DC measurements

We'll start with building the classic voltage divider. It's a beautiful little circuit, just 2 resistors + 1 source. You will see this motif over and over and over again in many electrical systems (for instance, check out the audio volume control in this lab!)

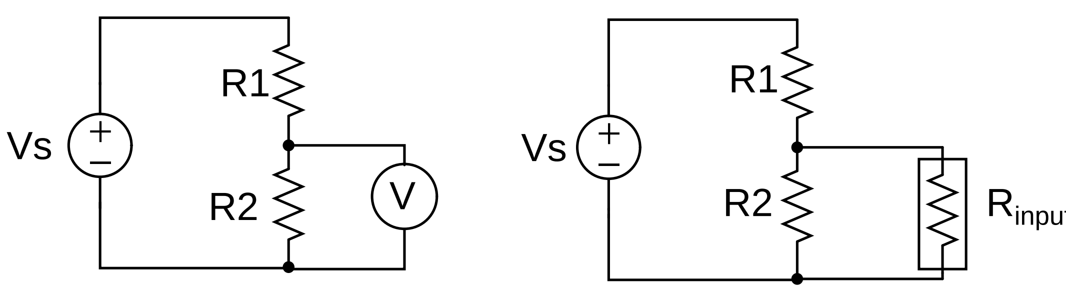


Figure 1: Left: Series circuit with ideal voltmeter. Right: Same series circuit, but this time accounting for the non-ideal behavior of the voltmeter. The voltmeter is modeled as a resistance R_{input}.

1. Build the circuit shown in Figure 1. Use values of $R_1 = R_2 = 10$ kΩ. What voltage do you expect to measure across R_2, assuming the volt meter (multimeter or oscilloscope) is ideal? Record this value in the handy-dandy table provided (Table 1).

Table 1: Data table for Voltage Divider/Voltmeter effect

Component	V (pred.)	V (meas.)	% diff.	Sanity check	I (pred.)	I (meas.)	% diff.	Sanity check
$R_1 =$								
$R_2 =$								
$R_1 =$								
$R_2 =$								

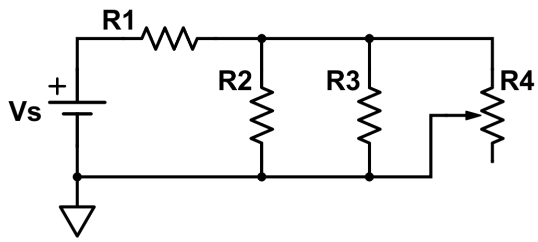
2. What is the voltage measured with the multimeter?
3. Time for a quick sanity check! Compare the predicted and measured values: Are the predicted and measured values in reasonable accord (say, a few % difference)?
4. Now change the value of the resistors R_1 and R_2. Use $R_1 = R_2 \approx 6.8$ MΩ. Any value ≥ 2 MΩ will do.
5. What is the resistance of an ideal voltmeter? How much current will flow through an ideal voltmeter? Briefly explain your rationale.
6. Calculate the voltage you would expect to measure across R_2 if the voltmeter were ideal
7. Now make the measurements, what's voltage across R_2?
8. Time for the quick sanity check again! Compare the predicted value (part 6 above) and measured values: Are the predicted and measured values in reasonable accord (say, a few % difference)? Hint: they should not be.
9. The good folk at Fluke (multi-meter manufacturers) specify that the meter has an input resistance $R_{input} = 10$ MΩ. Given this value, go back and calculate the voltage you expect to measure (i.e., see Fig. 1, right). How do these newly calculated values compare to your measured values? Sanity check: Are they in good agreement?
10. What's the take-home message? Suggest a reasonable "rule of thumb" for how large R_{input} must be relative to the resistance of the element whose voltage you want to accurately measure. Briefly justify (1–2 sentences is sufficient.)

The **take home message: Anytime you make a voltage measurement with your multimeter or oscillscope, you are adding another element to the circuit**. Some current has to "bleed off" to the meter—hopefully only a very small fraction! This is analogous to measuring pressure in a tire: you have to bleed off a little air to measure the pressure, but in doing so you reduce the pressure you are trying to measure in the first place. Carefully consider the effect anytime you make a measurement in the circuits lab (or any other lab).

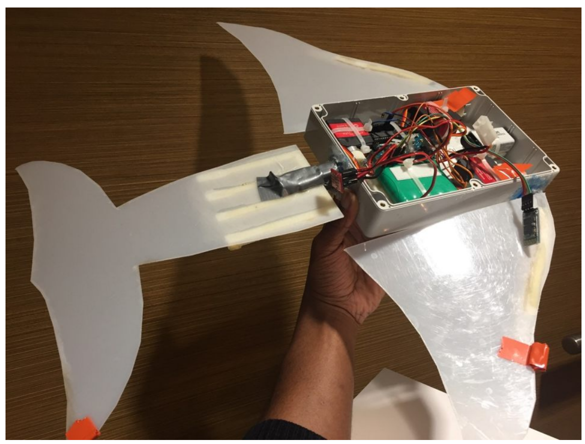
2 Series Parallel Circuits: KVL and KCL

Build the series-parallel circuit shown in Fig. 2. This circuit is a good model for burners on a stovetop; motors integrated into a robot; or even a sweet car stereo system with multiple speakers.

In each case, the ***real voltage source*** is modeled by an ***ideal voltage source*** V_s plus some internal resistance R_1. (All real sources have some internal resistance, often called the ***output resistance*** of the device)



(a)



(b)

Figure 2: (a) Series-parallel circuit modeling motors in a robot. (b)Raydolph manta ray dolphin hybrid bioinspired robot uses 3 battery-powered servo motors to flap the fins. Raydolph was designed and built by Jacob Ingber, Alfred Rwagaju, and Ryder Babik.

1. Now let's build the circuit in order to understand a bit deeper! Use nominal values of: $V_s =$ 5V, $R_1 \approx$100 Ω, $R_2 = R_3 \approx$500 Ω, $R_4 \approx$ 1 kΩ potentiometer

   Before you power up your circuit set the potentiometer to have an initial value of ≈ 500 Ω. This will prevent you from burning out some components!

   Remember to ***record the actual values of components used***.

2. Complete Table 2! You'll need to both make measurements and do a little bit of theory/computing. Make measurements of the voltage across each resistor. From here you can also compute how much current is flowing through each one too (Ohm's Law!). Alternatively, you could measure it directly using an ammeter, but doing so is difficult/painful in practice, thus not advised.

Table 2: Data Table for Series-Parallel Circuit. Compute both values predicted by theory "pred" and what you actually measured in lab "meas".

Component	V (pred.)	V (meas.)	% diff.	Sanity check?	I (pred.)	I (meas.)	% diff.	Sanity check
$R_1 =$								
$R_2 =$								
$R_3 =$								
$R_4 =$								

3. Interpret your results. Do your results pass the sanity check? As a rule of thumb in Circuits: differences between theory and experiment $\leq 5\%$ are "acceptable."

4. According to your results above, does KVL appear to be valid (to within some reasonable experimental uncertainty)? Briefly justify.

5. According to your results above, does KCL appear to be valid (to within some reasonable experimental uncertainty)? Briefly justify.

6. Lastly, let's check out the action of the pot. Turn the pot the maximum resistance. Report the voltage measured across parallel combination of resistors $R_2 - R_4$? Make the same measurement with the pot turned to its minimum resistance. Now sweep the pot through its full range while measuring the voltage across it. Provide an intuitive explanation for your observations. The main point of this exercise is to get familiar with the action of a potentiometer. **Turn off the power supply when you are done playing.** Leave the rest of the circuit intact.

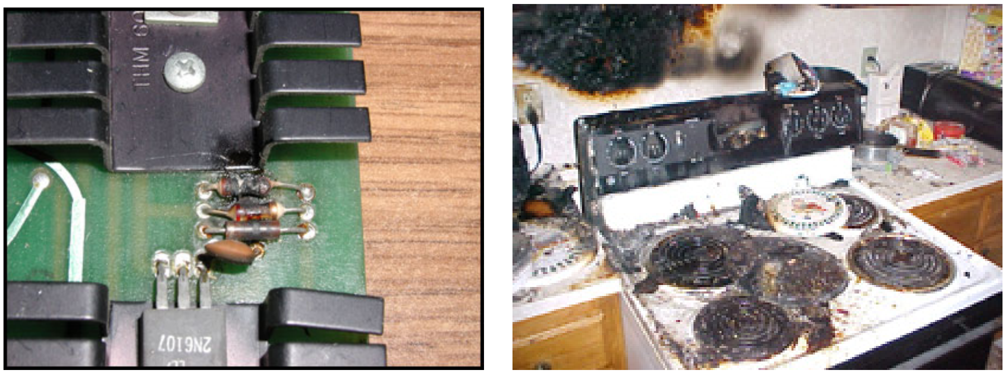
3 Feel the Heat: Power Dissipation in Resistors

Resistor dissipate energy (power) in the form of heat. This is how your floor heater works, your toaster and electric stove top works too. This useful conversion of electrical energy into heat is often referred to as ***Joule heating***. Of course, many times we don't want to feel the heat but can't avoid it. That's why computers have fans to blow out the hot air.

For this next experiment, This next experiment is a quick one that will cut to the heart of this matter and demonstrate a very important safety principle in circuits design. **READ ALL OF THESE DIRECTIONS BEFORE YOU PROCEDE TO BUILD. YOU WILL NEED TO BE PREPARED TO QUICKLY TURN OFF THE POWER SUPPLY TOTO AVOID FRYING YOUR EQUIPMENT!**

1. Verify the power supply is OFF.

2. Use the circuit from the previous section. Turn the pot to its midway point. You may safely remove resistors R_2 - R_4, if you wish; they have no bearing here.



(a) (b)

Figure 3: (a) Fried resistors in on a printed circuit board (PCB). The charred appearance is the tell-tale sign that the amount of power these resistors were dissipating far exceeded their power rating. Also note: fried resistors are not as tasty as fried chicken. (b) Home destroyed by electrical fire. A hot burner is great (especially for hot chocolate in winter!), but can spell disaster.

3. Compute how much power you expect to be dissipated in the resistor R_1, if R_4 were to its minimum value. Recall $P = IV = I^2R = V^2/R$.

4. Position a finger tip near or directly on the resistor R_1 in your circuit. It is also a good idea Your finger will serve as the crude temperature sensor. Your other hand and/or lab partner should be at the ready to control the power switch. WARNING: If you touch the resistor, it is possible that you get a small burn. It's nothing that will send you to the health center or hospital, but it may sting for a second.

5. Turn the power supply ON. Gradually turn the pot from it's middle value resistance toward minimum resistance. Qualitatively monitor the temperature of the R_1. You should feel it get toasty warm in a a few seconds. It's a good idea to monitor the temp of the potentiometer too. If R_1 doesn't feel hot after a few seconds, VERY SLOWLY begin to turn up the voltage on your power supply. Once you sense a noticeable amount of heat coming from the resistor, turn the power OFF immediately. If and when you smell burning plastic, power down immediately!

6. **IMPORTANT SAFETY ANNOUNCEMENT**: Now for the punchline. Every resistor has a ***power rating***. For instance, you may try to buy some resistors on digikey.com and see that they are rated for 1/8 W or 1/4 W (typical of the small resistors we use in lab). Translation: this is the maximum amount of power the resistor can safely dissipate without heating up. If you exceed the power rating, catastrophic failure may occur. Heed this warning—electrical fires lead to nasty and sometimes dangerous outcomes.

4 Audio Volume Control

Real world application time! Check out the volume knob on the guitar amp in Figure 4. How does it work in practice? You know have enough circuits under your belt to answer that question and build the circuit!

Figure 4: Classic Fender guitar amp

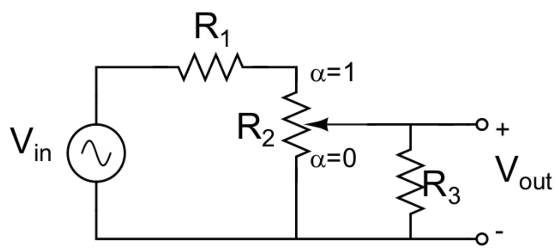


Figure 5: Audio volume control. $R_1 = 4.7$ kΩ. $R_3 = 15$ kΩ. $R_2 = 100$ kΩ pot. Circuit adapted from Elliott Sound Productions: `http://sound.whsites.net/project01.htm`

Figure 5 shows one very nice design of a high-quality audio volume control. You know that knob on your stereo or guitar amp! You know by now that it is just a pot. (Be sure you can interpret the circuit diagram correctly...which resistor is the pot?). The variable α specifies the position of the pot's wiper terminal—i.e. the percent rotation of the volume knob. A value of $\alpha = 1$ means that the wiper is turned all the way to the "top" of the circuit diagram; $\alpha = 0$ means all the way to the "bottom".

This volume control circuit was designed such that V_{out}/V_{in} has an approximately exponential dependence on the pot position α,i.e. $V_{out}/V_{in} \approx e^{\alpha}$. The reason why is because the human ear perceives sound loudness on a logarithmic scale of sound wave intensity: $S \approx \log(V_{out}/V_{in})$. The net effect is that the sound intensity increases linearly with pot position—a very, very nice user feature (no touchy spots on the knob):

$$S \approx log(V_{out}/V_{in}) \approx log(e^{\alpha}) \approx \alpha$$

With that prelude, time to build, test, and analyze. On the agenda:

1. Theory I: Provide an intuitive explanation which way the pot should be turned for maximum volume.
2. Theory II: Generate an expression for V_{out}/V_{in} in terms of α, R_1, R_2, and R_3.
3. Compute the expected value for V_{out}/V_{in} for $\alpha = 0, 0.1, 0.2, \ldots, 1$
4. Build the circuit. Measure V_{out}/V_{in} for ≈ 10 equally spaced pot positions (10 values for α).
5. Take your circuit for a test drive. The instructor will help you hook into an audio source (e.g. mobile phone) and audio amp. Please ask for help when you are ready!
6. Write a report on your findings. The instructor will provide more details on the expected content of the report.

The Multimeter

A multi-meter can be used to measure voltage, current, resistance, capacitance, etc. You will make extensive use of it in this lab, so it's important to know how to use it properly. Here are a few helpful hints/reminders:

Figure 6: Meet your new friend in Circuit lab: the Fluke multi-meter.

1. **Measuring Voltage:** The voltmeter measures the potential ***across*** two points:

$$V_{meter} = V_+ - V_-$$

   You must take care to properly place the probes of the voltmeter when making a measurement. By convention, the reference probe (V_-) is the one colored black and labeled COM. Take care that the other probe (V_+), typically red in color, is plugged into the proper port. Finally, make sure that the function dial is set to make a DC voltage measurement (the V with the straight bars above it).

2. **Measuring Resistance:** Your meter can immediately tell you the value of a resistor—or combination of resistors. You will find this feature to be incredibly useful (money back guarantee!). ***Firstly, make sure your circuit is powered down before attempting to make any resistance measurement (else you can damage the meter).*** Now, set the dial to the Ω symbol. Connect the red and black probes across any resistor, or combination of resistors. The polarity of the probes does not matter. The display reads out the resistance value. Be sure to carefully note the units on the right-hand side of the meter. Voila, you are done!

3. **Measuring Current:** To measure DC current, set the dial to the proper setting (A with the straight bars above it). Make sure the red probe is plugged into the port at lower left labeled "A". The meter measures current running ***through*** it. Thus, you have to insert the meter *into* the circuit.

The Potentiometer (aka “Pot”)

A ***potentiometer*** is just a variable resistor. Take a look at Fig. 7. You’ll see there are 3 terminals with labels A, B, and W. Terminals A and B are essentially just two terminals of a normal resistor. The magic happens at ***the wiper*** (W). As you turn the dial, the resistance between terminals A and W (or B and W) changes. Pretty much anywhere you see a rotating knob changing the output of electronics equipment (stereo, guitar pedal, etc.), rest assured it’s just a pot.

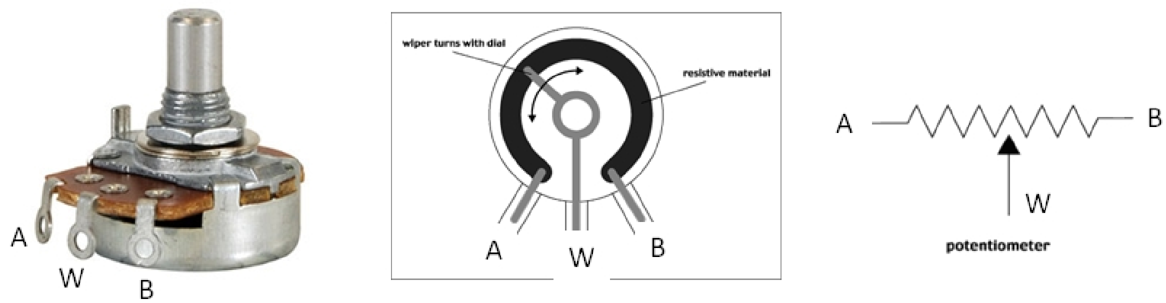


Figure 7: Potentiometer aka ”Pot”. Left: What you’ll find in lab. Center: what’s inside/theory of operation. Right: circuit component schematic. The magic really happens at the ***wiper terminal***, labeled W.