University of Colorado Boulder
ECEE Department

ECEN 2250 - Introduction to circuits and electronics - Fall 2023
Location: Engineering Center, ECCR 1B40, MWF 2:30PM - 3:20PM
Instructor: Professor Eric Bogatin, Dr. Mona ElHelbawy
Lab #3
Lab Title: V-R Circuits-2
Date of Experiments: October 1st, 2023
Names: Connor Sorrell

Experiment 1

Introduction:

The purpose of this lab is to experimentally confirm the two principles of combining resistors in series and in parallel. In addition, this experiment will introduce extreme cases, such as when one resistor is much larger than the other.

Experimentation:

After pulling out two 1k ohm resistors and measuring the resistance of both using the DMM, the values of the resistors were 981 ohms and 989 ohms. Using rule #9, I expect the series resistance to be 1970 ohms, or just around 2k. When using the DMM to measure the two resistors in series, the real value was 1985 ohms, which checks out. The expected value and measured value are slightly off, but that is due to the tiny errors in the DMM, breadboard, wires, etc.

I then repeated these steps, with two different 100k resistors, which actually measured 97.4k and 97.2k ohms according to the DMM. Using rule #9, I expect the circuit resistance in series to be ~190 ohms. After measuring, the real resistance is 195.2 ohms, which makes sense and is just a little off once again due to expected errors.

With a 100k and a 1k ohm resistor in series, (real values of 97.4k ohms and 989 ohms, respectively), the equivalent resistance should be around 98.4k ohms. Sure enough, the real measured value was 98.5k ohms, confirming rule #9. When one resistor is much much larger than another, the smaller one doesn't really have a role.

When combining two resistors in parallel, their equivalent resistance is (1/R1 + 1/R2)^-1. Or, if the two resistors are of equal resistance, the resistance in a parallel configuration will be 1/2R. In this case, with two 1k ohm resistors, I expect a value around 500 ohms. Turns out, the DMM measured 0.496 ohms, which aligns with my expectation.

With the 1k and 100k ohm resistors in parallel, I expect the total resistance to be approximately 990 ohms. After performing the measurement with the DMM, the real resistance was 985 ohms, which yet again is as expected.

The voltage divider circuit consists of two 1k ohm resistors connected in series. One resistor is connected to the 5V pin on the arduino, and one is connected to ground. Where the two resistors meet, there is a reference node to measure the voltage across the voltage divider. I expect the voltage across the resistor connected to ground to be 0, and sure enough, the DMM confirms that with a value of 0.04 mV. I also expect the voltage of the source to be 5V, because that is what is coming from the arduino. The real value was 4.98V, which makes sense.

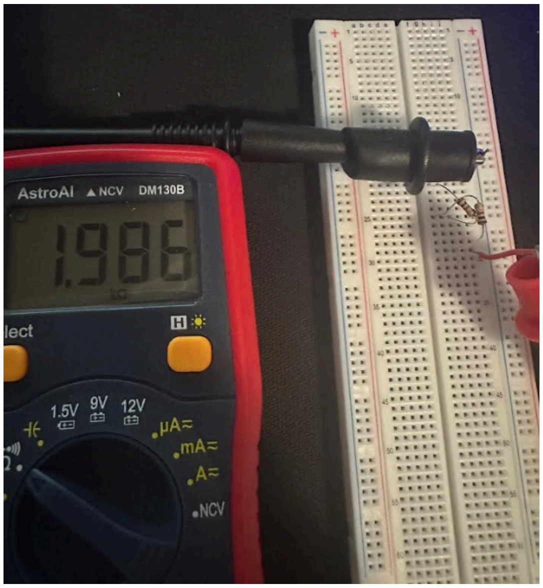


Figure 1.1.0: Showcases the circuit with 2 1k ohm resistors in series.

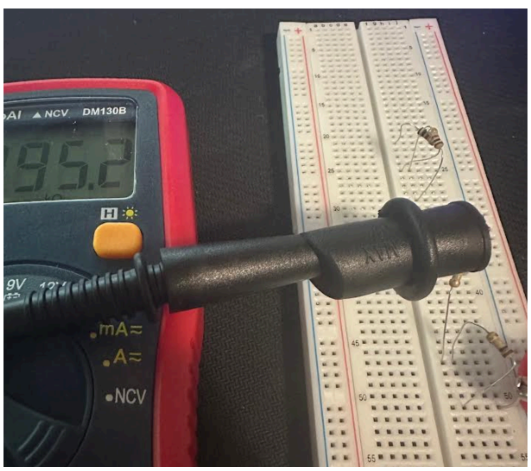


Figure 1.1.1: Showcases the circuit with 2 100k ohm resistors in series.

Figure 1.1.2: Showcases the circuit with a 1k and a 100k ohm resistor in series.

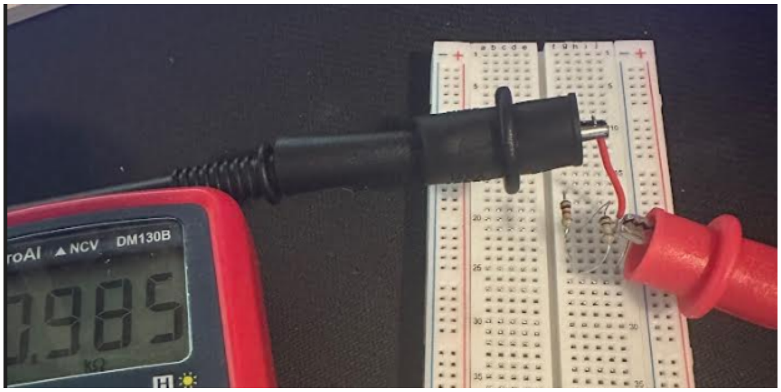


Figure 1.1.3: Showcases the circuit with a 1k and a 100k resistor in parallel.

Figure 1.1.4: Showcases the circuit with two 1k ohm resistors in parallel with one another.

Experiment 2

Because all the resistors are connected in series, the total current anywhere in the circuit is constant. We also know from previous experiments that the LED has a voltage drop of about 2V. So, over the course of the five other resistors, 3V will be dropped.
I = V/R, so I expect the current to be equal to 3/850 = 3.5 mA of current.
I expect the voltage drop across each resistor to be equal to V = IR.
R1: V = .0035(100) = .35V Real value via DMM 0.3601 V
R2: V = .0035(100) = .35V Real value via DMM 0.364 V
R3: V = .0035(100) = .35V Real value via DMM 0.3623 V
R4: V = .0035(220) = .77V Real value via DMM 0.789 V
R5: V = .0035(330) = 1.155V Real value via DMM 1.202 V

True current running through the circuit at any point = 3.6 mA.

Though the measured values from the DMM were not exact with the calculations done beforehand, they align very closely and show that my initial math and thought process was correct. However, there is a difference between the values, which can be attributed to the faults within the equipment, and also a fault in my initial guess of the LED's voltage drop. (1.94V as opposed to 2V).

It will not matter what order the resistors are placed in the circuit, because no matter what they are still in series and the same amount of current will be running through each resistor.

The current through each of the 100 ohms resistors is the same, as is the voltage drop across each. The sum of the voltage drops across each resistor is 3.07V. This makes sense because the LED voltage drop was 1.94V, so each component's voltage drop in the circuit adds up to be 5V, which was the supplied power. This is KVL, done physically. It does not matter the location of the resistors, as current stays constant throughout the series, and the sum of the voltage drops will equal the supplied voltage no matter what.

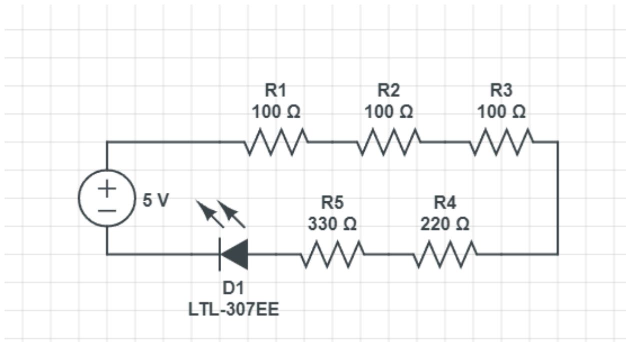


Figure 1.2.0: Circuit schematic

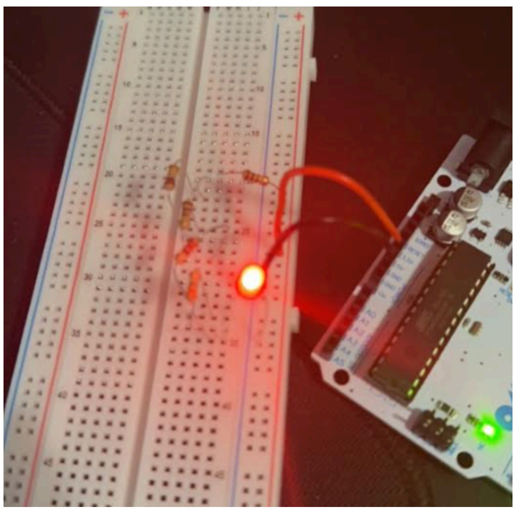


Figure 1.2.1: Picture of the arduino plugged into the breadboard and the 5 resistors in series.

Experiment 3

Introduction:
The purpose of this lab is to experimentally evaluate how good Ohm’s law is in a resistor.

Procedure and Analysis:
The first step in this lab is to measure the resistance of two 1k ohm resistors with the DMM. Resistor under test = 989 ohms, sense resistor = 993 ohms. This slight error is as expected, as the resistors are rated to 5% accuracy. With these two resistors, set up a voltage divider using the wave gen as the voltage source. This is done by connecting in series on a breadboard. Connect channel 1 to the scope to measure the voltage across the resistor under test, and connect channel 2 of the scope to measure the voltage across the sense resistor. Also connect a power and ground to the breadboard. Then, I set up the wave gen to create a triangle wave with a 5V amplitude at 1 kHz. I triggered the scope, and then zoomed until I saw the two traces as ramps on the screen. I then exported channel 1 and 2 and pasted them into the excel spreadsheet, this is the measured data. I then used excel to plot the voltage on the vertical axis and the current on the horizontal axis. Then it came time to make my model data, using ohm's law. After modeling data, my error was already quite small, however I made it smaller by “hacking” it. I adjusted the nominal resistance value, until the difference between the measured values and modeled values was near 0.005. This is my first order model. I then changed the offset to reduce the residual error, which drastically improved the model. After doing so, the difference between the real and modeled values was on average, less than 1 x 10 ^ -7. This is as small as I could get the error in this experiment, which is acceptable because the error is very very minor. The value of R_Model is the ideal resistance in which ohms law works with my data, while v0 slightly offsets the modeling equation in order to disguise the digitizing noise formed by the waveform. Both parameters exist in order to make the model fit the true values as accurately as possible. From this experiment, I can conclude that ohm's law is extremely accurate. In fact, if there were no errors between human fault, equipmental errors, etc, ohms law would be 100% accurate.

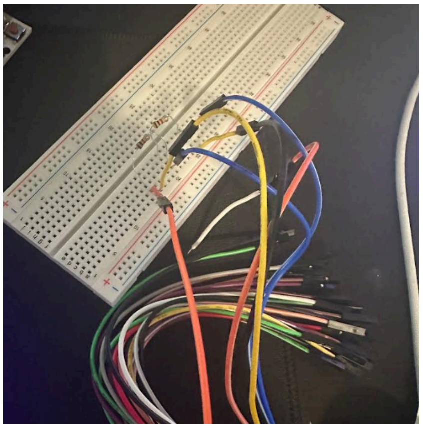


Figure 1.3.0: Picture of voltage divider circuit and wires plugged into the breadboard from the scope.

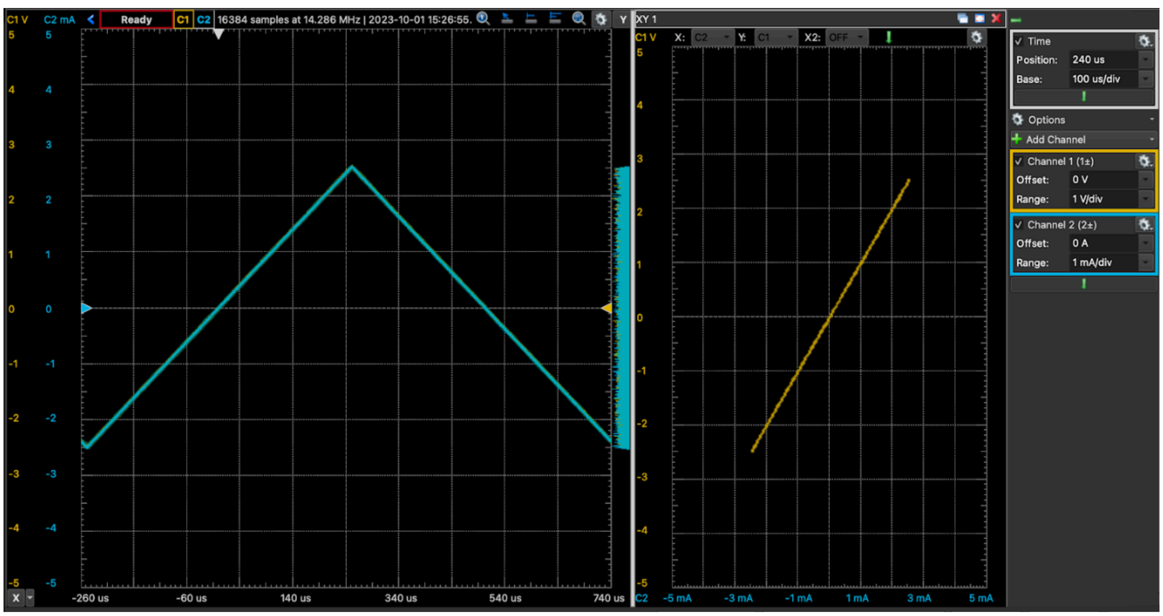


Figure 1.3.1: Screenshot of the scope set up before measurements were exported.

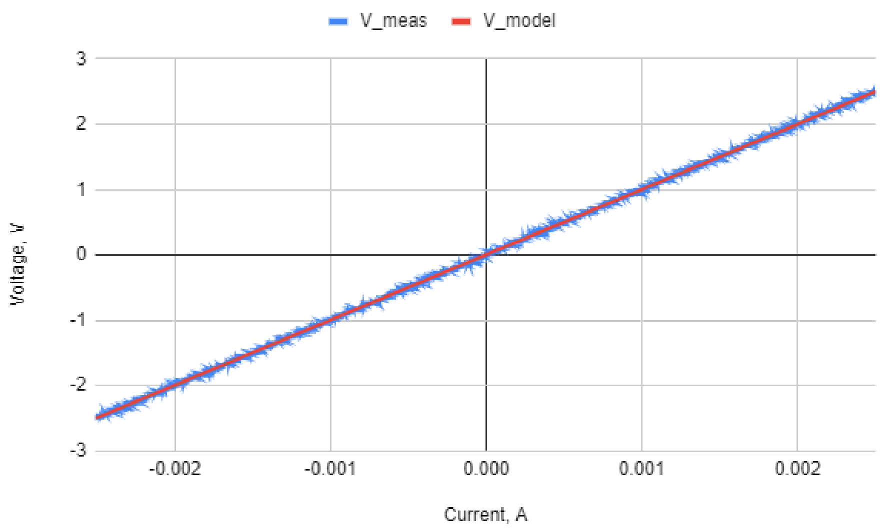


Figure 1.3.2: Plot of the measured voltage vs current as well as the modeled voltage vs current.

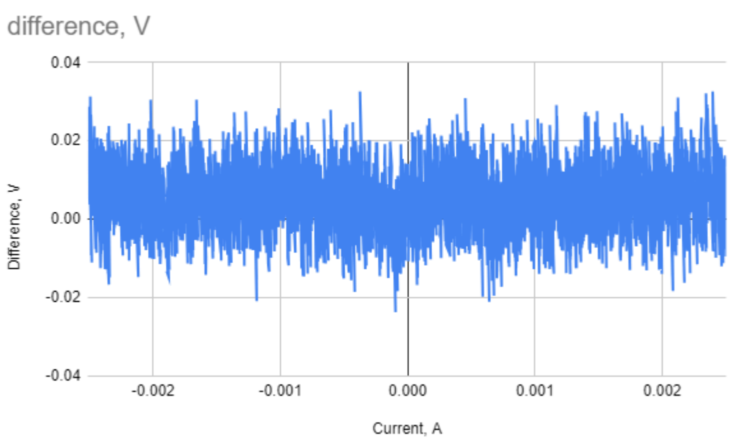


Figure 1.3.3: error between measured and modeled data

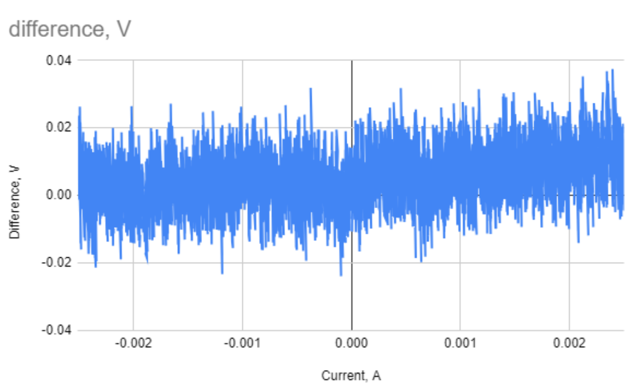


Figure 1.3.4: error between measured and first order simulated model using 998 ohms for R_model

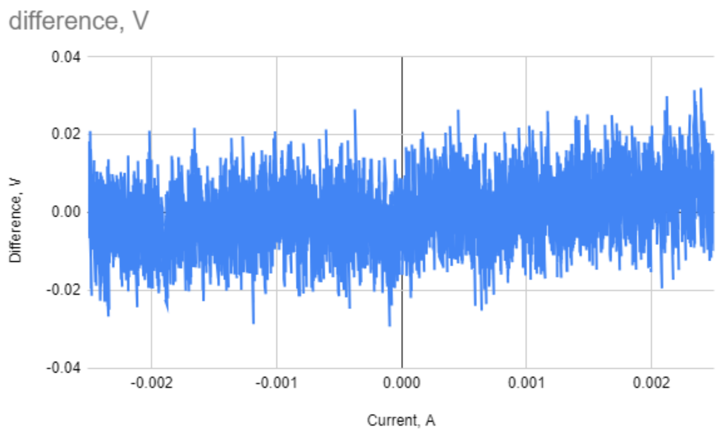


Figure 1.3.5: error between measured and second order simulated model using 0.005357 as V0.

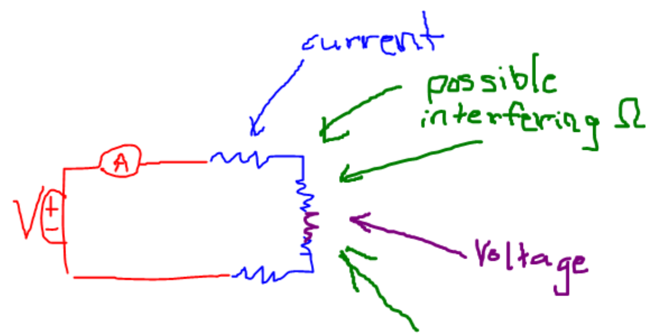
	A	B	C	D	E
1		R_model, ohms	998		
2		V_offset, volts	0.005357		
3	Channel 2 (A)	V_meas	V_model	difference, V	
4	-0.00250356361	-2.497874502	-2.493199484	-0.004675018379	0.00000009388679652
5	-0.00249800829	-2.492361552	-2.487655281	-0.004706271071	
6	-0.00250541538	-2.484092127	-2.495047552	0.01095542455	
7	-0.00250171184	-2.492361552	-2.491351416	-0.001010135858	
8	-0.00249800829	-2.494199202	-2.487655281	-0.006543921114	

Figure 1.3.6: Screenshot showcases the smallest error I got using the second order model.
Result = 0.00000009 V

Experiment 4

The 4 wire method of measuring resistance uses four leads rather than two. It is extremely useful, because it makes it possible to accurately measure small resistance values, such as values below a tenth of an ohm, and even to one milliohm. Essentially, the 4 wire method uses a pair of leads for the test lead (driving current), and another pair to measure the voltage across the resistor. By separating these two measurements, we can eliminate any impact that a lead or contact resistance has on the result.

Figure 1.4.0: Shows the equivalent circuit of a resistance measurement. The 4 wire method is not sensitive to the lead resistance or contact resistance because it breaks the measurement up into two parts, one lead for the current and another for the voltage. Then, everything except the voltage measurement is negligible.



The lowest resistance I can measure on my DMM is around a tenth of an ohm, but with the 4 wire method, I can measure up to a single milliohm. This will be extremely helpful moving forward because it is often necessary to measure very small resistances. To decrease the lowest resistance measurable, I can pump more current through the circuit.

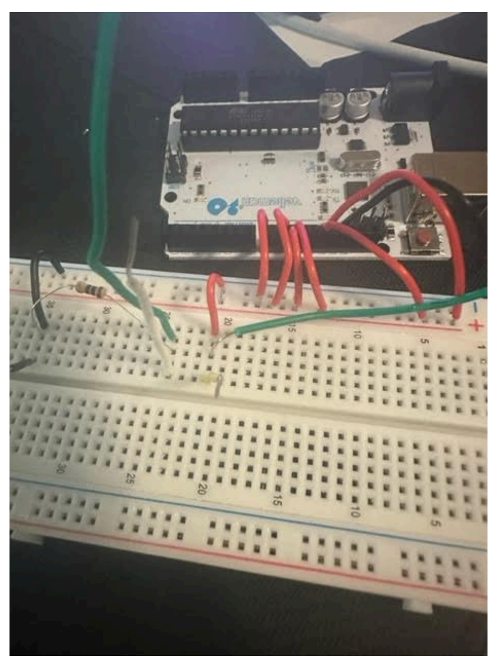


Figure 1.4.1: Shows the circuit connected to the SBB and Arduino. In this case, it shows the circuit while measuring the resistance of 12 lunch length 22 AWG wire.

Data and Experimentation:

When measuring the voltage drop of the 10 ft wire, I got 1.2mV using the 2 wire method and 1.5mV using the 4 wire method. Measuring the 10 ohm resistor, I got 122mV using the 2 wire method, and 126.7mV using the 4 wire method. The 0 ohm resistor measured 21.9mV and 25.9mV, respectively. Finally, the voltage drop resulted in 126mV in both the 2 wire and 4 wire method for the 1.5ohm resistor. The values aren't too far off, but it does show that the 4 wire method is more accurate.

Overall, the 4 wire method is extremely effective in finding smaller resistances. For something with a larger resistance, or low current, the method seems a little inefficient simply because judging from my results, the resistance differences aren't that drastic unless they are very low. However, this method is extremely useful to know and I'm sure I will be applying it a lot in the future.