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 #4
Lab Title: V-R-P Circuits-3
Date of Experiments: October 11th, 2023
Names: Connor Sorrell

Experiment 1

<u>Introduction:</u>

The purpose of this lab is to give a real sense of how much power consumption 0.1 watts and 1 watt feel like. The goal is to estimate the power consumptions expected before the measurement, and then compare to the true values.

<u>Experimentation and Discussion</u>

With the 9V battery supply plugged into the arduino, the output voltage of the 9V supply with nothing attached is 8.54 V, read by the DMM.

Before plugging in the 1k resistor, I estimate the power consumption to be P = V^2/R = (8.54)^2 / 1000 = 0.073 watts. Because of this, I do not expect the resistor to be very warm. After plugging in the resistor, the current through the resistor is roughly 0.02 mA and the voltage drop stays the same. The power consumed is roughly .07 watts, and the resistor is not warm at all. All of these values match my expectations.

Before plugging in the 100 ohm resistor, I estimate the power consumption to be P = V^2/R = (8.54)^2 / 100 = 0.73 watts. Because of this, I expect the resistor to be very hot. After plugging in the resistor, my prediction was confirmed to be right. The voltage across the power rail measured to be 8.45 V, which dropped slightly compared to the 1k ohm resistor. This is because of the heat in the resistor, which got very warm because the power consumed (0.73 watts) exceeded the resistors power consumption of 0.25 watts. Because of this, the resistor got very hot to the touch, and some energy was lost due to heat, causing the voltage on the power rail to drop.

If I were to connect a 50 ohm resistor across the Vin supply, I expect the power consumption to be P = V^2/R = (8.54)^2 / 50 = 1.45 W. This should cause the resistor to become extremely hot, and maybe even smoke, because it exceeds the resistors power capacity by almost 5x. After doing this experiment, it surprisingly did not smoke. However, the resistor did become scorching hot, and it maybe would have smoked if I left it plugged in longer. The voltage on the power rail dropped even more, this time to 8.3V. This goes to show how much energy is being dissipated into heat throughout the circuit.

If the voltage supplied to the circuit is 5V, the smaller resistor load I can use in my circuit in order to keep the power consumption below 0.25 watts is relatively simple to find. Using the equation for power, P = V^2/R can be derived into R = V^2/P, so R = 25 / 0.25 = 100 ohm. So, the smallest resistor load that should be plugged into this circuit is 100 ohms. After supplying the

Arduino with 5V and plugging the 100 ohm resistor in, it does not become extremely hot, but does feel a little warm to the touch. This is as expected, as the 100 ohm resistor supplies the max power consumption to which the resistor is rated.

My recommendations for safety and to prevent circuit elements from getting too hot is to always double check resistance values with the DMM. This can prevent accidentally plugging in the wrong resistor and having something smoke or blow up. I also recommend always using the Arduino power as a switch when doing measurements that might cause components to warm up. Doing so, you can quickly plug in and unplug the power so that you have full control over the circuit and nothing gets out of hand, even if something starts smoking.

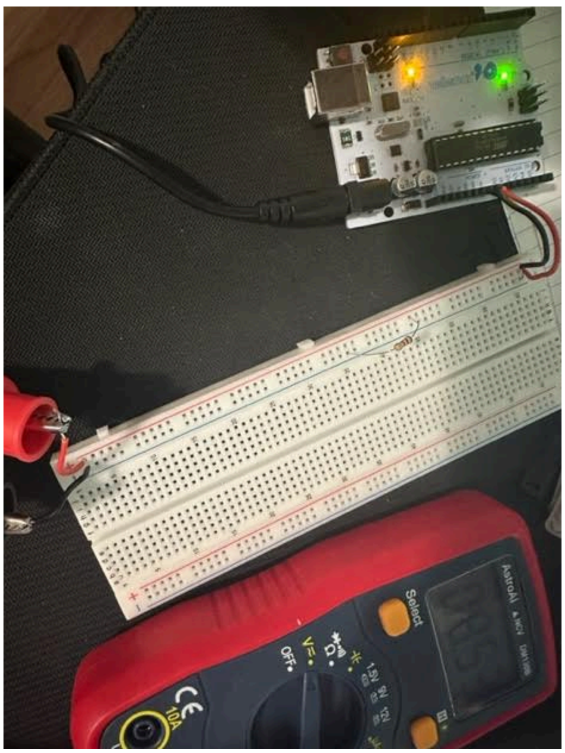

Figure 1.1.0: Shows the circuit set up with the “test” resistor.

Experiment 2

Introduction:

The purpose of this lab is to practice situational awareness and explore the process of reverse engineering an instrument to extract the figures of merit based on an assumed circuit model. By the end of this lab, I should be able to train my mind's eye to see a real voltmeter as its equivalent circuit, and be able to find its input resistance.

Data and Discussion:

When measuring the input resistance of the scope (between channel 1+ and 1-), the resistance is 2.017 M ohms on the DMM. Measuring between channel 1+ and the circuit ground on the AD2, the DMM reads 1.008 M ohms. I also read the resistance between channel 1- and circuit ground to be 1.008 M ohms. Based on these measurements, I can get a rough idea of what I think the equivalent resistance of the circuit model is inside of the AD2 scope.

Interpreting this data is the helpful part. This means that there are 1 M ohm resistors between the positive inputs and circuit ground, as well as the negative inputs and circuit ground on the AD2 scope. This means that when we connect the AD2 to some device on the test, we are essentially just connecting it to circuit ground through 1 M ohm resistors.
Because these resistance values are so high, connecting to sources with low resistance will be negligible. But, when connected to sources with high series resistance, we will then see an impact from the 1 M ohm resistor, which shorts the input to ground.
This experiment was very interesting and shows just how easy it is to reverse engineer and apply our knowledge in order to understand what is truly happening inside the AD2 scope.

To find the resistance of the DMM, I first plug a wire into the Vin pin. I then plugged a 1 M ohm resistor directly into the 5V pin. Before I connect both wires to the ends of the DMM, I use rule #9 to predict a value near 5V, because that is the supplied voltage. Sure enough, the DMM read 4.57V. Using the calculation Rin = 1M x Vmeas/(5v - Vmeas), Rin = 10.8 M ohms.
Interpreting this data, as long as the resistance of the voltage source we are measuring is really small compared to 11 M ohms, we simply have an ideal voltmeter. But, when we try to measure voltages from sources that have large resistances (100k+), we will start to see errors in the small percentage values. Now I know what is going on inside of the voltmeter.

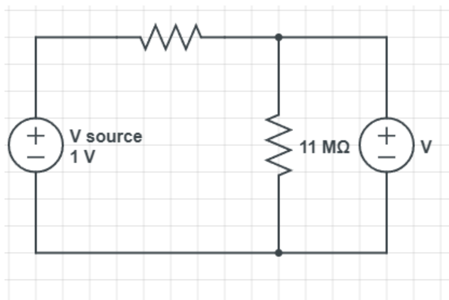

Figure 1.2.0: Shows the equivalent circuit model for the ideal voltmeter.

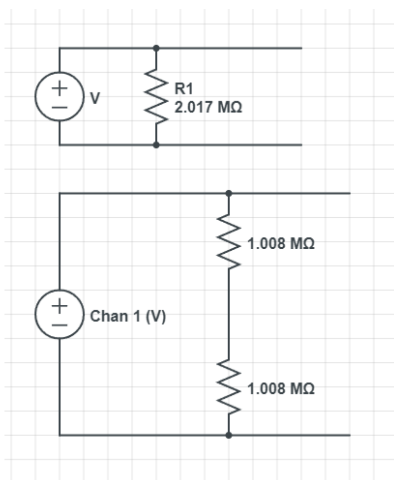

Figure 1.2.1: Shows the real model, and then the 2nd order model below that.

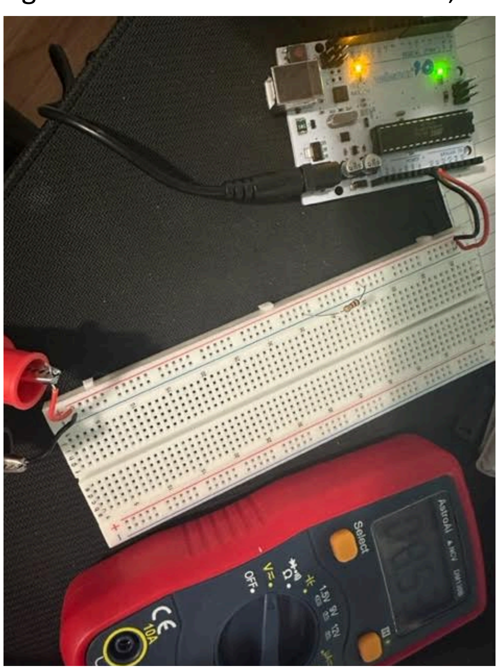

Figure 1.2.2: Shows the circuit built with arduino and SBB, and DMM plugged in to read voltage

Experiment 3

Introduction:

The purpose of this lab is to practice situational awareness and again train my mind to see the equivalent circuit model whenever I see a real voltage circuit. By the end, I should be able to develop a model of a real voltage source and be able to perform measurements to find the thevenin voltage and thevenin resistance.

Data and Discussion:

With the 3.3V source on the Arduino board, the open circuit voltage measured by the DMM is 3.303 V. This is the thevenin voltage of the source. It is important to use a smart resistance value that will be small enough to see a large change in voltage, but the resistance needs to be large enough to where its power consumption does not exceed 0.25 watts. To find the smallest load resistor possible that will keep the power consumption below 0.25 watts, simple algebra can be done.

P = V^2/R, so R = V^2/P = 3.303^2 / 0.25 = ~44 ohms.

Using a 46.4 ohm resistor, I should get about a quarter of a watt of power consumption, which should make the resistor warm, but not too hot to touch.

When adding the resistive load, the new voltage is 3.297, this is the loaded voltage.

Hence, the change in voltage inside the power supply is 0.006 V. This is a very small voltage drop that is hard to measure, but the next lowest resistor in our packs is a 10 ohm resistor, which would force the power consumption over the resistor to be far too high and probably smoke the resistor. So, for the sake of this experiment, I will still use the 46.4ohm resistor.

Finding the estimate of the thevenin output resistance on the 3.3V rail:

Rth = 46.4(0.006/3.297) = 0.844 ohms output resistance.

Now that I have successfully accomplished my objective, I realize that this experiment is extremely important because it is essential to be able to simplify, or “dumb down” a complex circuit into a simple equivalent circuit. The equivalent circuit is much easier to work with and once the Thevenin resistance and voltage are found, we can simplify circuits even further and find other values, like the max power consumption. This in turn helps us find a resistance value which will minimize the power consumption, or vice versa, which I envision to be a very practical skill that I will put to use often later on.

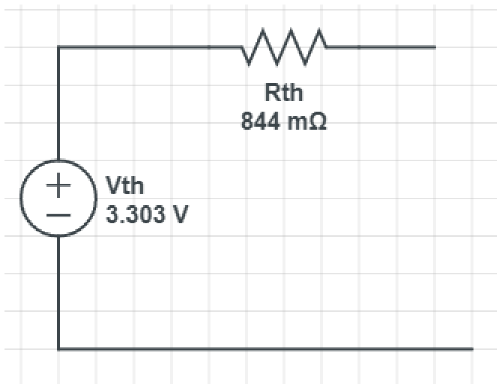

Figure 1.3.0: Shows the thevenin voltage and thevenin resistance inside the 3.3V power supply.

Figure 1.3.1: Shows the circuit built, plugged into the arduino and SBB and being read by DMM

Experiment 4

Introduction:

The purpose of this lab is to practice more situational awareness, this time seeing a real DMM as its equivalent circuit model. I will reverse engineer the inner workings of a DMM, and by the end, extract the figures of merit in each of its three modes of operation.

Data:

With the circuit model setup for DMM as a voltmeter and a 5v source being supplied by the arduino, we would expect a value of ~5 volts across the power rail. Sure enough, the reading from the DMM was 4.96V.
Then, I set the DMM as a current meter. I did this using the same method as a voltmeter, but I added a resistor in series with the ammeter, and am now measuring the voltage and current across the resistor, rather than the power rail.

With the ammeter set up, and a 1k ohm resistor in series, the DMM measured current to be 4.97mA, very close to the 5mA which was expected.
Voltage through the source using the scope = 4.99V
Voltage across the DMM = 5.64mV
R = V/I = ~5 mV / ~5 mA = ~1 ohm
With the DMM set up as an ohmmeter connected to the AD2 scope, the thevenin voltage according to the scope is 0.69V.
When the AD2 circuit ground is also connected to the ohmmeter, the voltage dropped to 0.51V. This is because the load resistance dropped from 2 M ohms to 1 M ohm. Because we lowered the input resistance by a half, but the voltage drop only changed by less than a third, this tells us that the thevenin resistance inside our ohmmeter is probably larger than 2 M ohms.

From the two values we have found, we can solve for the thevenin voltage and thevenin resistance, in order to understand what is going on inside the DMM.

Plugging into equations:

(Vmeas)(Rth)+(Vmeas)(Rin) = (Vth)(Rin)
(0.69)(Rth)+(0.69)(2) = Vm2M
(0.51)(Rth)+(0.51)(1) = Vm1M
Solving these equations out, we get the thevenin resistance to be equal to 1.029 M ohms, while the thevenin voltage is 1.044V.

Discussion:

This part of the experiment greatened my understanding of what an equivalent circuit model is, and how they affect our measurements with the DMM. I have learned that the internal workings of the DMM are sometimes important, and sometimes not. For the ammeter, we can reliably measure sources that are connected to a high resistance. If the DMM is measuring a source in series with a low resistance, the resistance can be negligible because of the large 1 M ohm internal resistance of the DMM.

The ohmmeter, on the other hand, can be considered an ideal instrument only when the resistance being tested is much larger than 1 ohm. We have found in previous experiments that reliably measuring a small resistance is very difficult, and now because of our reverse engineering and finding the large internal resistance, we have further proved our findings.

In the voltmeter mode, the internal resistance is ~10 M ohms which is a huge resistance value and can always be considered an ideal instrument when the resistors in the circuit have low resistance.

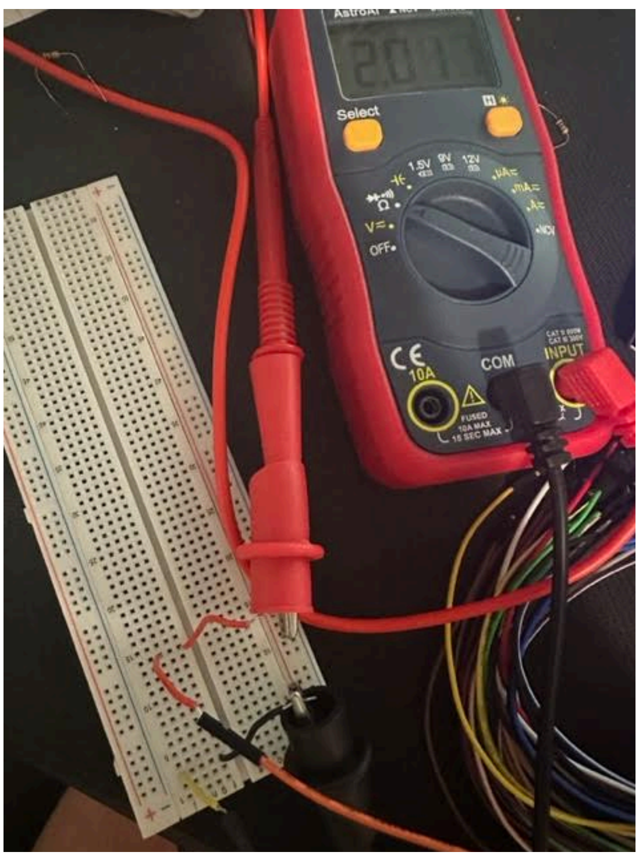

Figure 1.4.0: Shows the SBB, plugged into channel 1+ and 1- of the AD2 scope, all of which is being read by the DMM.

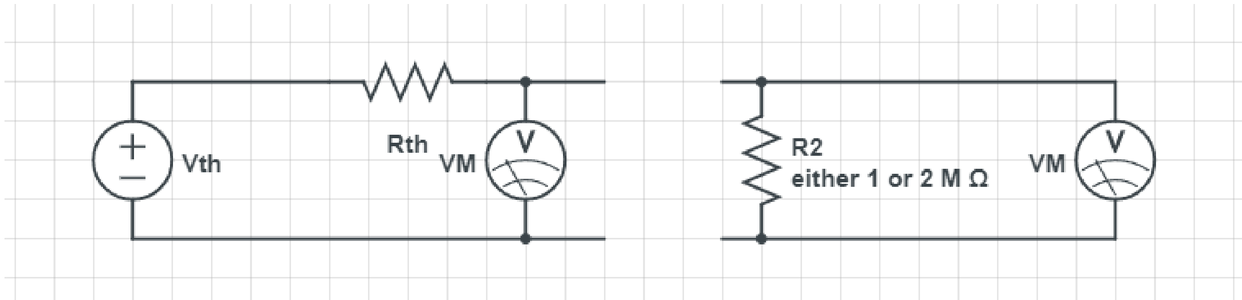

Figure 1.4.1: shows the equivalent thevenin circuit model for the ohmmeter, and how it is measured

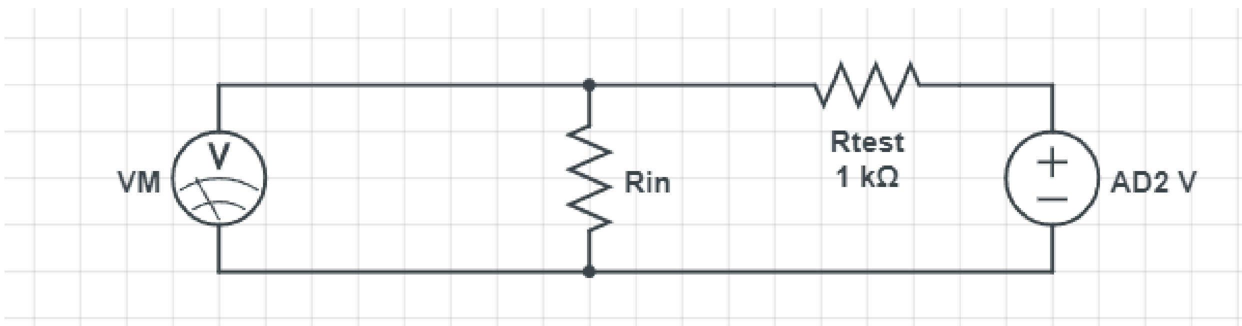

Figure 1.4.2: shows the equivalent thevenin circuit model of the ammeter, and how it is measured