Lab 2: Input and Output Impedance

Prelab

In lab 1 we built a voltage divider circuit which allowed us to set an output voltage to any value between zero and the supply voltage. However, if we actually use that voltage with a load, we will encounter an issue.

Q. Determine the equation for the voltage drop across the load resistor, V_L (this is the output voltage), as a function of V_{IN}, R_1, R_2, and R_L for the circuit show in figure 1. *Hint: Notice that* $V_L = V_2 = I_1(R_2||R_L)$

Q. Find V_L as a function of V_{IN} for $R_1 = R_2 = R_L = R$.

Q. Find V_{UL} as a function of V_{IN} for $R_1 = R_2 = R$, where V_{UL} is the voltage output of an unloaded voltage divider (no R_L).

Q. How does the unloaded output voltage (with $R_1 = R_2$) compare to the output voltage with a load ($R_1 = R_2 = R_L$)? That is, determine the ratio of the loaded output voltage to the unloaded output voltage. The loaded voltage is what percent of the unloaded voltage?

Q. For use in lab, rearrange the equation for V_L (from the first question) to solve for R_L.

Read
www.davidbridgen.com/earth.htm,
www.amasci.com/amateur/whygnd.html,
and section *2.10 Grounds* (pp. 40-48) in your textbook.

Q. List a few of the ways "ground" is used and the symbol for each.

The most common way we will encounter the word "ground" in this class is as a label for the reference potential, that is, the potential relative to which all our other voltage values are measured.

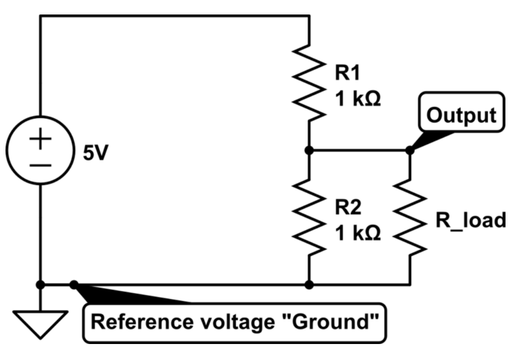

Figure 1: A voltage divider circuit with a load

Part I: Resistor Decade Box

Often it is convenient to quickly change out resistance values for testing purposes. On your desk is a small box with many switches which can be used to select exactly the resistance you need.

There are three terminals, two of which have a resistor symbol between them. For now we will only be using those two. The third terminal is used to ground the metal case.

- Use your multimeter to test out a few combinations and make sure you understand how to use the decade box.

Q. What is the largest resistance value achievable?

Part II: Voltage Divider with a Load

2.1 Concepts

When measuring the output voltage with a multimeter, the meter looks to the circuit like a load resistor of some value. This is what we call the "internal resistance" or "input impedance" of the meter. (We'll talk more later on about impedance vs resistance, for now we'll use them interchangeably.)

Q. To keep the multimeter from affecting your measurements, would you want it to have a high or low input impedance? Why?

We can also think of the voltage divider circuit itself as having an "output impedance" (a resistance in series with an ideal supply, over which voltage drops). Imagine there is a voltage divider circuit inside your DC power supply or function generator and the output you connect to is the output node of this divider. When you connect a 'heavy' load (one requiring lots of current), this can effect the output voltage. To prevent the load from effecting the supply, the ideal supply would have zero output impedance.

2.2 Build it

- Build the circuit shown in figure 1 using your resistance decade box for the load resistor and the HP power supply set to 5 volts with current limiting set to 100 mA.

Q. For a load resistance of 500Ω, calculate and then measure the voltage drop across each resistor.

Q. Repeat the voltage measurements for load resistances of 1kΩ and $10k\Omega$. What relationship do you see between the output voltage (i.e. the voltage across resistor R_2 and R_L) and the value of the load resistor?

Part III: Input and Output Impedance

We are going to experimentally determine the input impedance (internal resistance) of the multimeter in voltage mode. In this mode we can model the multimeter as a large resistor in parallel with an ideal voltmeter.

3.1 Voltmeter as a Load

- Obtain two 1 MΩ resistors. Use your multimeter to check the values of the resistors and be sure to obtain two which are close to 1 MΩ (±0.015 MΩ) and, more importantly, very close in value to each other (±0.005 MΩ). Your results will be very sensitive to these values.
- Note down each resistor value and which you are going to use for R_1 and which for R_2.
- Build the circuit in figure 2 using one of your multimeters as the load (connected across R_2 in voltage mode).
- Use the other multimeter to check the output of the power supply and adjust the output until your meter (which is more accurate than the display on your power supply) reads 10 ± 0.05 volts. Leave this meter in place

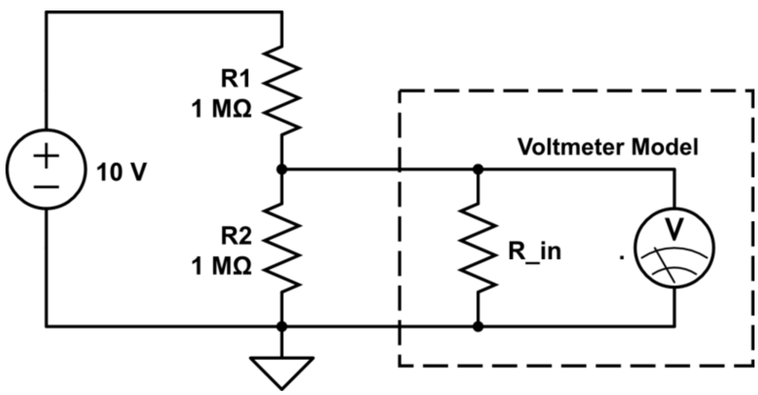

Figure 2: Voltage divider with the voltmeter as a load

Q. Using the equation you found in the prelab for V_L, what would you expect to measure as the voltage drop across R_2 if your voltmeter was ideal (infinite R_L)?

Q. What do you actually measure?

Q. Use the equation for R_L from the pre-lab to find R_{in} (which is acting as the load in this setup).

Q. From your multimeter measurements, what are the uncertainties in the input voltage (V), output voltage (V_L), R_1, and R_2?

Q. Using the partial derivative error propagation equation from lab 0, derive an equation for the uncertainty in your calculation of R_{in}.

Q. What value and uncertainty did you find for R_{in}? (Remember to round your uncertainty to one significant figure and then to round the value for R_{in} accordingly.)

3.2 Voltmeter in Series

A second method to determine the internal resistance of the meter is to connect it in series with various resistance values as shown in figure 3. The multimeter will show the voltage drop over its own internal resistance.

Q. What should this measured voltage value be when $R_1 = R_{in}$?

- Build the circuit shown in figure 3 using your resistor decade box as R_1. Adjust the value of R_1 until the measured voltage value tells you that $R_1 = R_{in}$.

Q. What value do you obtain for R_{in} using this method?

Q. Look up and make of note of the value listed in the multimeter manual. Do the values you obtained agree with the listed value?

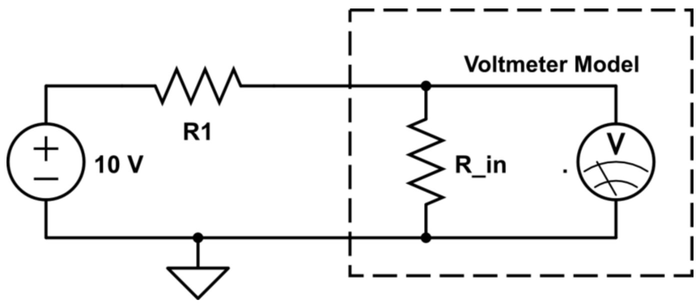

Figure 3: Voltmeter in series with a resistor

3.3 Oscilloscope Input Impedance

An Oscilloscope is really just a very fancy voltmeter which can take readings many times a second. While a scope could be used to measure constant voltages, its main use it to measure varying voltages and display them as a graph.

We're going to use the second method from above to measure the input impedance of the scope, but instead of using the DC power supply we are going to use the function generator as the voltage source.

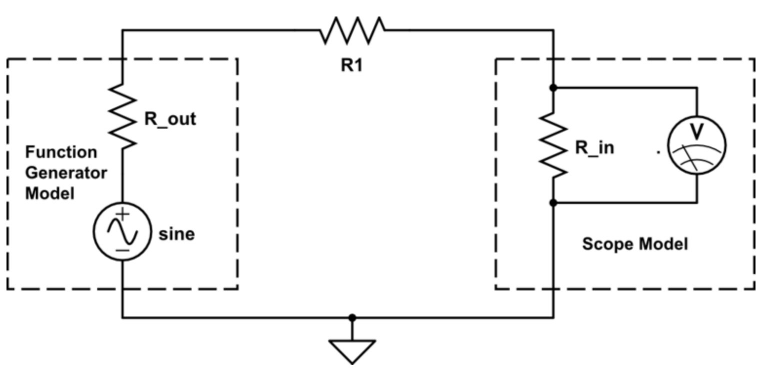

Figure 4: Oscilloscope's internal resistance in series with a external resistor

- Connect the function generator (set to 1 kHz) and scope as shown in figure 4, once again using your resistance decade box for R_1. (The internal resistance of the function generator is much less than 1 kΩ so we can ignore it for this part.)
- Be sure the probe and the scope are in X1 mode.
- **When taking measurements, don't touch the metal cover of the decade box.**
- Set the decade box to zero ohms, then use the MEASURE menu to find the peak-to-peak voltage of the sine wave and adjust it to as close to 10 volts as you can get.
- Now adjust R_1 (the decade box) until you find the value for R_{in}.
- Switch the probe to X10 mode (remember to also change the attenuation setting on the scope under the channel menu) and repeat the above process to find the X10 mode input impedance.

Q. What two values did you find?

Q. Do these values match what is listed in the manual (look in the appendix)?

3.4 Function Generator Output Impedance

All circuits have internal resistance, which we call input impedance if they are something which uses power (like a voltmeter) and output impedance if they provide power. The output impedance of the function generator is much less than the input impedance of the scope, so for this section we can assume the internal resistance of the scope is infinite and has no effect on our circuit.

Your function generator should still be outputting a 1 kHz 10 V peak-peak sine wave.

- Construct the circuit shown in figure 5, using the resistor decade box as R_1. If you set R_1 to zero, you are shorting out the function generator. It does have overload protection circuitry so you won't harm it, but go ahead and start with the decade box set at 10Ω.
- Now R_1 is in series with R_{out} (taking the scope R_{in} to be effectively infinite).

Q. Find the output impedance using the same method we used previously for finding input impedance, that is, adjust R_1 until it equals R_{out}

Q. Compare your result with what is listed in the manual.

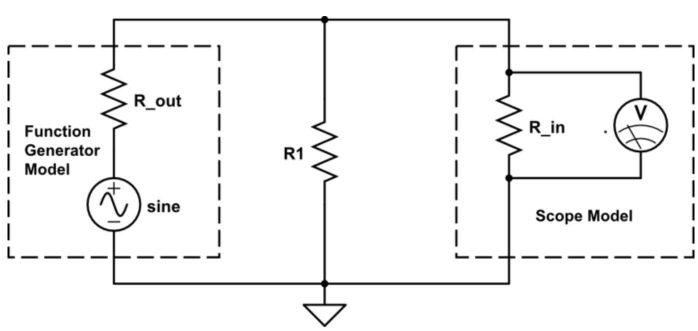

Figure 5: Function generator's internal resistance in series with an external resistor.

Part IV: Capacitive Voltage Divider

Last week you used resistors to reduce the peak-to-peak voltage of a sine wave. A voltage divider for alternating signals can also be constructed out of capacitors. This type of divider has the advantage of being far more power efficient in certain situations.

The amount by which a capacitor resists an alternating voltage is called the "reactance" and is given by equation 4.1. This quantity is measured in Ohms just like DC resistance, but it's value changes with frequency.

$$X_c = \frac{1}{2\pi f C} \tag{4.1}$$

- Pick any two identical capacitors in the range of 0.01μF to 1μF, and build a voltage divider.
- Use a 1000 Hz 10 Vpp input sine wave.
- Show the input and output signals on your scope. Use the MEASURE menu to display the peak-to-peak voltages of each signal.

Q. Take a picture of this output to include in your lab report.

- Now that you have seen a capacitive divider working, design one which will take a 10 V_{pp}, 10 kHz sine wave as an input and output a 1 V_{pp} sine wave as an output. The voltage divider equation will still work, just replace resistance with reactance. (DON'T USE THE ELECTROLYTIC CAPACITORS.)

Q. In your report, include your calculations, values, and a picture of the scope showing both the input and the output waves.

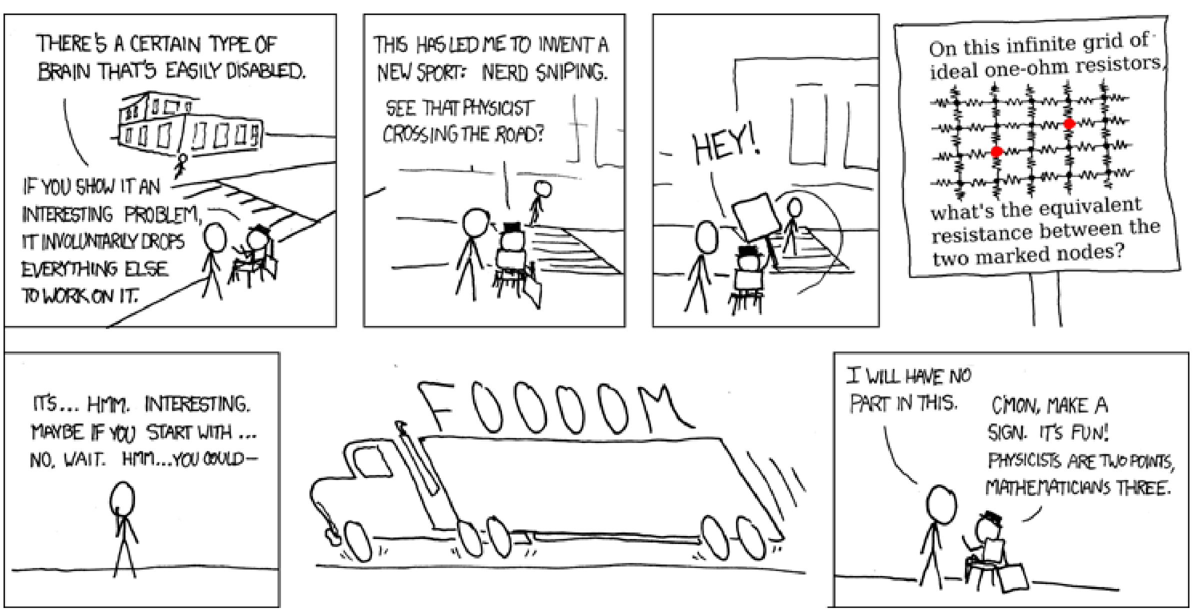

Figure 6: https://xkcd.com/356/