

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.

Determine the equation for the voltage drop across the load resistor, V_L , as a function of V , R_1 , R_2 , and R_L for the circuit show in figure 1. (*Hint: $V_L = V - V_1$*) How does the unloaded output voltage (with $R_1 = R_2$) compare to the output voltage with a load when $R_1 = R_2 = R_L$?

Rearrange the equation to solve for R_L . What minimum value of R_L will result in a V_2 of at least 90% of the unloaded value (in terms of R where $R = R_1 = R_2$)?

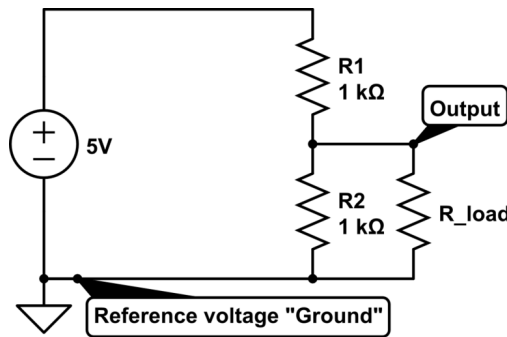


Figure 1: A voltage divider circuit with a load

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 which 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 which is important when dealing with higher frequencies.

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

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.)

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

We can also think of the voltage divider circuit itself as having an “output impedance” (the apparent resistance as viewed by the load). Imagine that there is a voltage divider circuit inside your DC power supply or function generator and the output you connect to is the output of this divider. To be able to keep a constant output voltage for as heavy of a load as possible, would you want the output impedance of this divider to be high or low? Why?

2.2 Build it

Build the circuit shown in figure 1. Use your resistance decade box for the load resistor.

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

Repeat just the measurements for load resistances of $1k\Omega$ and $10k\Omega$. What trends do you notice?

Part III: Input and Output Impedance

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

3.1 Voltmeter as a Load

Build the circuit in figure 2. Use your multimeter to check the values of the resistors and be sure to get two that are close to $1\text{ M}\Omega$ ($\pm 0.015\text{ M}\Omega$) and very close in value to each other ($\pm 0.005\text{ M}\Omega$). Also use your 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. Failure to do so can cause very skewed results.

What would you expect to measure as the voltage drop across R_2 if your voltmeter was ideal? What do you actually measure?

Use the equation for R_L from the pre-lab to find R_{in} .

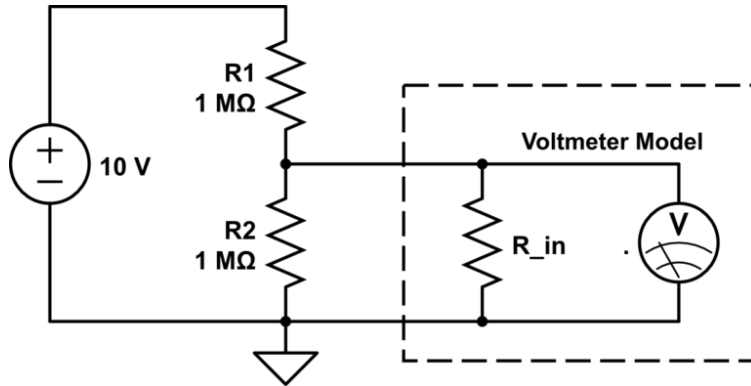


Figure 2: Voltage divider with the voltmeter as a load

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 internal resistance.

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

Build this circuit using your resistor decade box as R_1 . Adjust the value of R_1 until $R_1 = R_{in}$.

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

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

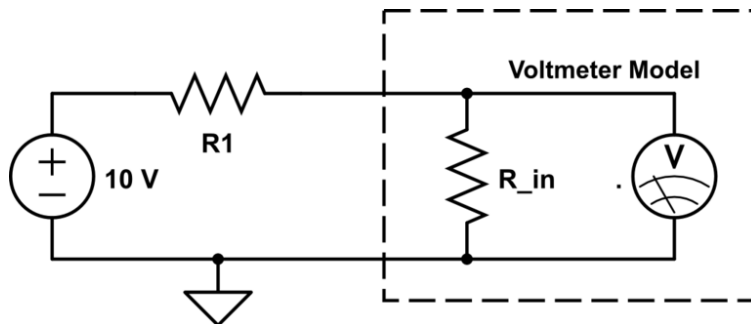


Figure 3: Voltmeter in series with a resistor

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 DC voltages, its main use is to measure varying voltages.

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.

Connect the function generator 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 $1\text{ k}\Omega$ so we can ignore it for this part.)

Be sure the probe is in X1 mode. The signal will probably look quite noisy. If so, use the ACQUIRE menu to change to averaging 4 or 16 samples. You will also notice that when you are touching the metal decade box, the measurement will change, why do you think this is?

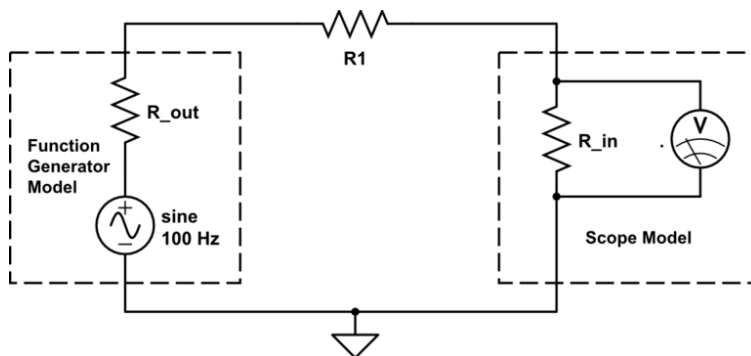


Figure 4: Oscilloscope's internal resistance in series with a external resistor

First set the resistance box to zero ohms, then use the MEASURE menu to find the peak-to-peak voltage of the sine wave and adjust it to exactly 10 volts.

Now add in resistance, just like you did for the multimeter, until you find the value for R_{in} . *Tip: It will be helpful to have several wavelengths showing on the screen and be as zoomed in on the y-axis as much is possible without clipping the waveform.*

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 new input impedance.

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

Is the impedance independent of frequency? What happens to the amplitude of the waveform as you increase the frequency?

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 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). Find the output impedance using the same method we used previously for finding input impedance.

Does this match what is listed in the manual? What happens to the output impedance at higher frequencies?

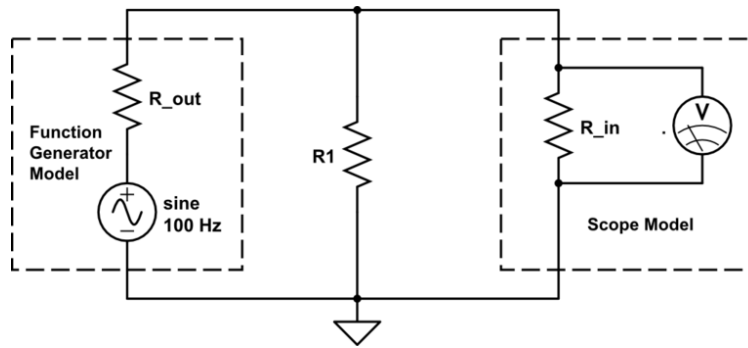


Figure 5: Function generator's internal resistance in series with an external resistor.

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.

$$X_c = \frac{1}{2\pi fC} \quad (4.1)$$

Pick any two identical capacitors in the tens to thousands of nanofarad range and build a voltage divider. Show the input and output signals on your scope. Use the MEASURE menu to display the peak-to-peak voltages of each signal. 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. DON'T USE THE ELECTROLYTIC CAPACITORS. Include your calculations, values, and a picture of the scope output in your report.