ECE 214 - Lab #1 — Test Equipment Loading

27 January 2020

Introduction In this lab you are to determine the voltage ratio, V_{OUT}/V_{IN}, produced by the voltage divider with resistors R_a and R_b shown in Figure 1.

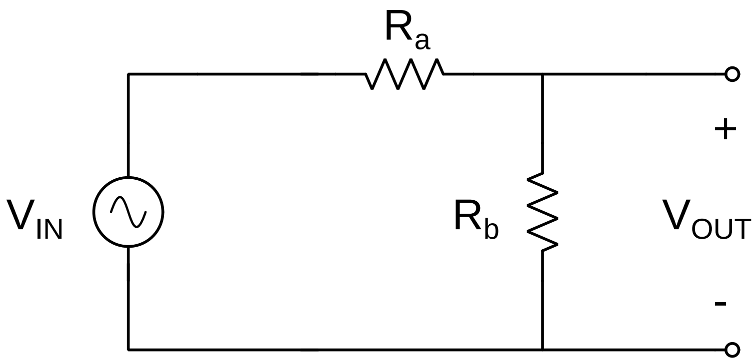

Figure 1: The circuit under test (CUT) is an ideal resistor divider circuit.

This lab illustrates that the actual values of the components, and the impedances associated with the test equipment and cables, must be considered when determining the actual value of the voltage across a circuit element. All voltage sources, including batteries, have a finite source impedance. All measurement equipment, including oscilloscopes and digital volt meters (DVMs), have a non-infinite input impedance that presents a load to the circuit. Cables that connect the circuit to the test equipment introduce additional impedances in the circuit. The schematic of the circuit under test (CUT) when connected to a function generator and oscilloscope is shown in Figure 2.

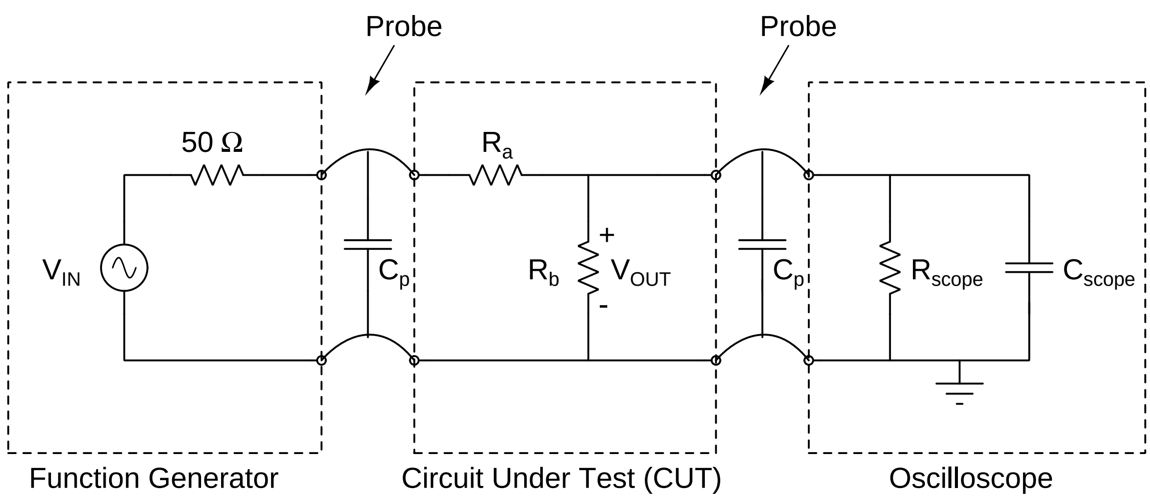

Figure 2: Measurement set–up for the resistor divider circuit.

R_a	R_b	V_{OUT} / V_{IN}		
		Ideal Components	Real Components	%Error (R Tolerance)
$10\,\Omega$	$10\,\Omega$			
$10\,\text{k}\Omega$	$10\,\text{k}\Omega$			
$1\,\text{M}\Omega$	$1\,\text{M}\Omega$			

Table 1: Measurement error due to tolerance in the resistor values.

Lab Procedure

Part A

1. Use the Keystone E4980A LCR Meter to measure the capacitance and dissipation factor of the 1X probes and the scope probes, at frequencies of 1 kHz and 10 kHz. Record these values in your notebook. You will use them for the rest of the semester.
2. Calculate the ESR of the probes at a frequency of 1 kHz and 10 kHz. Do your probes represent a high quality capacitor at these frequencies?
3. Obtain two resistors with each of the following values: $10\,\Omega$, $10\,\text{k}\Omega$, and $1\,\text{M}\Omega$. Measure the resistance of each resistor using your digital volt meter (DVM). Record these values in your notebook.
4. For each of the three pairs of resistors, place two resistors with the same value on the breadboard to make a series circuit as shown in Figure 1. If the resistors have slightly different values, make sure you keep track of which resistor is which.
5. Assuming that the resistors had the ideal values, calculate the ratio of V_{OUT}/V_{IN} assuming an ideal world where the voltage source is ideal (with zero source resistance), the probes are perfect connectors (with zero resistance, capacitance, and inductance), and V_{OUT} is measured with an ideal scope (with infinite input impedance). Record the values in your notebook in the form of a table like Table 1 in a column labeled “Ideal Components.”
6. Using the measured values of the resistors, calculate the expected ratio of V_{OUT}/V_{IN} assuming an ideal world where the voltage source is ideal (with zero source resistance), the probes are perfect connectors (with zero resistance), and V_{OUT} is measured with an ideal scope (with infinite input impedance). Record the values in your notebook in a table like Table 1 in a column labeled “Real Components.”
7. Calculate the %Error caused by the tolerance in the resistor values. The %Error is defined by:

$$\%\text{Error} = 100 * \frac{\left|\frac{V_{OUT}}{V_{IN}}(\text{Ideal Components}) - \frac{V_{OUT}}{V_{IN}}(\text{Real Components})\right|}{\frac{V_{OUT}}{V_{IN}}(\text{Ideal Components})} \tag{1}$$

   Record the values in your notebook in a table as like Table 1 in a column labeled “% Error (R Tolerance).”
8. Using the measured values of the resistors, the measured capacitance of the 1X probes and scope probes, the output resistance of the FG and the input impedance of the

scope, calculate the expected ratio of V_{OUT}/V_{IN} for the three values of resistors. Show all calculations in your notebook. Record the calculated values in Table 2 in a column labeled "Calculated" and place the table in your notebook.

9. Configure the Keystone InfiniiVision Function Generator (FG) to generate a 5 kHz sinusoidal signal with an output voltage of 1 V peak.
10. Connect the output of the FG directly to the input of the Keystone InfiniiVision Oscilloscope (scope) and measure the FG output voltage and frequency. Verify that the FG is producing a 1V peak signal with a frequency of 5 kHz.
11. Use the scope to measure the peak value of the output voltage (V_{OUT}) across resistor R_b for the three pairs of resistors. Record the values of V_{OUT} in Table 2 in a column labeled "Measured" and place the table in your notebook.
12. Calculate the %Calculated-Measured (%CM) Error for the three pairs of resistors. The %CM Error is defined by:

$$\%\text{CM Error} = 100 * \frac{|\frac{V_{OUT}}{V_{IN}}(\text{Calculated}) - \frac{V_{OUT}}{V_{IN}}(\text{Measured})|}{\frac{V_{OUT}}{V_{IN}}(\text{Calculated})} \tag{2}$$

Record the values in Table 2 in a column labeled "%CM Error" and place the table in your notebook. Your %CM Error should be on the order of 1% or less. If the error is greater than 2%, there is either a mistake in your calculation or an inaccuracy in your measurement. Try and obtain values such that the %CM Error is less than 1.5% for all three resistor pairs. Explain in your notebook any discrepancy between the measured and calculated values. Indicate possible sources of the error.

13. Calculate the %Total Error for the three resistor pairs. The %Total Error is defined by:

$$\%\text{Total Error} = 100 * \frac{|\frac{V_{OUT}}{V_{IN}}(\text{Ideal}) - \frac{V_{OUT}}{V_{IN}}(\text{Measured})|}{\frac{V_{OUT}}{V_{IN}}(\text{Ideal})} \tag{3}$$

Record the values in Table 2 in a column labeled "%Total Error" and place the table in your notebook.

14. For which pair of resistor values does the measurement equipment have a minimal effect on the circuit under test?

R_a	R_b	V_{OUT} / V_{IN}			
		Calculated	Measured	% C-M Error	% Total Error
$10\,\Omega$	$10\,\Omega$				
$10\,k\Omega$	$10\,k\Omega$				
$1\,M\Omega$	$1\,M\Omega$				

Table 2: Measurement error introduced by the measurement equipment and 1X probes.

Part B

1. Change the FG output to a square wave with a 1 V peak amplitude. Keep the frequency at 5 kHz.
2. For the 10 kΩ resistors, record in your notebook the shape of the rising edge of the signal as observed on the oscilloscope. Make sure to expand the time scale to see the details of the rising edge of the signal. It is not just a vertical line. The signal should appear similar to the response of a first order RC system studied in ECE 210.
3. What is the approximate mathematical equation which can be used to describe this waveform? Record the equation in your notebook.
4. Measure and record in your notebook both the rise time and the time constant of the signal at V_{OUT}.

Post-Lab

Part A

For the voltage divider circuit, an estimate of the error introduced by the measurement apparatus can be obtained by comparing the values of V_{OUT} obtained from an analysis of the circuit in Figure 1, with the values of V_{OUT} obtained from an analysis of the circuit in Figure 2.

Assume that $V_{IN} = 1.0$ Vp, $f = 5$ kHz, and $R_a = R_b = R$.

1. Derive an equation $V_{OUT\,1}(R)$ expressing the output voltage V_{OUT} as a function of the resistance R for the circuit of Figure 1. Do not include in the calculation the capacitance of the probes, the output resistance of the FG, or the input impedance of the scope.
2. Derive an equation $V_{OUT\,2}(R)$ expressing the output voltage V_{OUT} as a function of the resistance R for the circuit of Figure 2. Include in the calculation the capacitance of the probes, the output resistance of the FG, and the input impedance of the scope. A Matlab® template file for solving for $V_{OUT\,2}(R)$ symbolically is available at `https://davidkotecki.com/ECE214/docs/Matlab/Lab1_Postlab_Symbolic.m`.

Record these equations in your notebook.

Use Matlab® to plot $V_{OUT\,1}(R)$ and $V_{OUT\,2}(R)$ when the value of R is varied from 10 Ω to 10 MΩ. Plot the data on a semi-log graph with the x-axis (resistance value) as the logarithmic scale. On the same graph, plot the three measured values of V_{OUT}, appropriately scaled, from the Table on page 3. Place a copy of the graph in your notebook and place an entry to this graph in the table of contents. Make sure the axes and the data are correctly labeled using Matlab® . A Matlab® template file for generating graphs is available at `https://davidkotecki.com/ECE214/docs/Matlab/ECE214_2020_Lab1_A.m`.

Part B

Use NGspice to simulate the expected output voltage V_{OUT} as a function of the resistance R for the circuit of Figure 2. Include in the simulation the capacitance of the 1X probes, the output resistance of the FG and the input impedance of the scope. A Matlab® template file is available on the course website at: (`https://davidkotecki.com/ECE214/docs/Matlab/ECE214_2020_Lab1_B.m`).

Part C

In your notebook, provide a summary of the major results and conclusions from this lab. Compare the measured results with the calculated and simulated results. What is the most important concept you learned in this laboratory? Make an entry of the location of this information in the table of contents.

Note: a summary should be provided for every lab in ECE 214, where the measured results are compared to the calculated and simulated results, and the most important concepts learned in the lab are explained.