ECE 214 - Lab #1 — Test Equipment Loading

18 January 2024

Introduction

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

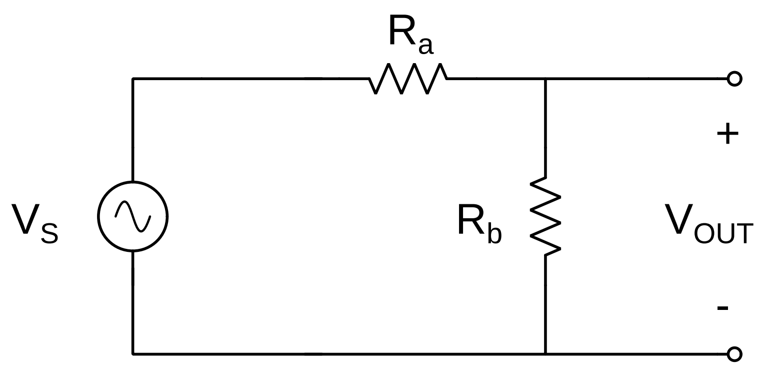

Figure 1: The circuit under test (CUT) is an ideal resistor divider circuit.

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 and waveform generators, have a finite source impedance. All measurement equipment, including oscilloscopes and digital volt meters (DVMs), have a finite 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 waveform generator (WG) and oscilloscope (scope) is shown in Figure 2.

The engineering notebook should be used to record all calculations, preliminary and final designs, circuit simulation schematics and results, measured data, graphs, and analysis pertaining to the laboratory experiments. A photograph of your breadboard showing the working circuit should be included in the notebook. Basically, everything you do in this lab must be recorded in the notebook.

Parts List

1. (2) 30Ω resistors
2. (2) 10 kΩ resistors
3. (2) 1 MΩ resistors

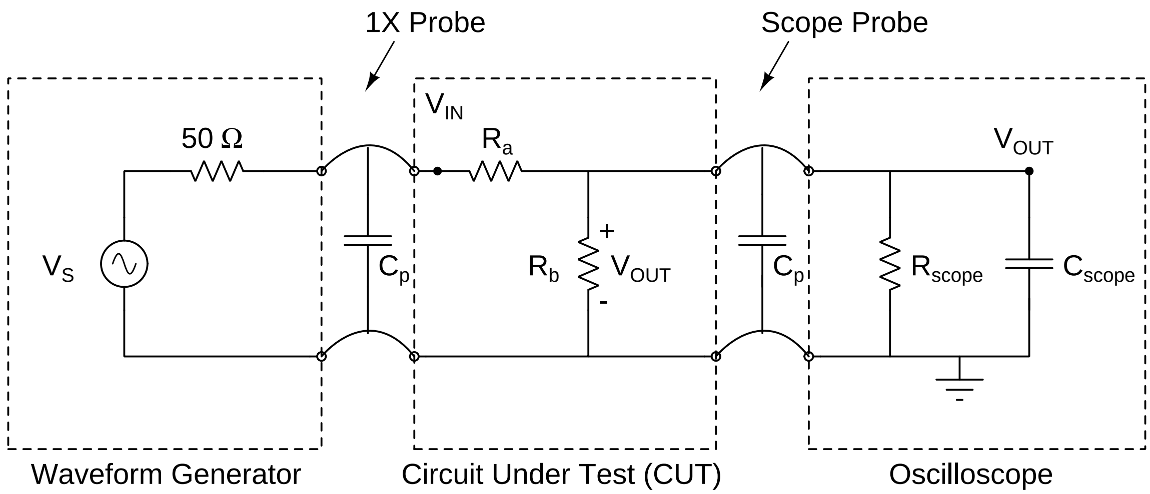

Figure 2: Measurement set–up for the resistor divider circuit.

Lab Procedure

1. Use the Keystone E4980A LCR Meter to measure the capacitance and dissipation factor (DF) of the 1X probes (cables with a BNC connector and alligator clips) and the scope probes (cables with a BNC connector and probe clip) at frequencies between 100 Hz and 100 kHz. Make sure the black switch on the scope probe is set to the 1X position. Record at least three frequency values per decade (*e.g.*, 100, 200, 500, 1,000, 2,000, 5,000, 10,000, 20,000, 50,000, 100,000 Hz) in a table in your notebook. You will use these values for the rest of the semester.
2. Calculate the Equivalent Series Resistance (ESR) associated with each of the capacitance measurements made in the previous step.
3. Obtain two resistors with each of the following values: $30\,\Omega$, $10\,\mathrm{k}\Omega$, and $1\,\mathrm{M}\Omega$. Measure the resistance of each resistor using your digital volt meter (DVM).
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. Create a table in your notebook with the column and row headings shown in Table 1.

R_a	R_b	V_{OUT} / V_S		
		Ideal Components	Real Components	%Error (R Tolerance)
$30\,\Omega$	$30\,\Omega$			
$10\,\mathrm{k}\Omega$	$10\,\mathrm{k}\Omega$			
$1\,\mathrm{M}\Omega$	$1\,\mathrm{M}\Omega$			

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

6. Assuming that the resistors had the ideal values, calculate the ratio of V_{OUT}/V_S 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 ratio under the column labeled “Ideal Components.”

7. Using the measured values of the resistors, calculate the expected ratio of V_{OUT}/V_S 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 under the column labeled “Real Components.”

8. Calculate the %Error caused by the tolerance in the resistor values. The %Error is defined by:

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

   Record the %Error caused by the tolerance in the resistor values under the column labeled “% Error (R Tolerance).”

9. Additional parasitic capacitances and resistances.

   (a) Cables that connect an electrical test instrument to a circuit introduce additional capacitance into the circuit. The BNC to Alligator Clip cable (1X probe) that you were provided with has a capacitance of approximately 100 pF/meter; the X1-X10 Scope Probe that you were provided with has a capacitance of approximately 130 pF/meter when the black switch on the scope probe is set to the 1X position. Both of these cables are approximately one meter in length.

   (b) Electrical test equipment also introduces additional impedances into a circuit. The input impedance of the Digilent Analog Discovery 2 oscilloscope (scope) consists of a 1 MΩ resistor in parallel with a 24 pF capacitance. The output impedance of the Digilent Analog Discovery 2 waveform generator (WG) when used with a properly configured BNC Adapter Board is 50 Ω.

   (c) Create a table in your notebook with the column and row headings shown in Table 2.

   (d) Using the measured values of the resistors, the capacitance of the 1X and scope probes, the output resistance of the WG, and the input impedance of the scope, calculate the expected ratio of V_{OUT}/V_S for the three values of resistors when the input signal is a sine wave at a frequency of 5 kHz. Show all calculations in your notebook. Record the calculated ratio of V_{OUT}/V_S in the table under the column labeled “Calculated.”

10. Connect the BNC Adapter to the Analog Discovery. Ensure that the jumpers on the BNC Adapter board are set to 50 Ω and DC coupling. Configure the WG to generate a 5 kHz sinusoidal signal with an output voltage of 1 V peak.

11. Connect the output of the WG directly to the input of the scope and measure the WG output voltage and frequency. Verify that the WG is producing a 1 V peak signal with a frequency of 5 kHz. Make sure the black switch on the scope probe is set to the 1X position.

R_a	R_b	V_{OUT} / V_S			
		Calculated	Measured	% C-M Error	% Total Error
$30\,\Omega$	$30\,\Omega$				
$10\,\text{k}\Omega$	$10\,\text{k}\Omega$				
$1\,\text{M}\Omega$	$1\,\text{M}\Omega$				

Table 2: Measurement error introduced by the measurement equipment and cables.

12. 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} under the column labeled "Measured."

13. Calculate the %Calculated-Measured (%CM) Error for the three pairs of resistors. The %CM Error is defined by:

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

Record the values under the column labeled "%CM Error." 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.

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

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

Record the values under the column labeled "%Total Error."

15. For which pair of resistor values does the measurement equipment have a minimal effect on the circuit under test? Why? Explain in your notebook any discrepancy between the measured and calculated values. Indicate possible source of the error.

16. Change the WG output to a square wave with a 1 V peak amplitude. Keep the frequency at 5 kHz.

17. Using 10 kΩ resistors, record 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. Measure and record both the rise time and the time constant of the signal at V_{OUT}.

18. What is the approximate mathematical equation that can be used to describe this waveform?

Post-Lab

1. Use Matlab® to plot the capacitance, DF, and ESR as a function of frequency for the 1X-probe and scope probe that you recorded during the Lab Procedure item 1 and item 2.

2. Use NGspice to simulate the expected output voltage V_{OUT} as a function of the resistance R, when the value of R is varied from 10 Ω to 10 MΩ. Simulate the circuit of Figure 2. Include the capacitance of each probe, the output resistance of the WG, and the input impedance of the scope. A Matlab® file is available at: (`https://davidkotecki.com/ECE214/docs/Matlab/ECE214_2022_Lab1.m`).

3. Plot the simulated results from Post-Lab item 2 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} from Table 2.

4. Provide a summary of the major results and conclusions from this lab. Compare the calculated, measured, simulated results. What is the most important concept you learned in this laboratory?