ECE 214 - Lab #1— Test Equipment Loading

24 January 2017

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.

This lab illustrates that the actual values of a component and the impedance associated with all test equipment and cables must always be considered when determining the true value of the voltage being measured 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.

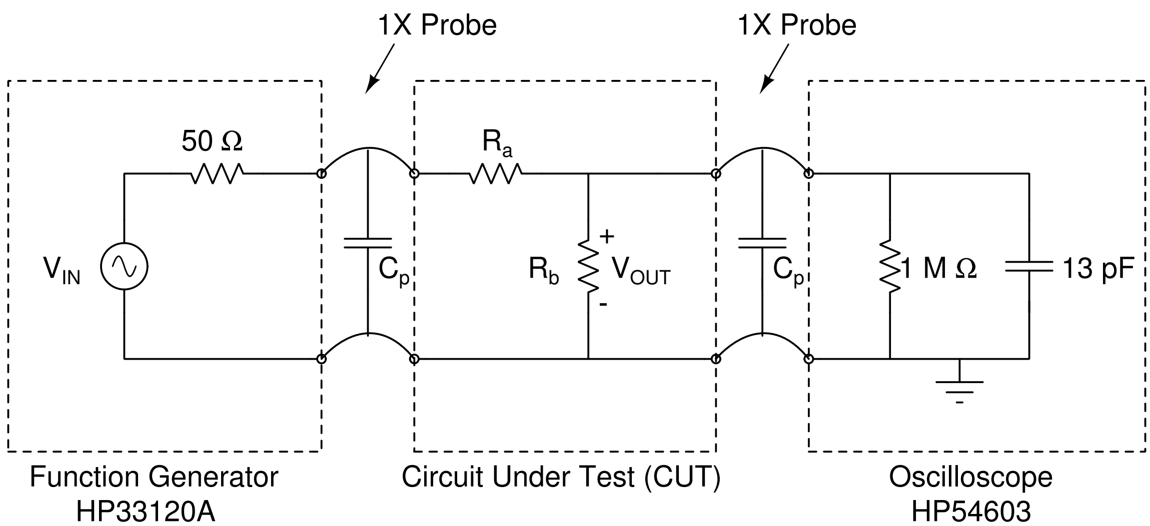

Figure 1: Test set–up for the resistor divider circuit.

Lab Procedure

Part A

1. Configure the HP33120A Function Generator (FG) to generate a 1kHz sinusoidal signal with an output voltage of 1 V peak.
2. Connect the output of the FG directly to the input of the HP54603 Oscilloscope (scope) and measure the FG output voltage and frequency. Verify that the FG is producing a 1V peak signal with a frequency of 1kHz. Make sure you understand the relationship between the voltage displayed on the FG panel and the value of the output voltage. Record this relationship in our notebook and try to remember this relationship in the future when you use the FG.

Part B

1. Use the Tenma 72-1025 LCR Meter to measure the capacitance of your 1X probes at a frequency of 1kHz. Make sure the capacitance meter is set to measure capacitance with series resistance. Also measure the Dissipation Factor (DF) of the probes at a frequency of 1kHz. Record these values in your notebook.
2. Calculate the ESR of the probes at a frequency of 1kHz. Do your probes represent a high quality capacitor at a frequency of 1kHz?
3. Obtain two resistors with each of the following values: 10Ω, 10kΩ, and 1MΩ. 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 2 below. If the resistors have slightly different values, make sure you keep track of which resistor is which.

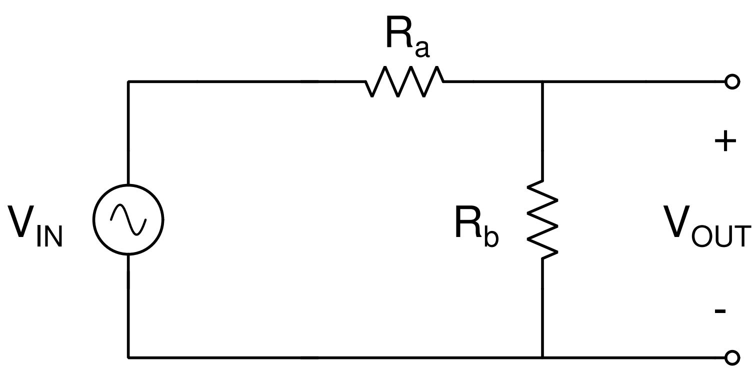

Figure 2: Ideal resistor divider circuit.

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)."

R_a	R_b	V_{OUT} / V_{IN}		
		Ideal Components	Real Components	%Error (R Tolerance)
10Ω	10Ω			
10kΩ	10kΩ			
1MΩ	1MΩ			

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

8. Using the measured values of the resistors, the measured capacitance of the 1X 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. Set the FG to generate a 1kHz sinusoidal signal with peak voltage $V_{IN} = 1V$. Verify both the frequency and peak voltage using the scope then connect the FG and scope to the resistors as shown in Figure 1.
10. Use the scope to measure the peak value of the output voltage (V_{OUT}) across resistor R_b for the pairs of resistors. Record the value of V_{OUT} in Table 2 in a column labeled "Measured" and place the table in your notebook.
11. Calculate the %Calculated-Measured (%CM) Error for the three pairs of resistors. The %CM Error is defined by:

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

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.

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

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

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

R_a	R_b	V_{OUT} / V_{IN}			
		Calculated	Measured	% C-M Error	% Total Error
10Ω	10Ω				
10kΩ	10kΩ				
1MΩ	1MΩ				

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

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

Part C

1. Change the FG output to a square wave with a 1V peak amplitude. Keep the frequency at 1kHz.
2. For the 10kΩ 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 signals at $\mathrm{V_{OUT}}$.

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} from an analysis of the circuit in Figure 1 with the values of V_{OUT} from an analysis of the circuit in Figure 2.

Assume that $V_{IN} = 1.8$ V, $f = 1$ 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. Include in the calculation the capacitance of the 1X probes, the output resistance of the FG and 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. Do <u>not</u> include in the calculation the capacitance of the 1X probes, the output resistance of the FG and the input impedance of the scope.

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 10Ω to 10MΩ. 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® .

Part B

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

Part C

Extra credit: The measured output voltage V_{OUT} from the resistance divider is not only a function of resistance R but also of frequency f. Derive an equation $V_{OUT\,1}(R, f)$ expressing the output voltage V_{OUT} as a function of both the resistance R and the frequency f for the circuit of Figure 1. Use Matlab® to plot $V_{OUT\,1}(R, f)$ when the value of R is varied from 10Ω to $10\text{M}\Omega$ and the value of f is varied from 100 Hz to 10 kHz. Plot the data as a 3-dimensional surface plot with V_{OUT} on the z-axis (linear) and R and f on the x-axis and y-axis (logarithmic). Place a copy of the graph in your notebook and place an entry to this graph in the table of contents.