

ECE 214 - Lab #4 — First Order RC Circuits

15 February 2024

Introduction

In this lab you will investigate the magnitude and phase shift that occur in an RC circuit excited with a sinusoidal signal. You will also measure the circuit response to a square-wave input signal.

The circuit under test (CUT) is shown in **Figure 1**. Node voltages V_A and V_B will be measured using the two input channels on the scope. The 1X probe connecting the function generator to the circuit, and the scope probes connecting the CUT to the scope are not explicitly shown in **Figure 1**. As in Lab #1, the capacitance of these probes and the input impedance of each scope channel may influence the circuit behavior.

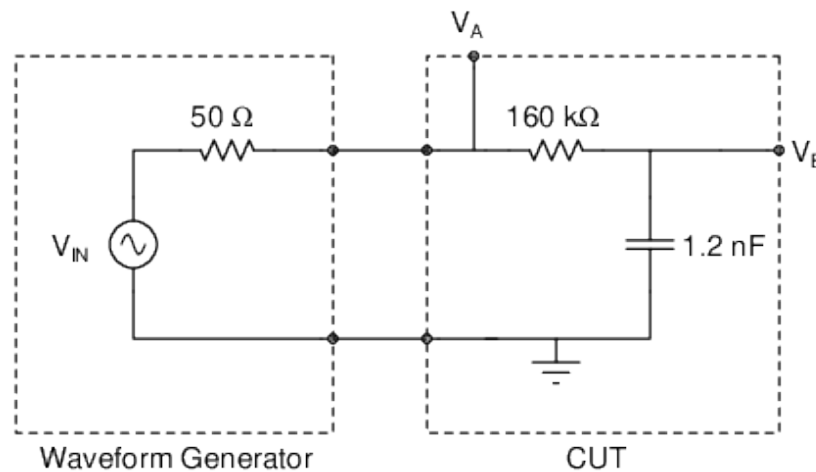


Figure 1: Circuit to be analyzed in Lab #2.

Parts List

1. 160 k Ω resistor
2. 1.2 nF capacitor

Pre-Lab

1. For the RC circuit shown in **Figure 1**:
 - (a) What is the time constant of this RC circuit?
 - (b) Does this RC circuit behave as a low-pass filter or a high-pass filter at node V_B ?
 - (c) What is the cutoff frequency of this filter?
 - (d) Add **Table 1** to your notebook.

f (Hz)	Calculated Values	
	Amplitude V_B/V_{IN}	PS ($^{\circ}$)
100		
1 k		
10 k		

Table 1: Calculated amplitude and phase shift at node V_B in the circuit of **Figure 1**.

- (e) Derive an expression for the amplitude of V_B/V_{IN} as a function of frequency. Complete the amplitude column of the table.
 - (f) Derive an expression for the phase shift of V_B with respect to V_{IN} as a function of frequency. Complete the phase shift (PS) column of the table.
 - (g) Derive an expression that relates the rise-time of the signal at node V_B to the time constant of the signal at node V_B , when V_{IN} is a step function. This relationship is only valid for a first-order RC circuit.
2. Simulate the transient response of the circuit. The MATLAB® file for NGspice is available at https://ece214.davidkotecki.com/docs/Matlab/ECE214_2024_Lab4.m.
 - (a) Add **Table 2** to your notebook.
 - (b) For the circuit in **Figure 1**, set the peak input voltage set to 1 V, and simulate the node voltages V_A and V_B , and the phase shift (PS) in degrees between the two nodes. Record your results in the “Ideal Simulated Circuit” columns in the table.
 - (c) Modify the schematic in **Figure 1** to include the capacitance of the 1X probe, the two scope probes, and the input impedances of the two oscilloscope channels at nodes V_A and V_B . Draw the circuit in your notebook. With the peak input voltage set to 1 V, simulate the node voltages V_A and V_B , and the phase shift (PS) in degrees between the two nodes. Record your results in the “Complete Simulated Circuit” columns in the table.
 - (d) Does including the cable capacitance and input impedance of the oscilloscope scope channels make a difference when measuring this circuit? Explain why.

Lab Procedure

1. Measure and record the values of the circuit components. When measuring the capacitance, measure both C and DF at frequencies between 1 kHz and 10 kHz. Calculate the ESR of the capacitor at these frequencies. Can the ESR be ignored in this circuit? Explain your reasoning in your notebook.
2. Build the circuit shown in **Figure 1**:
 - (a) Use the 1X probe to connect the WG to the circuit, and two scope probes to connect the two scope channels to nodes V_A and V_B in the circuit.

f (Hz)	Ideal Simulated Circuit			Complete Simulated Circuit		
	V_A	V_B	PS ($^{\circ}$)	V_A	V_B	PS ($^{\circ}$)
100						
200						
400						
600						
800						
1 k						
2 k						
4 k						
6 k						
8 k						
10 k						
20 k						
40 k						

Table 2: Simulated node voltages and phase shifts as a function of frequency for the “Ideal” and “Complete” circuit models.

- (b) Set the WG to produce a 1 V peak sine wave at a frequency of 100 Hz. Verify that the peak voltage is set to 1 V by measuring the signal on the scope.
 - (c) Measure the WG signal on your DVM using the AC voltage setting. Does the voltage measured on the DVM agree with that of the scope? If not, explain why.
 - (d) Add **Table 3** to your notebook.
 - (e) For each of the frequencies listed in the table, measure the peak voltages at V_A and V_B , and the phase shift between the two voltages. One probe should be connected to Channel #1 of the scope, and the other to Channel #2. When making the measurements, use the averaging feature of the scope to improve the accuracy of the measurements. Record the results in **Table 3**.
 - (f) Does the voltage across the capacitor lead or lag the voltage across the resistor?
 - (g) Add one more frequency to your measurements: Determine the frequency needed to produce a -45° phase shift between V_A and V_B . Use XY-mode and the Lissajous figures to help determine this frequency. Provide a sketch of the Lissajous figure in your notebook.
3. Change the WG to produce a square wave at a frequency of 100 Hz and a peak-to-peak voltage of 5 V. Verify the signal voltage on the scope.
 - (a) Measure the rising edge of the signal across the capacitor. Determine the time constant of this signal. Compare this time constant to the time constant predicted in part **1a** of the Pre-Lab.
 - (b) Set the WG frequency to 500 Hz. See the lecture for instructions on using the FFT feature of the scope.
 - i. Use the FFT function of the scope to display the voltage at Node V_A as a function of frequency, and record the magnitude (in dB) of the frequency components in your notebook.

f (Hz)	Measured Circuit		
	V_A	V_B	PS ($^{\circ}$)
100			
200			
400			
600			
800			
1 k			
2 k			
4 k			
6 k			
8 k			
10 k			
20 k			
40 k			
			-45 $^{\circ}$

Table 3: Measured node voltages and phase shifts as a function of frequency.

- ii. Use the FFT function of the scope to display the voltage at Node V_B as a function of frequency, and record the magnitude (in dB) of the frequency components in your notebook.
- iii. Does the circuit act as a low pass or high pass filter?

Post-Lab

Use MATLAB[®] to generate graphs of the simulated and measured magnitudes and phase shifts as a function of frequency. Use a log scale when plotting the frequency. Generate two plots, each showing two sets of data, as described below. Make sure the axes of the graphs are properly labeled with the correct units.

Plot #1 Plot the peak voltage across the capacitor from the “simulated complete circuit” and the “measured circuit” as a function of frequency. These data should be plotted using a semi-log scale. The data from the “simulated complete circuit” should be plotted as a solid line, and the “measured” data should be represented as points (\circ) on the graph.

Plot #2 Plot the phase shift of the voltage across the capacitor with respect to V_A from the “simulated complete circuit” and the “measured circuit” as a function of frequency. These data should be plotted using a semi-log scale. The data from the “simulated complete circuit” should be plotted as a solid line, and the “measured” data should be represented as points (\circ) on the graph. The phase shift should be in degrees.

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.