ECE 214 - Lab #2 — First Order RC Circuits

8 February 2021

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 he 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.

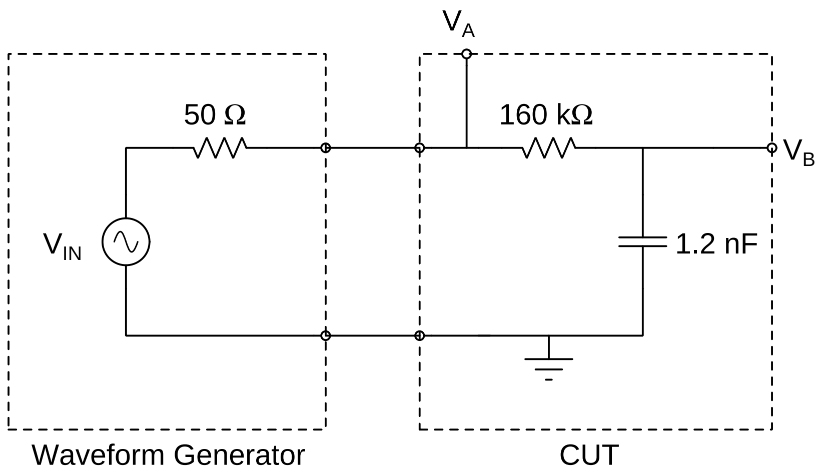

Figure 1: Circuit to be analyzed in Lab #2.

Parts List

1. 160 kΩ 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.
   (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 (Hz)	Calculated Values	
	Amplitude V_B/V_{IN}	PS (°)
100		
1 k		
10 k		

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

(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.

2. Simulate the transient response of the circuit. The MATLAB® file for NGspice is available at `https://ece214.davidkotecki.com/docs/Matlab/ECE214_2021_Lab2.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 you results in the "Ideal Simulated Circuit" columns in the table.

   (c) Draw a complete schematic of the circuit under test (CUT). Include the input impedance of the two oscilloscope channels, and the capacitance of the 1X probe and two scope probes.

   (d) Modify the schematic in Figure 1 to include the probe capacitances and the input impedances of the two oscilloscope channels at nodes V_A and V_B. 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 you results in the "Complete Simulated Circuit" columns in the table.

   (e) 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 the values of the circuit components using your DVM.

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.

   (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 the AC voltage setting. Does the voltage measured on the DVM agree with that of the scope? If not, explain why.

f (Hz)	Ideal Simulated Circuit			Complete Simulated Circuit		
	V_A	V_B	PS (°)	V_A	V_B	PS (°)
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.

(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.

      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.

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°

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

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 (o) 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 (o) on the graph. The phase shift should be in degrees.

Make sure to include a summary section for the lab in your lab notebook.