ECE 214 - Lab #2 — First Order RC Circuits

3 February 2020

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/autoreffig1. Node voltages V$_A$ and V$_B$ will be measured using the two input channels on the oscilloscope. As in Lab #1, the input impedance of each channel will influence the circuit behavior. The 1X probe connecting he function generator to the circuit, and the scope probes connecting the CUT to the oscilloscope are not explicitly shown in Figure 1. However, the capacitance of these probes may influence the circuit behavior.

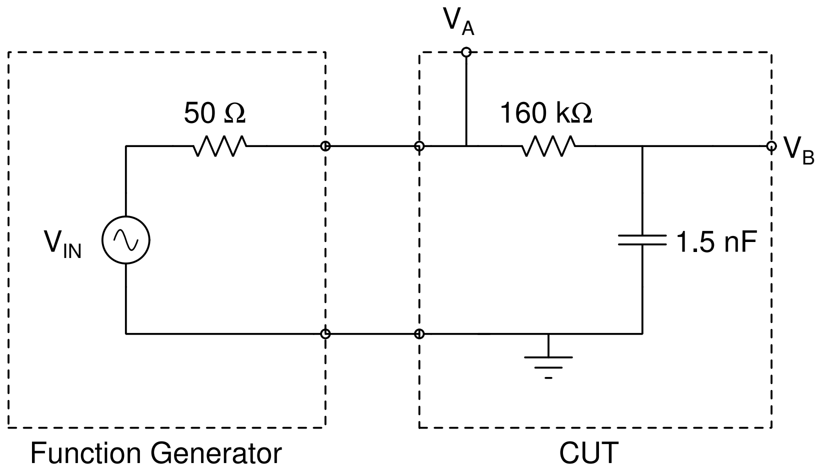

Figure 1: Circuit to be analyzed in Lab #2.

Pre-Lab

1. Using the results from Lab #1, devise an experiment to measure the input resistance of your DVM when making a DC voltage measurement. Describe the experiment in your notebook.
2. 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?
   (c) What is the cutoff frequency of this filter?
   (d) Derive an expression for the amplitude of V$_B$/V$_{IN}$ as a function of frequency. Complete the amplitude column of Table 1.
   (e) Derive an expression for the phase shift of V$_B$ with respect to V$_{IN}$ as a function of frequency. Complete the phase shift column of Table 1.
   (f) 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.

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.

3. 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.

4. Simulate the transient response of the circuit. A MATLAB® file is available on the course website.

   (a) 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 Table 2.

   (b) 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 Table 2.

5. Does including the cable capacitance and input impedance of the oscilloscope scope channels make a difference when measuring this circuit? 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.

f (Hz)	Measured Circuit		
	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			
			-45°

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

Lab Procedure:

1. Determine the input resistance of your DVM when making a voltage measurement. Use the experiment you devised in step 1 of the Pre-Lab. Record in your notebook the manufacturer and model number of your DVM along with the measured input resistance. Put an entry for this data in the table of contents.
2. Measure the values for each component needed in the circuit shown in Figure 1 using the LCR meter and a DVM. When measuring the capacitance, measure both C and DF at frequencies of 1 kHz and 10 kHz. Calculate the ESR of the capacitor at these frequencies. Can the ESR be ignored? Explain your reasoning in your notebook.
3. Build the circuit shown in Figure 1:
   (a) Set the FG to produce a 1 V peak sine wave at a frequency of 100 Hz. Make sure the peak voltage is really set to 1 V by measuring the signal on the scope.
   (b) Measure the FG 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.
   (c) For each of the frequencies listed in Table 3, 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. Press the `Acquire` key to locate the averaging feature. Record the results in Table 3.
   (d) Does the voltage across the capacitor lead or lag the voltage across the resistor?
   (e) 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.

4. Change the FG 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 2a of the Pre-Lab.
   (b) Set the FG frequency to 500 Hz. See page 5 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.
      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.

Using the Fast Fourier Transform (FFT) Function of the Oscilloscope

The oscilloscopes in the lab are able to measure the spectral content of periodic signals. This function will display frequency on the horizontal axis of the screen and $\mathrm{dBV_{rms}}$ on the vertical axis. This brief description will provide details for turning on and using this feature. Some terms used with this function are defined below:

Span This term describes the width of the screen display in Hertz. You can adjust the span of the display to view different amounts of the total span available. The span should be set to $\approx 10-15$x the fundamental frequency.

Center Frequency This term refers to the frequency displayed at the center of the screen. If you want to measure the magnitude of a particular frequency, set the center frequency to that value and read the value at the center of the screen. When you change the span, the center frequency stays fixed and the display expands and contracts around it.

Reference Level The vertical display for FFT measurements is dimensioned in $\mathrm{dBV_{rms}}$/div. You can set the value of the top of the screen so that all measurements would be referenced to that level. The top of the screen is the Reference Level location. $\mathrm{dBV_{rms}}$ is defined as:

$$\mathrm{dBV_{rms}} = 20 \log \left(\frac{\mathrm{Voltage_{rms}}}{1\ \mathrm{V_{rms}}} \right)$$

A voltage of 1.414 peak is equal to 1 volt rms or 0 $\mathrm{dBV_{rms}}$.

Window Windows are used to process the data representing the signal to be measured to improve the FFT display. Use the Hanning window to make accurate frequency measurements and the Flattop window to measure amplitude.

To enter the FFT mode, press the `math` key, then:

- For `function`, choose f(t).
- For `operator`, choose FFT.
- For `source` select the appropriate channel 1 through 4.
- Set the span to 8 x fundamental frequency (4 kHz).
- Set the center frequency to the third harmonic (1.5 kHz).
- Use the knob to the right of the `math` key to set the vertical scale `dB/div`.
- Use the knob just above to set the vertical offset in `dB`.