ECE 214 - Lab #2 — First Order RC Circuits

31 January 2017

Introduction In this lab you will investigate the magnitude and phase shift that occurs in an RC circuit excited with a sinusoidal signal. You will also measure the output voltage that results from a transient 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 oscilloscope. As in Lab #1, the input impedance of each channel will influence the circuit behavior. Also, the 1X probes are not explicitly shown between the CUT and the measurement equipment. However the the probe capacitance can also influence the circuit behavior.

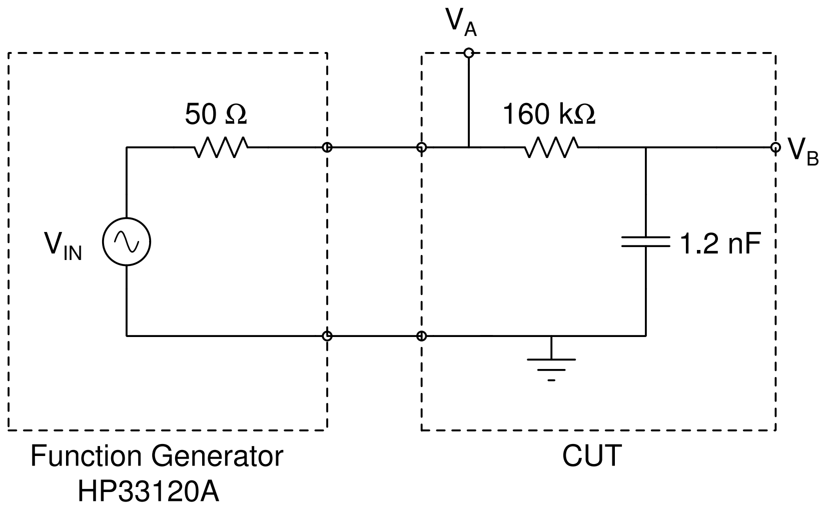

Figure 1: Circuit to be analyzed in Lab #2.

Pre–Lab

1. Use your knowledge from Lab #1 to 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) This RC circuit behaves as a low pass filter at node V_B. What is the cutoff frequency of this filter?
   (c) If V_{IN} is a square wave with a frequency of 10 Hz, derive an expression that relates the rise time of the signal at node V_B to the time constant at node V_B.
3. NGspice simulations:

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 1: Simulated node voltages and phase shifts as a function of frequency for the "Ideal" and "Complete" circuit models.

(a) For the circuit shown in Figure 1, use NGspice to simulate the node voltages V_A and V_B and the phase shift (PS) in degrees between the two nodes. Set the peak voltage to 5 V. Record you results in the "Ideal Simulated Circuit" columns in Table 1.

(b) Modify the circuit schematic shown in Figure 1 to include the 1X probe capacitances and the input capacitance of the oscilloscope at both nodes V_A and V_B. Use NGspice to simulate the node voltages V_A and V_B and the phase shift (PS) in degrees between the two nodes. Set the peak voltage to 5 V. Record you results in the "Complete Simulated Circuit" columns in Table 1.

This step is part pre–lab, part lab and part post–lab. Try and complete as much as possible before lab but you are not expected to complete the simulations before lab.

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

Lab Procedure:

1. Determine the input resistance of your DVM when making a voltage measurement. 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 100 Hz, 1 kHz, and 10 kHz. Calculate the ESR of the capacitor. Can the ESR be ignored? Explain your reasoning in your notebook.

3. Build the circuit shown in Figure 1. Set the V_{IN} to a 5 V peak sine wave at a frequency of 100 Hz. Make sure the peak voltage is really set to 5 V by measuring V_{IN} on the scope.

f (Hz)	Measured Circuit		
	$\mathbf{V}_A$	$\mathbf{V}_B$	PS (°)
100			
200			
400			
600			
800			
1 k			
2 k			
4 k			
6 k			
8 k			
10 k			
20 k			
40 k			
			45°

Table 2: Measred node voltages and phase shifts as a function of frequency.

4. Measure the voltage V_{IN} on the DVM using the the AC voltage setting. Do the two measurements agree? If not, explain why.

5. For each of the frequencies listed in Table 2, use the scope and two X1 probes to 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 2.

6. Does the voltage across the capacitor lead or lag the voltage across the resistor?

7. 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.

8. Change the FG to produce a square wave at a frequency of 100 Hz. Sketch the signal across the capacitor and measure what you will need in order to determine the time constant of the exponential signal. Compare this time constant to the time constant predicted in part 2a of the pre–lab.

9. Change the FG to produce a square wave at a frequency of 500 Hz.

   (a) Use the FFT function of the scope to display the voltage at Node V_A as a function of frequency and record the magnitude of the frequency components in your notebook. See page 5 for instructions on using the FFT feature of the scope.

   (b) Use the FFT function of the scope to display the voltage at Node V_B as a function of frequency and record the magnitude of the frequency components in your notebook.

   (c) Does the circuit act as a low pass or high pass filter?

Post Lab

1. Use MATLAB® to generate graphs of the calculated and measured magnitudes and phase shifts as a function of frequency. Use a log scale when plotting the frequency. Generate two plots, each showing three 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 ideal circuit," "simulated complete circuit," and the "measured circuit" as a function of frequency. These data should be plotted as a function of frequency using a semi–log scale. The data from the "simulated ideal circuit" should be plotted as a sold line; the data from the "simulated complete circuit" should be plotted as a broken 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 ideal circuit," "simulated complete circuit," and the "measured circuit" as a function of frequency. These data should be plotted as a function of frequency using a semi–log scale. The data from the "simulated ideal circuit" should be plotted as a sold line; the data from the "simulated complete circuit" should be plotted as a broken line; and the "measured" data should be represented as points (o) on the graph. Plot the phase shift in degrees.

2. Extra Credit - Use NGspice, to simulate the time constant of the voltage across the capacitor with a square wave input. Compare the simulated time constant with the measured time constant from the data you generated in part 8 of the lab procedure. Record the simulation result along with any matlab.m files in your notebook and add an entry to the table of contents.

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 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 need to be defined.

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 total span available is set by the sweep speed in sec/div. A sweep setting of 500μs/div will measure frequencies up to 97.5 kHz. Slower sweep speeds reduce the maximum frequency measured.

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. If you want to measure the frequency of a peak in the display, move it to the center and read the center frequency. 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 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. 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 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.

Controls needed for the FFT Function:

- The ± math key displays Function #1 and Function #2.
- Turn on Function #2 and then display the menu for that function.
- The `Operand` key selects a source to use for the FFT measurement. You can select either channel or the results from Function #1.
- The `Units/div` key sets the vertical sensitivity of the screen in dBV_{rms}/div. This setting can be changed using the cursor control knob.
- The `Ref Levl` key will set the reference level for the screen. This will set the level for the top of the screen. This setting can be changed using the cursor control knob.
- The `FFT Menu` key will reveal the following 5 FFT menus.

  - `Cent Freq` sets the frequency of the center of the screen. This setting can be changed using the cursor control knob.
  - `Freq Span` sets the span of the screens display. This setting can be changed using the cursor control knob.
  - `Move 0Hz To Left` will set the left hand side of the screen to DC or zero Hertz. The FFT function will not measure DC values.
  - `Autoscale FFT` sets the `Ref Levl` and `Units/div` to display the FFT data. You can use it if you can not see any display on the screen.
  - `Window` selects one of four windows: `Hanning` and `Flattop` are the best to use for this work.

- The `Cursors` key contains two selections to automate measurements of the frequency and magnitude. Press `Cursors` and then set the `Source` key to F2.
  - The `Find Peaks` key sets one voltage marker (f1) on the highest peak of the display and the second voltage cursor (f2) on the second highest peak. The magnitudes of these peaks are displayed on the screen.
  - The `Move f1 To Center` key will change the center frequency to the peak marked by the f1 cursor. The frequency of this peak will then be displayed.