ECE 214 - Lab #6
Inductors and the RLC Circuit

9 March 2020

Introduction: Additional features of the oscilloscope including input coupling and triggering are introduced. The inductor is introduced, and an RLC circuit is analyzed, simulated, and measured. The theoretical, simulated, and measured results are compared.

Pre-Lab:

1. Watch the videos series titled: "Tutorial - How to use an oscilloscope, Part 1, 2 and 3" located at https://goo.gl/aYCn5g You are already familiar with much of this information. However, make sure you understand the differences between AC and DC input coupling, and pay attention to the concept of triggering, especially the role of the trigger slope and the trigger level, and the difference between internal and external triggering. The input coupling and triggering features of the scope will be utilized in this and future labs.

2. Review the natural response and step response for a series RLC circuit from your notes in ECE 210. Make sure you can distinguish between under-damped, over-damped, and critically-damped circuits, and are able to determine the equations for the voltage across the circuit elements as a function of time.

3. Consider the circuit in Figure 1 with $R_C = R_L = 0\,\Omega$ and $L = 1$ mH.

   (a) Calculate the voltage across the capacitor (V_C) and the voltage across the inductor ($V_{IN} - V_C$) when the FG produces a 1 Volt peak sine wave at frequencies of 1 kHz, 10 kHz and 100 kHz.

   (b) Simulate the frequency response of this circuit (AC simulation) for frequencies between 1 kHz and 500 kHz.

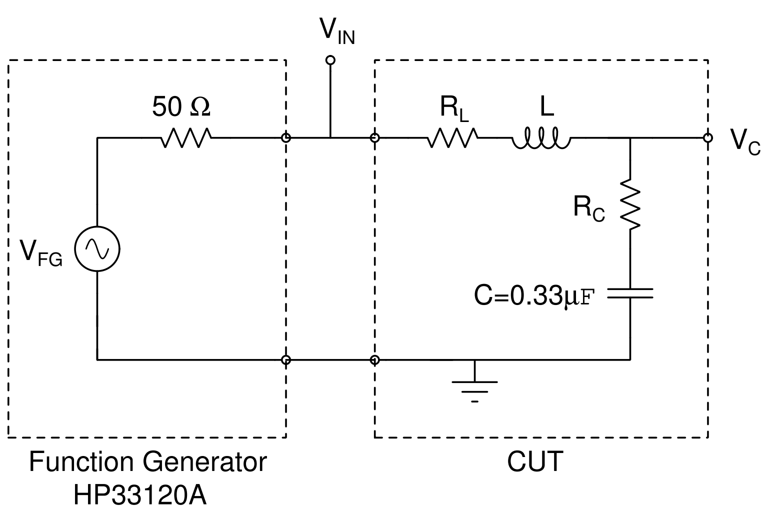

Figure 1: RLC circuit analyzed and measured in Lab #6.

i. Plot the magnitude of the node voltages V_{IN} and V_C as a function of frequency on one graph, and he voltage across the inductor $V_{IN} - V_C$ as a function of frequency on a separate graph. The frequency should be plotted on a logarithmic scale.

ii. Plot the phase of the node voltages V_{IN} and V_C as a function of frequency on one graph, and the phase of the voltage across the inductor $V_{IN} - V_C$ as a function of frequency on a separate graph. The phase should be in degrees and the frequency should be plotted on a logarithmic scale.

(c) Do the magnitude and phase of V_C and $V_{IN} - V_C$ from the simulation agree with your calculations at1 kHz, 10 kHz and 100 kHz? Explain and differences in your notebook.

(d) If the FG is set to produce a step function, does this circuit exhibit an under-damped, over-damped, or critically-damped response?

(e) Derive the equation describing the voltage across the capacitor (V_C) and the voltage across the inductor ($V_{IN} - V_C$) when the input is a 1 Volt step function. Calculate V_C and $V_{IN} - V_C$ at a time of $10\,\mu$s and $40\,\mu$s.

(f) Simulate the step response of this circuit (transient simulation) when the input signal is a 1 Volt step function. Simulate the transient response for 200 μs. Plot three voltages: V_{FG}, V_{IN} and V_C on one graph, and plot the voltage across the inductor: $V_{IN} - V_C$ on a separate graph.

(g) Compare the calculated results from step 3e to the simulated results from step 3f at $t = 10\,\mu$s and $t = 40\,\mu$s. Include this data in a table in your lab notebook. The calculated and simulated results should agree to within ~ 2%. Explain any differences.

Lab Procedure:

1. In this part of the lab procedure, you will utilize the triggering function and the input coupling function of the oscilloscope to determine the time required for the Agilent E3630A power supply (PS) to turn-on and turn-off, and measure the AC ripple when the PS voltage is 10 V.

   (a) Turn on the PS. Adjust the ± 20 V knob to set the output voltage to 10 Volts. Turn off the PS.

   (b) Connect the scope to the PS by connecting the black lead to the COM of the power supply, and the red lead to the +20 terminal.

   (c) Set the scope for a single trace. Set the trigger level and trigger slope to the values needed to capture the PS output voltage when the PS is turned on. Record these values. Set the time axis to approximately 20 ms/div. Turn on the PS and capture the output signal so that if fills up most of the oscilloscope screen. Measure the rise time and time constant of the PS output voltage as it reaches 10 V.

   (d) Adjust the trigger level and trigger slope to the values needed to capture the PS output voltage when the PS is turned off. Set the time axis of the scope to approximately 100 ms/div. Turn on the PS and capture the output signal so that if fills up most of the oscilloscope screen. Measure the fall-time and time constant of the PS output signal. Note: wait at least 5 seconds after turning the PS off or on before turning the PS back on or off to make sure it has reached its final value.

   (e) Turn on the PS. With the output set to 10 V, measure the amplitude and frequency of the ripple on the output voltage. You will need to properly set the trigger level and use AC input coupling to correctly capture this signal.

2. Inductor measurement.

   (a) Measure the inductance and quality factor Q for the inductor using the LCR meter at frequencies of 1kHz and 10kHz.

   (b) Calculate the equivalent series resistance of the inductor from the measured value of Q.

   (c) Measure the DC resistance of the inductor using a DVM. Make sure the DVM reads $0\,\Omega$ when shorting the DVM leads together or subtract the offset from the measured results.

   (d) What is the approximate the number of turns of wire on the inductor? Provide an explanation of how you determined the number of turns.

3. Build the RLC circuit shown in Figure 1.

   (a) Set the function generator to produce a sinusoidal signal with a peak–to–peak voltage of 2 V. Verify on the oscilloscope that the function generator is producing the correct waveform then set up the oscilloscope to measure the voltages V_C and V_{IN}.

   (b) Measure the voltage across the capacitor V_C at frequencies of 1kHz, 10kHz, 50kHz, 100kHz, 300kHz, and 500kHz. Use the averaging function of the scope to reduce the random noise. If necessary, connect the "sync" output from the function generator to the external trigger input of the scope and set the scope to external triggering. Note any problems you encounter.

   (c) Determine the frequency that produces a phase shift across the capacitor of $45°$ with respect to V_{IN}. Does the voltage across the capacitor lead or lag the input voltage at this frequency? How do the measured results compare to the simulated results?

   (d) Determine the frequency or frequencies that produce a phase shift across the capacitor of $90°$ with respect to V_{IN}? Does the voltage across the capacitor lead or lag the input voltage at these frequencies?

   (e) Adjust the function generator to produce a pulse from 0 to 1 V, with a pulse width of 50 ms.

   (f) Now use the single trace and trigger controls on the scope to capture a single event. Capture the signals that appear at V_{IN} and V_C when a single pulse is generated. Use the Math key (+/-) on the scope to generate V_{IN} - V_C, the voltage across the inductor. Record these three signals in your notebook, and measure the values of V_C and V_{IN} - V_C at $t = 10\,\mu$s and $t = 40\,\mu$s.The measured results should be similar to the simulated results from Pre-Lab section 3f.

Post-Lab:

1. Explain the differences in the resistance of the inductor calculated in step 2b and measured in step 2c.

2. Use NGspice to simulate the RLC circuit shown in Figure 1 using the measured values of the capacitor and inductor including the equivalent series resistances R_C and R_L.

   (a) Analyze the frequency response of this circuit (AC simulation) for frequencies between 1 kHz and 500 kHz. Generate the plots described in step 3b of the Pre-Lab.

(b) Create a table in your notebook and compare these simulated results to the measured results from step 3b. Explain any differences in your notebook.

(c) Analyze the step response of this circuit (transient simulation) when the input signal is a 1 V step function. Simulate the transient response for a time of 200 μs. Generate the plots described in step 3f of the Pre-Lab.

(d) Create a table in your notebook and compare these simulated results to the measured results from step 3f. Explain any differences in your notebook.

3. Reference this Post-Lab in the table of contents of your notebook.