ECE 214 - Lab #6 — Inductors and the RLC Circuit

21 March 2017

Introduction: The basic functions of the oscilloscope, function generator and power supply are reviewed. Additional features of the oscilloscope including the input coupling and triggering settings are utilized. The inductor is introduced and an RLC circuit is analyzed, simulated in NGspice, and measured. Theoretical, simulated, and measured results are compared.

Pre Lab:

1. Watch the videos titled: "Tutorial - How to use an oscilloscope" Parts 1, 2 and 3 located at `http://web.eece.maine.edu/kotecki/ECE214/html/oscilloscope.html`. 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 step response of a series RLC circuit from your notes in ECE 210. Make sure you can distinguish between an under-damped, over-damped, and critically-damped circuit and you can derive the equations for the voltage across the circuit elements as a function of time.

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

   (a) Is the circuit under-damped, over-damped, or critically-damped?

   (b) Calculate the voltage across the capacitor (V_C) and the inductor ($V_{IN} - V_C$) when the input is a 2 Volt peak-to-peak sine wave with a frequency of 10 kHz.

   (c) Use NGspice to analyze the frequency response of this circuit (AC simulation) for frequencies between 1 kHz and 500 kHz.

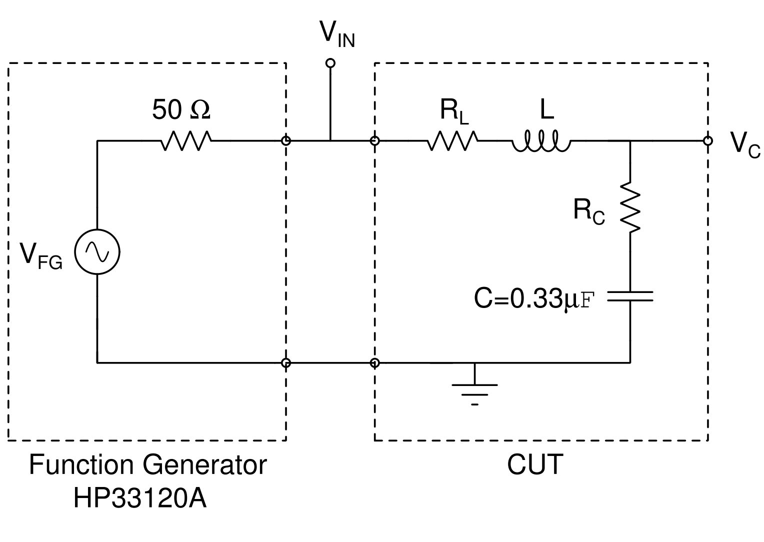

Figure 1: RLC circuit analyzed and measured in Lab #6.

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 using 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 he 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 using a logarithmic scale.

iii. Do the magnitude and phase of V_C and $V_{IN} - V_C$ from the simulation agree with your calculation at 10kHz? Explain and differences in your notebook.

(d) Derive an equation describing the voltage across the capacitor (V_C) and the inductor ($V_{IN} - V_C$) when the input is a 1 Volt step function.

(e) Use NGspice to analyze 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.

(f) Compare the simulation results from step 3e with the calculations from step 3d when $t = 40\,\mu$s. What is the error between the simulated and calculated voltages?

Lab Procedure:

1. Review of oscilloscope and function generator.

   (a) Turn on the Agilent E3630A DC power supply (PS). Adjust the ± 20 V knob to set the output voltage to 12 Volts. Turn off the PS by pushing the on/off button.

   (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 and set the trigger level and slope to capture the PS output voltage when the PS is first turned on. Turn the PS on. How long does it take for the PS to reach 12 V? What is the time constant of this signal?

   (d) Adjust the slope and trigger level of the scope to capture the PS output voltage when it is turned off. Turn the PS off. How long does it take for the PS output voltage to decay to 0.5 V? What is the time constant of this 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) Set the function generator (FG) to produce a 1 Vp sine wave with a 2 Vdc offset and a frequency of 1 kHz. Verify the signal is correct using the oscilloscope. What DC offset voltage is displayed on the FG?

   (f) Set the FG to produce a burst of one cycle every time you press the *trig* button. The FG output signal should be one cycle of a sine wave with a period of 1 ms, an amplitude of 1 Vp, and a DC offset of 2 volts. Capture this signal on the oscilloscope.

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 output a single pulse of 2 V peak-to-peak and a pulse width of 50 ms. Make the generator produce only a single pulse when you press the *trig* button. Adjust the offset to make the generator's output 0 volts when the pulse is not present.

   (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. Record these three signals in your notebook. Use the Math key (+/-) on the scope to look at the voltage across the inductor (the difference between channel #1 and #2).

Post Lab:

1. Explain the difference in the resistance of the inductor measured in step 2c and the value obtained in step 2b.

2. Use NGspice to simulate the 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) Use NGspice to analyze the frequency response of this circuit (AC simulation) for frequencies between 1 kHz and 500 kHz. Generate the plots described in step 3c of the Pre Lab.

   (b) Use NGspice to analyze the step response of this circuit (transient simulation) for a time of 200 μs. Generate the plots described in step 3e of the Pre Lab.

   (c) Compare these simulated results to the theoretical and simulated results from the Pre Lab and the measured results from the Lab Procedure. Explain and differences in your notebook.

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