Lab Summary

In this laboratory you are asked to characterize circuits that consist of all three passive elements. These differ from the circuits that you investigated last week in that they are second order instead of first order. Generally these circuits have one or two zeros and two poles. Both series and parallel combinations of the inductive and capacitive components are presented. Commonly used terminology is covered in the screencast portion of the lab.

Lab Preparation

Screencast:

Second Order Screencast.mp4

Video:

Second Order Response Video.mp4

Lab Supplies

2 BNC to dual mini-grabber cables
1 Red Banana to Minigrabber
1 Black Banana to Minigrabber
Breadboard and jumper kit
Lab Tool Kit
The following Components from your Lab Kit:

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
<th>Markings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inductor</td>
<td>1 mHenry</td>
<td>102</td>
</tr>
<tr>
<td>Capacitor</td>
<td>.001 uF</td>
<td>102</td>
</tr>
<tr>
<td>Resistor</td>
<td>100 Ohm</td>
<td>Brn-Blk-Blk-Blk-Brn</td>
</tr>
<tr>
<td>Resistor</td>
<td>1.62 K Ohm</td>
<td>Brn-Blu-Red-Brn-Brn</td>
</tr>
<tr>
<td>Resistor</td>
<td>10 KOhm</td>
<td>Brn-Blk-Blk-Red-Brn</td>
</tr>
<tr>
<td>Potentiometer</td>
<td>5 KOhm</td>
<td>502</td>
</tr>
<tr>
<td>Additional Caps and Resistors</td>
<td>TBD</td>
<td></td>
</tr>
</tbody>
</table>
Part 1 - Transient Response

1. Construct the RLC circuit shown in the following schematic.

![Figure 1 RLC Circuit Schematic](image1)

2. Connect CH1 of the waveform generator to the circuit as indicated in the schematic. Also connect the input signal to CH1 of the oscilloscope as demonstrated in the lab video.

3. Connect the output of the circuit to CH2 of the oscilloscope as indicated on the schematic. Again, refer to the video if you wish.

4. Set up CH1 of the waveform generator for a 1000 Hz, 2 Vp-p, Square wave signal. Enable the OUTPUT on the waveform generator.
5. Expand the output waveform as demonstrated in the video and measure and record the *resonant frequency* of the RLC circuit.

6. If a circuit exhibits overshoot and damped harmonic oscillations, it is said to be *underdamped*. In this instance, the signal *rise time* is defined as the time it takes the transient response to go from 10% of $V_{\text{FINAL}}$ (You may assume that this is 2 volts, so begin at 0.2V ABOVE BASELINE), to the *first time* that the voltage crosses 90% of $V_{\text{FINAL}}$ (in this case 1.8V ABOVE BASELINE). Measure and record the *rise time* of the underdamped circuit.

**NOTE:** You will complete the rest of the table later in the lab.
Part 2 - Sinusoidal Response

1. Change the waveform generator to a 1Vp-p sine wave.

2. Vary the frequency until you find the maximum amplitude. Record both the amplitude and the frequency at which this amplitude occurs.

   **NOTE:** You may notice that the amplitude at low frequencies is a constant value of 1 Vp-p. Technically, this is RLC configuration is a Low Pass Filter. The bandwidth and amplitude associated with the second order response makes this circuit is MUCH easier to measure the step response than the Band Pass configuration. Moreover, the values that you measure are valid for the Band Pass filter as well. You may consider the circuit as a band pass filter for the purposes of this laboratory. You do investigate the sinusoidal response to an actual Band Pass configuration in the Practical Applications section of Part 2 of the lab.

3. Does the frequency of the maximum amplitude match the **resonant frequency** from Part 1 (within 10%)? The ratio of the maximum voltage to the original input amplitude of 1 Vp-p is the voltage gain. Recall from the screencast that this ratio can be expressed in **decibels**.

4. What is the voltage gain?

5. What is the voltage gain in **decibels**?

6. The two cutoff frequencies of the RLC passband occur when the amplitude is reduced by **3dB** relative to **resonant frequency**. Using the equation for **decibels**, solve for the output voltage (Vp-p) when the amplitude is 3 decibels less than the maximum. (Start with the maximum amplitude, subtract 3 dB, and solve the inverse equation:

   \[
   \frac{V_{OUT}}{V_{IN}} = 10^{(x \text{ decibels}/20)}
   \]

   Since is 1, will be the signal amplitude at the cutoff frequencies if you set x equal to your maximum amplitude in dB minus 3dB.

7. Vary the frequency until the output voltage is equal to the Vp-p value that you calculated. Record these frequencies. There are TWO.

8. The difference between the two cutoff frequencies (-3dB frequencies) is **bandwidth**. From your measured values, calculate and record the measured bandwidth of the RLC circuit.
9. Recall that the second coefficient in the denominator of the transfer function is equal to the bandwidth. Using your component values, calculate the bandwidth from the transfer function. Don’t forget to use Farads, Henries and Ohms for your units to come out correctly. Is your answer Hertz or radians/second?

**NOTE:** You must include ALL of the resistance on your circuit for your calculation! The waveform generator has 50 Ohms of series output resistance that must be added to resistor value you are using in the circuit. Additionally, the inductor has a series resistance of 1.5 Ohms. **Add 51.5 Ohms to your resistor values throughout the lab.**

10. Calculate the percentage difference between your measured bandwidth and the calculated bandwidth.

There is a great deal of confusion in electronics regarding 3 terms: **damping coefficient**, **damping factor** and **damping ratio**. Many authors use them erroneously which does not help matters. In the screencast, each of these terns was defined. By far the most useful one is the **damping RATIO**.

11. Calculate the **damping RATIO** for your circuit using .001 Henry, .001 microFarad a resistance of 100 Ohms.

The RLC is said to be **Critically damped** when the **damping coefficient** is equal to the **resonant frequency**, or the **damping RATIO is equal to 1**.

12. Calculate resistance value for your RLC circuit that results in a damping ratio of 1.0

13. Replace the resistor with a 5 KiloOhm potentiometer

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*Figure 3 RLC Circuit (using Potentiometer) Schematic*
14. Set the potentiometer to the value to critically damp the circuit.

15. Change the waveform generator back to a 1000 Hz, 2 Vp-p, Square wave.

16. Measure the **RISE TIME** when the circuit is critically damped.

17. Place 10 KOhm resistor in Circuit.

18. Calculate the **damping ratio**. If the damping ratio is greater than 1, the circuit response is **overdamped**.

19. Measure the **rise time**.

*Complete the table for the rise time that you started in Part 1. Record the rise times of the underdamped, critically damped and overdamped circuits on your Results sheet.*
**Practical Applications**

You are asked to design an RLC "tuned" filter that is centered at 500 KHz and has a bandwidth of 100 KHz. The only constraint is that you must use a 0.001 Henry inductor. Also, please include the series resistance of the waveform generator and the inductor into account in your design (51.5 Ohms total).

1. What is the capacitor value required?

2. What is the resistor value required?

3. It should come as no surprise that these values are part of your lab kit for the semester. Construct the circuit.

4. Measure and record the **resonant frequency** at the maximum amplitude, and the **bandwidth**.

5. Calculate and record the **resonant frequency and bandwidth** of the circuit using your component values and the equations provided.

6. Calculate and record the percentage of error between your circuit measurements and your calculated value for both the frequency and the bandwidth

Don't be too disappointed in the error. Both the inductor and capacitor are +/-5% (these are considered tight tolerances), and the resistor is +/- 1%. Collectively, they could result in as much as 11% error in all parameters of the design.
Part 3 - Parallel RLC Circuit

1. Construct the following circuit.

2. Change to sine wave 1Vp-p, and vary the frequency from 10 KHz to 250KHz

3. What kind of filter is this?

4. What is the frequency at the minimum amplitude?
5. The bandwidth is still defined as the difference between the two frequencies that are -3 dB less than the maximum Vp-p. Find the two cutoff frequencies, and then calculate and record the bandwidth from your measurement.

For this configuration the resonant frequency is still:

\[ \frac{1}{\sqrt{LC}} \text{ radians/second} \]

but the bandwidth is:

\[ \frac{1}{RC} \text{ radians/second} \]

6. Calculate the bandwidth for your component values on Hertz.

7. Calculate the percentage error between your measured resonant frequency and calculated resonant frequency, and your measured bandwidth and the calculated bandwidth.

*** END of LAB ***