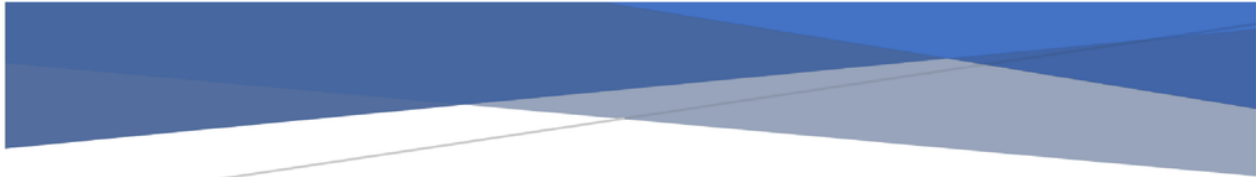


ASsignment

by Luke Savin

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RESONANT FREQUENCY IN RLC CIRCUITS

OME - ELECTRICAL & ELECTRONIC PRINCIPLES

Luke Savin

Student Number - 1810328

Abstract

This report investigates when the resonant frequency occurs in an RLC circuit. The Resistor value that was used was said to be $3.3\ \Omega$, the Inductor was said to be $1\ \text{mH}$ and the Capacitor was said to be $1\ \mu\text{F}$. When these components were measured, these values were actually $2.89\ \Omega$ for the resistor, $0.977\ \text{mH}$ for the Inductor and $1.013\ \mu\text{F}$ for the capacitor. These values were used and compared to the stated value when calculating the bandwidth and the Q factor.

The results for the resonant frequency for the simulated circuit came to $5000\ \text{Hz}$ where the lab circuit came to $5100\ \text{Hz}$. These results were slightly different to what the ones that came from the calculated results. The frequency for the calculated Proteus came to $5032.921\ \text{Hz}$ and the Lab, with the measured values came to $5059.040\ \text{Hz}$. The difference in the real result and calculated results were down to the amount of reading that were taken. Setting the frequency value on the signal generator in the lab was proven difficult.

Table of Contents

Abstract	1
Introduction	3
Method	4
Results	6
Discussion	8
Q factor	9
Bandwidth	10
Reactance	13
Conclusion	15
Equations	16
References	17

Introduction

An RLC circuit is an electrical circuit that contains three components, a Resistor (R), an Inductor (L), and a Capacitor (C). A Resistor is a passive component that provides resistance to a circuit. In basic terms, an Inductor can be seen as a coil that is able to store electrical energy. It stores this energy in the form of a magnetic field. In a capacitor, there are two metal plates separated by a non-conducting substance. Much like the inductor, the capacitor is able to store electrical energy but instead of a magnetic field, it is stored in-between the two metal plates as an electric field. When these three electrical components are assembled into a series, they create a resonant circuit.

The way the RLC circuit resonates is from the Inductor and Capacitor charging and discharging. When the capacitor is charging, it causes the inductor to discharge and vice versa but in the opposite polarity. The current oscillates between the electric field of the capacitor and the magnetic field of the inductor. When this type of oscillation occurs, it is referred to as Resonance. Resonant Frequency occurs when the *'inductive and capacitive reactance are equal in magnitude but cancel each other out because they are 180 degrees apart in phase'* [1].

RLC circuits are used in many real-world appliances. They can be found in radio communications to TV receivers and are used in tuning a narrow range of frequencies. These types of RLC are called low Band-pass filters. They are used to pass through frequencies and reject other frequencies. When looking at the range of frequencies a circuit can produce, it is called bandwidth. For example, when picking up a radio station, it is transmitted at a specific frequency which has a narrow bandwidth so that it does not overlap other frequencies. To pick this signal up and cut out other signals, an RLC Band-pass filter circuit is used and tuned to the correct hertz (Hz). The sharpness of the peak of the frequency is determined by its Quality factor (Q factor).

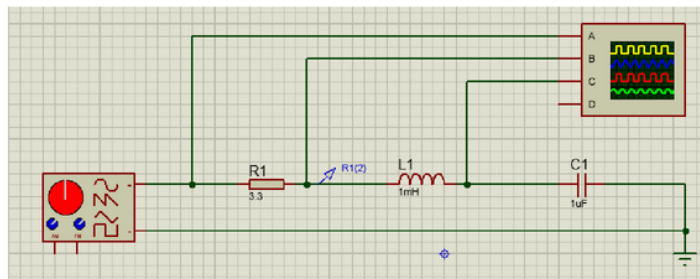
This report therefore investigated when the resonant frequency occurs in an RLC circuit and how it is affected. Two circuits were experimented with. The first was simulated on a computer to give perfect conditions. The second RLC circuit was tested in a lab with a Resistor, Inductor, and a Capacitor. The bandwidth and the Q factor were then calculated to see if there was any difference between the two circuits.

Method

To find the resonant frequencies two RLC circuits were created. One was created with hardware the other on a computer simulation.

The first circuit was designed and generated on a computer program called Proteus. Proteus is used in the out-side world by electronic engineers and technicians to create and design electronic schematics. The computer simulated circuit was used to give accurate and precise readings as it could be set to the precise values required for the test. These results predict what was to be expected in the lab experiment from the hardware set up.

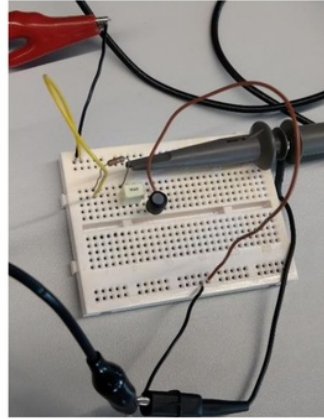
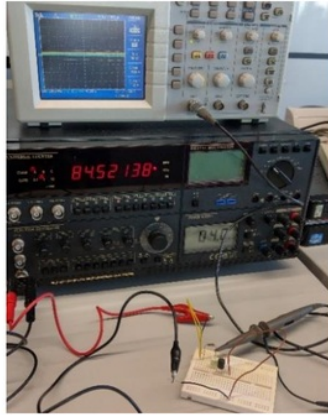
The circuit had a peak to peak voltage of 4v. 4v was used in this experiment as it was a safe value to use again in the lab experiment. A signal generator was used to create the 4v and sent to the Resistor, Inductor and Capacitor. These were set to values that could be replicated in the lab. The value of the Resistor was set at $3.3\ \Omega$, the Inductor was 1 mH and the Capacitor was set at $1\ \mu\text{F}$. These were set out in a series circuit. An Oscilloscope was built in to the simulation for taking the reading of the voltage and the $V_L + V_C$. The $V_L + V_C$ readings were taken and written as the frequency was increased on the signal generator. The frequency started at 100 Hz and was raised up to 14 KHz.



Once the computer circuit was simulated and the results were taken, a physical circuit was built in the lab to test the real-world components. This was so that there would be a direct comparison between real world and simulation.

The set up and method was kept the same as best as they could. The lab experiment used the same values for the Resistor, Inductor and Capacitor as the computer generated circuit. Before the components were used, they were tested to see if they worked and to find out if they were working at their stated value. These were inserted into an electrical breadboard in the same order to keep continuity. Various wires were used to complete the circuit. A signal generator was used to produce the 4v peak to peak as was used in Proteus. To measure the voltage coming out from the signal generator it was connected to the oscilloscope which was connected to the leg of the resistor to measure the $V_L + V_C$. The frequency was increased as the Proteus experiment, so that there could be a

better comparison. To read the Oscilloscope, the graphics were paused so that the $V_I + V_C$ readings could be read more clearly and remove any noise.

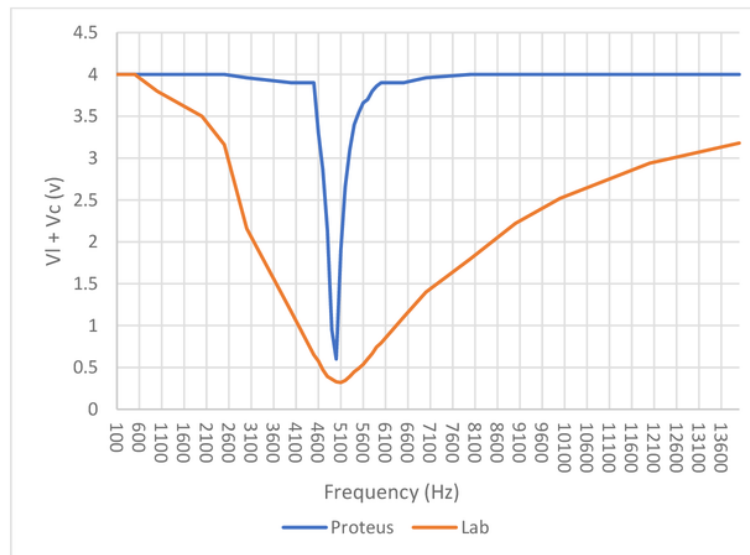


Results

The results from the experiments were collected by reading off each of the oscilloscope directly. The readings were taken at various frequencies during the tests, starting from 100 Hz leading up to 14000 Hz. The readings of these frequency did not go in even increments. This was so that there was more result that were closer to the point of resonant frequency. This was the same approach for Proteus and the Lab. When all the results were collected, they were captured into an Excel spreadsheet to create the table below.

	Proteus	Lab
Freq	VI +Vc	VI +Vc
100	4	4
200	4	4
500	4	4
1000	4	3.8
2000	4	3.5
2500	4	3.16
3000	3.96	2.16
4000	3.9	1.16
4500	3.9	0.65
4600	3.3	0.576
4700	2.86	0.472
4800	2.14	0.392
4900	0.95	0.36
5000	0.6	0.328
5100	1.9	0.32
5200	2.66	0.344
5300	3.1	0.392
5400	3.4	0.448
5500	3.54	0.488
5600	3.66	0.536
5700	3.7	0.6
5800	3.8	0.664
5900	3.86	0.744
6000	3.9	0.792
6500	3.9	1.1
7000	3.96	1.4
8000	4	1.8
9000	4	2.22
10000	4	2.52
12000	4	2.94
14000	4	3.18

1 The table shows the results from both the Proteus simulation and Lab. With the table of results a scatted graph was produced to show the difference in the deterioration in the voltage as the frequency become more resonant in the two circuits.



From creating the graph, it shows that at the resonant frequency for the simulated circuit occurs at approximately 5000 Hz, whilst the resonant frequency for the lab experiment happens at approximately 5100 Hz. The graph also shows that the decrease in voltage is more gradual in the Lab experiment, whereas the Proteus results show a sharp decrease in voltage.

Discussion

The purpose of this report was to provide results on a simulated and physical RLC circuit and to find the resonant frequency by measuring the $V_L + V_C$ and increasing the frequency. When looking at the tables of results and graphs that were produced from the results, they illustrate that resonance frequency occurs at a different frequency for each of the circuits. It shows that for the simulated experiment it occurs at 5000 Hz whereas for the Lab experiment it occurs at 5100 Hz.

The resonant frequency is different on each of the circuits due to the fact that the Lab and the simulated circuits had different resistance values. For example, the value of the Resistor that was used stated it was 3.3Ω but when the resistance was measured it gave a reading of 2.89Ω . This was also the same for the Inductor. It's stated value was 1 mH but its measured value dropped to 0.977 mH. The Capacitor value was $1 \mu\text{F}$ but when it was measured is was $1.013 \mu\text{F}$. With these small changes in the values, they can make a difference when we calculate the resonant frequency using the equations. To calculate the value of the resonant frequency the given figures where used to calculate the Proteus experiment and the measured value of the Inductor and Capacitor.

$$f_r = \frac{1}{2\pi\sqrt{LC}} [2]$$

Proteus Experiment

$$\frac{1}{2\pi\sqrt{(1 \times 10^{-3})(1 \times 10^{-6})}} = 5032.921 \text{ Hz}$$

Lab Experiment

$$\frac{1}{2\pi\sqrt{(0.977 \times 10^{-3})(1.013 \times 10^{-6})}} = 5059.040 \text{ Hz}$$

Even though the two calculated resonant frequencies is more similar than the ones shown in the Excel table and graphs there is still show a slight difference between the two.

Q factor

'The Q factor is a measure of the sharpness of the peak.' [3]. To compare the of the peak at resonant frequency, the equation for Q factor was used. Q factor is used to measure the performance of the resonant frequency in the RLC circuit and is used across many physics and engineering applications. It is a dimensionless value that relates to the energy lost through the resistance in the circuit.

$$Q = \frac{1}{R} \sqrt{\frac{L}{C}} [4]$$

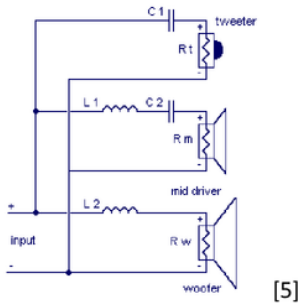
To calculate the Q factor the given value of the components was used and the measured value. When using this equation, the Q factor was calculated as 9.583 using the given values of the components. In comparison, when we calculated the Q factor for the measured values of the lab experiment the Q factor increases to 10.746. When stating Q factor the higher the value the better the circuit is. With these calculated values it shows that there was a bigger loss in power in the simulated rather than the Lab experiment.

These two calculations also do not take into account the total resistance of the circuit. Resistance of the resistor and inductor came to a total of 5.78 Ω . When this is put in the equation rather than the 2.89 Ω , the result is a drop in Q factor to 5.373. This value would drop again if the resistance of the breadboard and the wires included.

Bandwidth

The Bandwidth is the circuits range of frequencies. It is important when looking at the bandwidth of an RLC circuit as if the bandwidth is too narrow the desired frequency required will be missed. Or if the bandwidth is too wide it will pick up frequencies that are unwanted.

For example, when designing a 3-way Crossover speaker system for a music system which consist of 3 series RLC circuits. The 'tweeter' circuit in the speaker system will be set up so that the bandwidth will only be able to pick up the higher frequencies. The 'woofer' circuit will need a bandwidth in the lower frequencies and the mid speakers having a circuit that picks up a frequency bandwidth that is between the tweeter and the woofer. There will be a slight crossover between each of the circuits, hence the name. If these RLC circuits were set up incorrectly with each having a smaller bandwidth than what is required, then the full range of frequencies will not get picked up. Whereas if the bandwidth of each of the circuits was too wide then frequencies would overlap too and quite possibly break the speakers.



To determine the bandwidth of the simulated and lab circuits, it was first calculated using the equations when worked out using the results and the graphs from the experiments. Once again, the simulated circuit used the given values of the components whereas the Lab calculation used the measured values of the components.

Proteus Bandwidth

$$\frac{3.3}{2\pi(1 \times 10^{-3})} = 525.211 \text{ Hz [2]}$$

Lab Bandwidth

$$\frac{2.98}{2\pi(0.977 \times 10^{-3})} = 485.447 \text{ Hz [2]}$$

From the equations it shows that the bandwidth on the Lab experiment has a narrower bandwidth than the Proteus.

When the bandwidth of the two circuits has been calculated, the upper bandwidth and lower bandwidth can be worked out using the equations below.

$$f_L = f_r - \frac{1}{2}BW [2]$$

$$f_H = f_r + \frac{1}{2}BW [2]$$

Proteus Upper and Lower Bandwidth

$$5032.921 + \frac{1}{2} (525.211) = 5295.527 \text{ Hz}$$

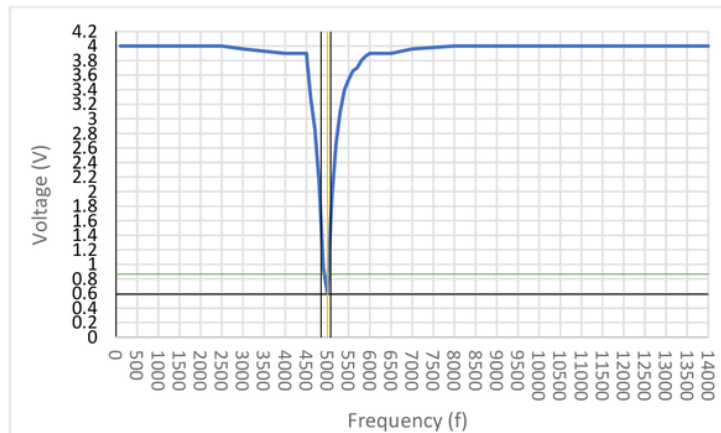
$$5032.921 - \frac{1}{2} (525.211) = 4770.316 \text{ Hz}$$

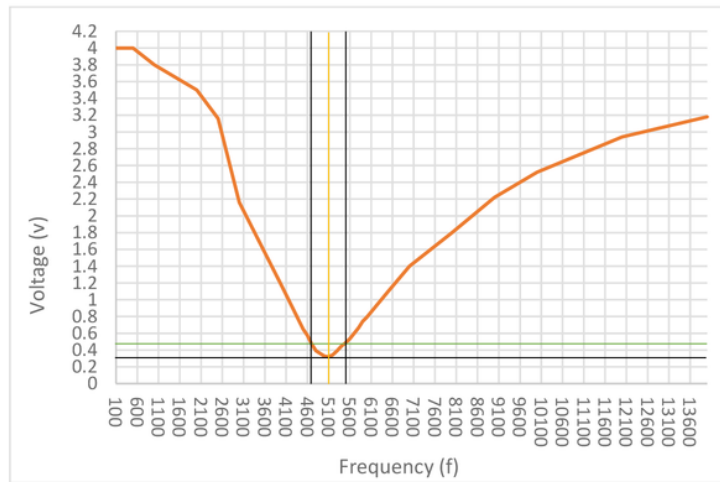
Lab Upper and Lower Bandwidth

$$5059.040 + \frac{1}{2} (485.447) = 5301.764 \text{ Hz}$$

$$5032.040 - \frac{1}{2} (485.447) = 4816.317 \text{ Hz}$$

To work out the bandwidth using the graphs, 70.7% (green line) of the voltage at resonant frequency (yellow line) was found. The upper and lower bandwidth is where $V_i + V_c$ meet the 70.7% line.





Proteus

RF 5000 Hz
 Upper Bandwidth 5100 Hz
 Lower Bandwidth 4800 Hz
 Bandwidth 300 Hz

Lab

RF 5100 Hz
 Upper Bandwidth 5400 Hz
 Lower Bandwidth 4700 Hz
 Bandwidth 700 Hz

By find the bandwidth from the two graphs it shows that the Proteus has a narrower bandwidth than the Lab bandwidth. When compared with the calculated values of the bandwidth the Lab result are vastly different. This is due to the fact the resistance was not been taken into account in the calculations.

Reactance

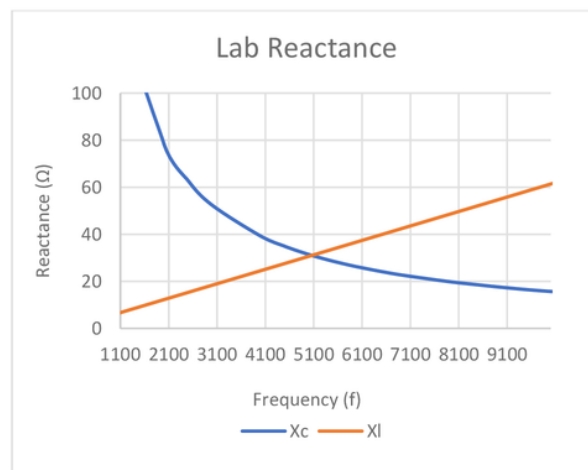
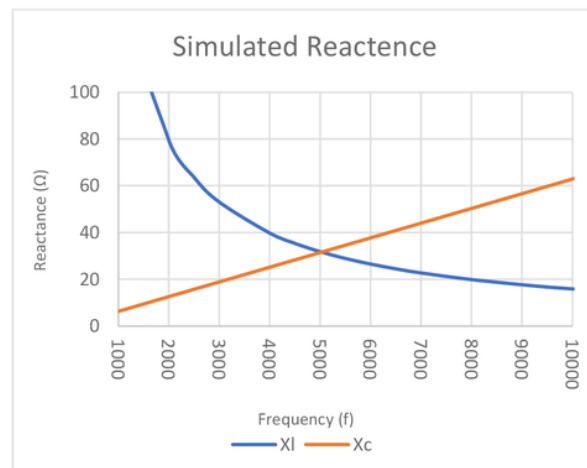
Reactance is *'the opposition of change of flow of current within a circuit'* [6]. As an RLC circuit has an Inductor and capacitor we needed to work out the Reactance of each of the components. When we calculate the reactance, we were able to find the resonant frequency. To calculate this, we used two different formulas. For the Inductor it was;

$$X_L = 2\pi fL [2]$$

and for the reactance of the Capacitor.

$$X_C = \frac{1}{2\pi fC} [2]$$

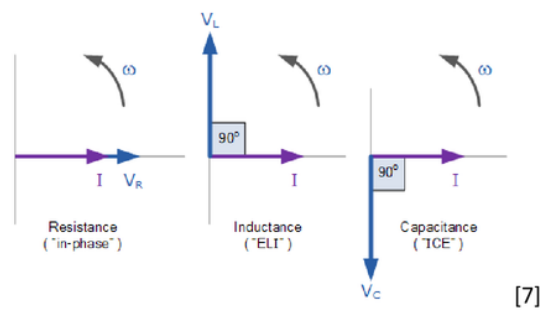
Using these equations, a graph showing the reactance for the Capacitor and the Inductor that were used in the experiments at the can be plotted.



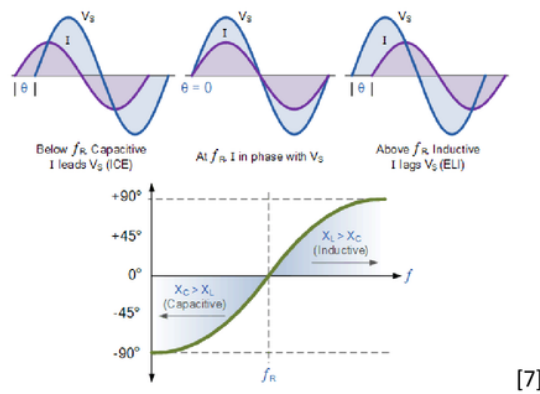
On Each of the graphs the lines of the X_L and X_C intersect, this is where the resonant frequency occurs in the both circuits. The graphs also show that before resonant frequency X_C leads X_L . However, when the circuits reach resonance, X_L and X_C swap and X_L leads. When this occurs in a circuit this is known as Phase Shift. This can be seen when looking more closely at the Sine waves.

Phase Shift

At the beginning of the experiment the Sine waves of the Resistor, Inductor, and Capacitor are all out of phase from each other. However the Resistor is in phase with the current. The Inductor leads the current by 90° and the capacitor lags the current and inductor by 90° but both are at a higher voltage. This means the Inductance and Capacitance are 180° out of phase. This can be shown in a phase diagram below.



When the frequency in the circuit increase, the impedance from the Inductor is decreased. As the circuit gets to resonant frequency the Inductor Sine wave becomes in phase to the current wave.



Conclusion

To find the resonant frequency, two circuits were designed and built. One of the circuits was simulated on a computer program whilst the other was built in a lab. From this the Q factor and bandwidth was calculated. What was found was the calculated value was different each time from result we got from the lab experiment. This was down to the fact when calculating the it does no take into account the total resistance of the circuit. When the Q factor was calculated with the total resistance of the resistor and inductor and the Q factor significantly decrease. This is because the resistance in the circuit dampens the oscillations in the circuit. There were also other places in the circuit was resistance was added but not calculated. For example, in the breadboard and the cables that were used. To remove these occurrences of where resistance was added the components the components could be solder onto a board, where each of the legs made the connection rather than using cables.

To find a more accurate resonate frequency from the lab experiment a few changes could be made to how the experiment was carried out. One way the experiment could be improved was by taking more readings. As the calculated results show that occurs in-between two of the reading that was taken from the experiment. To set the frequency value on the signal generator in the lab was proven difficult. Where the Proteus frequency could be set on a specific value the signal generator was always few Hz out each time. Finally, when taking the readings in the lab, the oscilloscope was showing a lot of background noise making it problematic to get an accurate result.

Equations

Resonant Frequency – Proteus

$$\frac{1}{2\pi\sqrt{(1 \times 10^{-3})(1 \times 10^{-6})}} = 5032.921 \text{ Hz}$$

Q Factor - Proteus

$$\frac{1}{3.3} \times \sqrt{\frac{(1 \times 10^{-3})}{(1 \times 10^{-6})}} = 9.583$$

Bandwidth - Proteus

$$\frac{3.3}{2\pi(1 \times 10^{-3})} = 525.211 \text{ Hz}$$

Upper and Lower Bandwidth - Proteus

$$5032.921 + \frac{1}{2} (525.211) = 5295.527 \text{ Hz}$$

$$5032.921 - \frac{1}{2} (525.211) = 4770.316 \text{ Hz}$$

Resonant Frequency – Lab

$$\frac{1}{2\pi\sqrt{(0.977 \times 10^{-3})(1.013 \times 10^{-6})}} = 5059.040 \text{ Hz}$$

Q Factor - Lab

$$\frac{1}{2.89} \times \sqrt{\frac{0.977 \times 10^{-3}}{1.013 \times 10^{-6}}} = 10.746$$

Bandwidth - Lab

$$\frac{2.98}{2\pi 0.977 \times 10^{-3}} = 485.447 \text{ Hz}$$

Upper and Lower Bandwidth - Lab

$$5059.040 + \frac{1}{2} (485.447) = 5301.764 \text{ Hz}$$

$$5059.040 - \frac{1}{2} (485.447) = 4816.317 \text{ Hz}$$

References

- [1] C. R. (. Nave, "Resonant RLC Circuits," 2017. [Online]. Available: <http://hyperphysics.phy-astr.gsu.edu/hbase/electric/serres.html>. [Accessed 10 02 2019].
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ASsignment

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

67/100

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8



Comment 1

Not sure this is the right word....

PAGE 9

PAGE 10

PAGE 11



Comment 2

Including the DC resistance of the inductor would have increased the experimental bandwidth in line with your observations.

PAGE 12

PAGE 13

PAGE 14

GRADING FORM: SMU GENERIC_SMOSEY

LUKE SAVIN

67.30

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



A comprehensive range of research informed literature embedded in the work. Excellent selection of relevant and credible sources. High-level referencing skills, consistently applied

3.75

KNOWLEDGE & UNDERSTANDING

Knowledge of the basic underlying concepts and principles of a subject.



Knowledge is extensive. Exhibits understanding of the breadth and depth of established views.

20.1

COGNITIVE & INTELLECTUAL

Evaluate underlying concepts and principles of a subject and interpret qualitative and quantitative data in order to develop lines of argument and make sound judgements.



Sound, logical, analytical thinking; and evaluation. You have shown an ability to devise and sustain a persuasive argument and to review the validity of evidence. Ability to communicate ideas and evidence accurately and convincingly. Sound, convincing conclusions.

18.9

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



An advanced application of a range of methods in the analysis of the data gathered in this investigation. The context of the application is well considered, with use of relevant examples.

21.3

TRANSFERABLE SKILLS

Communicate the results of their study/work accurately and reliably, and with structured and coherent arguments; the qualities needed for employment requiring the exercise of some personal responsibility within a structured and managed environment.



Can communicate well, confidently and consistently in a suitable format. Work is coherent and fluent and is well structured and organised.

3.25