

University of Wales Trinity St David

Investigation into Resonant Circuits

By
Nathan Scott Morgan

A report submitted addressing the measured data
produced.

BEng (Hons) Energy & Environmental Engineering

26th April 2021

Contents

Abstract.....	3
Introduction	3
Simulation Setups – Series.....	3
Voltage Gain Across Each Component Graph Set Up	4
Bandwidth and Q factor Graph Set Up	5
RLC Band Stop Filter and Attenuation Graph Set Up.....	6
Simulation Setups - Parallel	7
Voltage, Current and Phase Values Across RLC Parallel Circuit Graph Set Up.....	7
RLC Low Pass Filter and Attenuation Graph Set Up.....	10
Current Transaction Graph Set Up.....	10
Results - Series Circuit.....	12
Results – Parallel Circuit.....	14
Discussion.....	16
Voltage Gain Across Each Component.....	16
VC+VL graph.....	16
RLC Band Stop Filter and Attenuation	17
RLC Wide Band Pass Filter and Attenuation	17
Current Oscillation	17
Conclusion.....	18
Bibliography	19

Abstract

The task set out, is to investigate into resonant circuits by using software simulation “Proteus” to collect data on RLC circuits (series and parallel). By selecting RLC components to create the two types of circuit and using the probes to measure the values needed. Setting up graphs to present data and discover how resonance works, then comparing selected data to basic theory.

The results carried lots of information and helped visualise what is going on. The results also required more research into the “Band Stop Filter” and what it means. Overall, the results were clear and presented a lot of detail.

Introduction

“RLC Circuits” consist of three main components. A Resistor (R), Inductor (L), and a Capacitor (C) and can be used to form a series or parallel circuits. “RLC Circuits” are commonly applied to radio receivers and television. For example, to tune to a specific radio station, the circuit will require a specific resonance. The resonant frequency of a circuit can be resolved by using basic theory, Equation 1 - Equation for Resonant Frequency. [1]

$$f_{res} = \frac{1}{2\pi\sqrt{LC}}$$

Equation 1 - Equation for Resonant Frequency.

Which is transposed from the equation,

$$|X_L| = |X_C|$$

Equation 2 – Equation for Magnitude of Inductive Reactance and Capacitive Reactance are Equal.

Where the inductive reactance equals,

$$X_L = 2\pi f L$$

Equation 3 - Inductive Reactance

And the capacitive reactance equals,

$$X_C = \frac{1}{2\pi f C}$$

Equation 4 - Capacitive Reactance.

This report will show the results from measuring the voltage and current through each RLC circuit and be represented by graphs as well as a discussion on what the results show.

Simulation Setups – Series

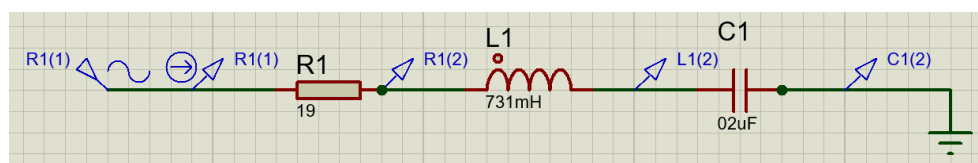


Figure 1 – RCL Series Circuit Diagram with Component Values and Probes.

Component Values are based on personal student identification numbers (1902731)

Resistor	19 Ω , Ohms
Inductor	731 mH, Milli-Henry's, 10^{-3}
Capacitor	02 μ F, Micro-Farads, 10^{-6}

Table 1 - Personal Identification Number, Prefixes and Order of Magnitude.

Figure 2- Sine Generator Parameter Values for RLC Series Circuit.

Voltage Gain Across Each Component Graph Set Up

Figure 26 illustrates the voltage gain across each component. This can be calculated by using the voltage probes (R1(1), R1(2) and L1(2)) shown in Figure 1.

Figure 3 shows the frequency graph parameter set up.

Figure 4, Figure 5, and Figure 6 show the individual component parameter trace set ups.

Figure 3 - Parameters for Frequency Graph, RLC Series Circuit.

Calculating the voltage gain across the resistor by subtracting the values from R1(1) by the values of R1(2). As shown in Figure 4

Figure 4 - Parameters to show Voltage Gain across Resistor.

Calculating the voltage gain across the inductor by subtracting the values from R1(2) by the values of L1(2). As shown in Figure 5 below.

The 'Edit Graph Trace' dialog box shows the following configuration:

- Trace name: VL
- Expression: P1-P2
- P1: R1(2)
- P2: L1(2)
- P3: (empty)
- P4: (empty)
- Show data points?: ☐
- Buttons: OK, Cancel

Figure 5- Parameters to show Voltage Gain across Inductor.

Calculating the voltage gain across the capacitor by selecting only the value of L1(2) as shown in Figure 6 below. The reason for not subtracting is because the voltage coming from that probe will be the voltage of the capacitor.

The 'Edit Graph Trace' dialog box shows the following configuration:

- Trace name: VC
- Expression: P1
- P1: L1(2)
- P2: (empty)
- P3: (empty)
- P4: (empty)
- Show data points?: ☐
- Buttons: OK, Cancel

Figure 6 - Parameters to show Voltage Gain across Capacitor.

Bandwidth and Q factor Graph Set Up

Figure 27 illustrates a band with which bandwidth and Q can be solved from. This can be calculated using the following information.

The 'Edit Frequency Graph' dialog box shows the following configuration:

- Graph title: FREQUENCY RESPONSE
- Reference: R1(1)
- Start frequency: 1
- Stop frequency: 20k
- Interval: DECADES
- No. Steps/Interval: 1000
- Options:
 - Y Scale in dBs: ☐
 - Always simulate: ☒
 - Log netlist(s): ☐
- Buttons: SPICE Options, Set Y-Scales, OK, Cancel

Figure 7- Series Bandwidth and Q factor Frequency Graph Set Up

Calculating the total voltage across the inductor and capacitor by adding the values from C1(2) and L1(2) together as shown in Figure 8.

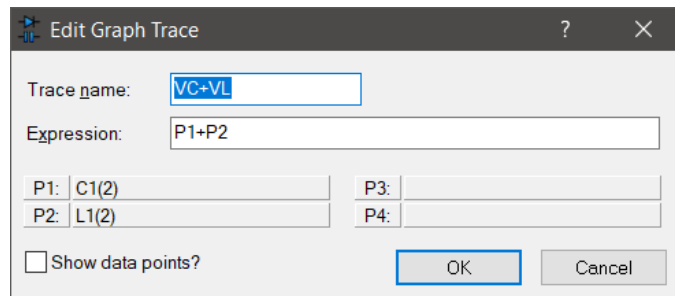


Figure 8 - Parameters to show Bandwidth and Q factor.

RLC Band Stop Filter and Attenuation Graph Set Up

This set up is logarithmic and in dBs.

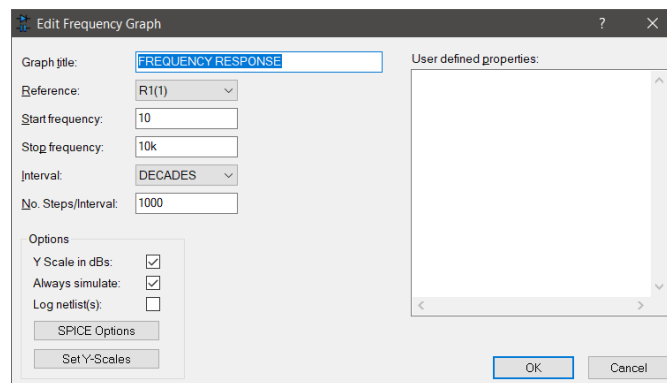


Figure 9 - Attenuation Frequency Graph Set Up

Calculating the power across the resistor by selecting the value from R1(2) shown on Figure 1 and seen in effect on Figure 29.

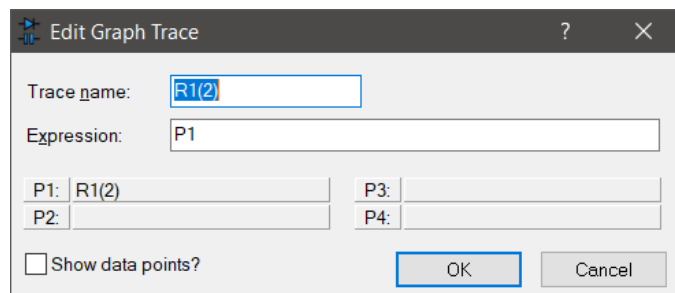


Figure 10 – Parameters to show dBs value across R1(2).

Simulation Setups - Parallel

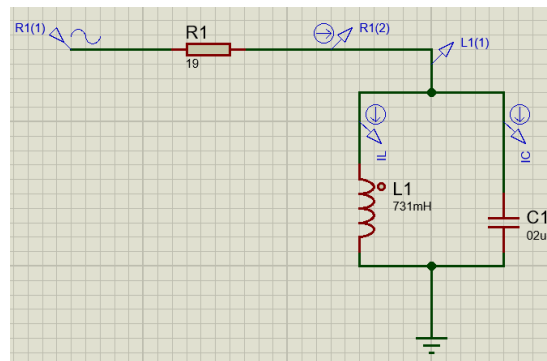


Figure 11 - RCL Parallel Circuit Diagram with Component Values and Probes.

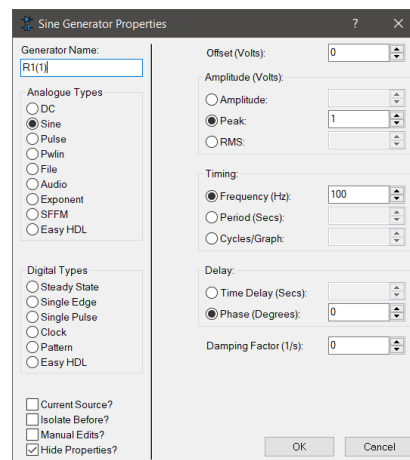


Figure 12 - Sine Generator Parameter Values for Parallel Circuit.

Voltage, Current and Phase Values Across RLC Parallel Circuit Graph Set Up

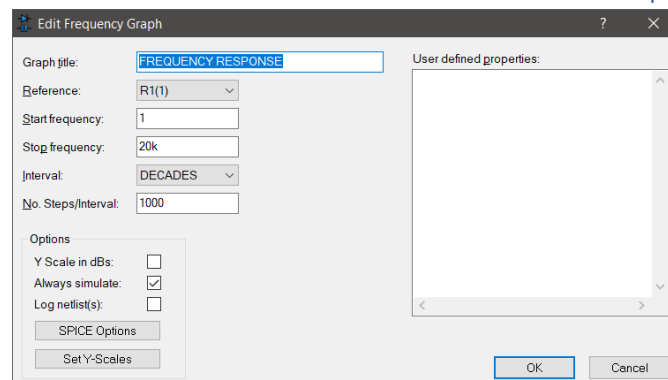
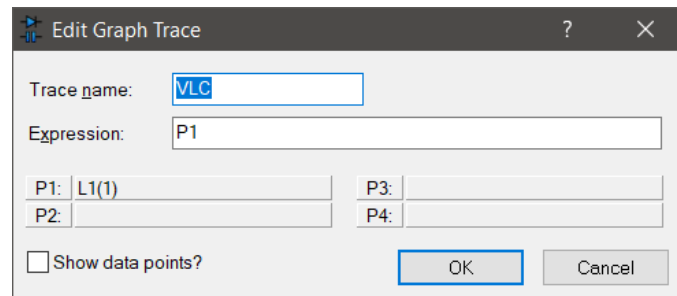


Figure 13 - Parameters for Frequency Graph, RLC Parallel Circuit.

Calculating the voltage for both inductor and capacitor by selecting only the value of “L1(1)” as shown in Figure 11 above and seen in effect on Figure 31 below. Trace set up shown below, Figure 14.



Trace name:

Expression:

P1: P3:

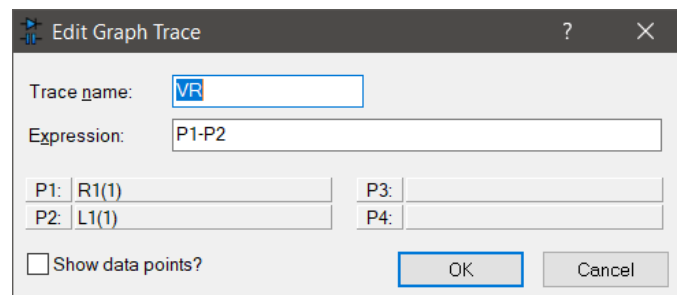
P2: P4:

☐ Show data points?

OK Cancel

Figure 14 – Parameters to show Voltage across Inductor and Capacitor.

Calculating the voltage across the resistor by subtracting the values from “R1(1)” by the values of “L1(1)” as shown on Figure 11 above and seen in effect on Figure 31 below. Trace set up shown below, Figure 15.



Trace name:

Expression:

P1: P3:

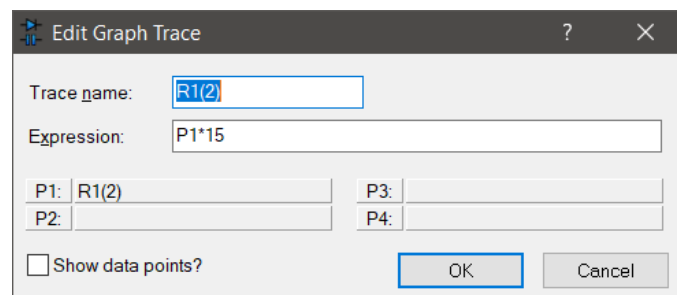
P2: P4:

☐ Show data points?

OK Cancel

Figure 15 - Parameters to show Voltage across Resistor.

Calculating the current across the circuit by selecting only the value of “R1(2)” as shown on Figure 11 above and seen in effect on Figure 31 below. Trace set up shown below, Figure 16.



Trace name:

Expression:

P1: P3:

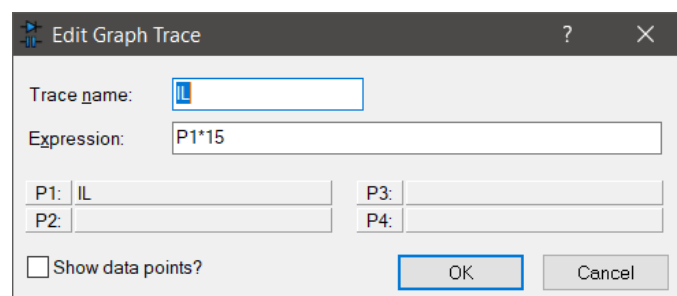
P2: P4:

☐ Show data points?

OK Cancel

Figure 16 - Parameters to show Current through the Circuit, Multiplied by 15.

Calculating the current across the circuit by selecting only the value of “IL” as shown on Figure 11 above and seen in effect on Figure 31 below. Trace set up shown below, Figure 17.



Trace name:

Expression:

P1: P3:

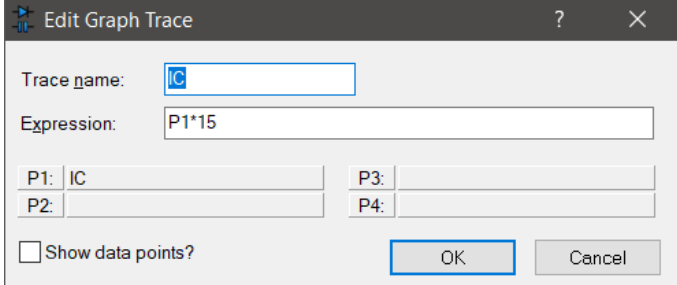
P2: P4:

☐ Show data points?

OK Cancel

Figure 17 - Parameters to show Current through the Inductor, Multiplied by 15.

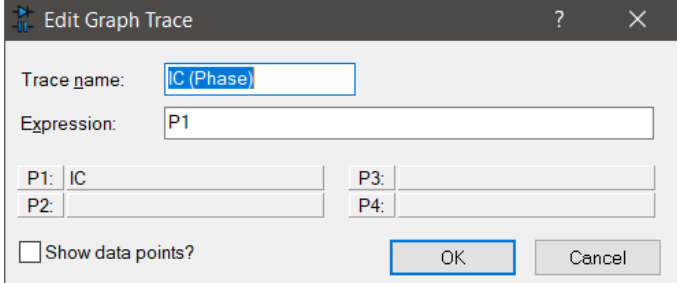
Calculating the current across the circuit by selecting only the value of “IC” as shown on Figure 11 above and seen in effect on Figure 31 below. Trace set up shown below, Figure 18.



The 'Edit Graph Trace' dialog box is shown. The 'Trace name' field contains 'IC'. The 'Expression' field contains 'P1*15'. Below these are four parameter selection fields: 'P1:' is set to 'IC', 'P2:' is empty, 'P3:' is empty, and 'P4:' is empty. At the bottom left is a checkbox labeled 'Show data points?' which is unchecked. At the bottom right are 'OK' and 'Cancel' buttons.

Figure 18 - Parameters to show Current through the Capacitor, Multiplied by 15.

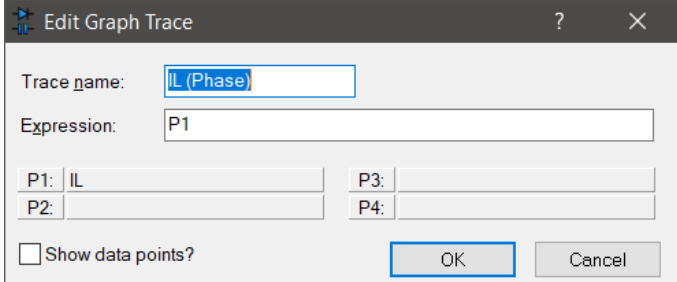
Calculating the phase difference in relation to the voltage supply by selecting the value of “IC” as shown on Figure 11 and seen in effect on Figure 31 below. Trace set up shown below, Figure 19.



The 'Edit Graph Trace' dialog box is shown. The 'Trace name' field contains 'IC (Phase)'. The 'Expression' field contains 'P1'. Below these are four parameter selection fields: 'P1:' is set to 'IC', 'P2:' is empty, 'P3:' is empty, and 'P4:' is empty. At the bottom left is a checkbox labeled 'Show data points?' which is unchecked. At the bottom right are 'OK' and 'Cancel' buttons.

Figure 19 – Parameters to show Phase Shift through the Capacitor

Calculating the phase difference in relation to the voltage supply by selecting the value of “IL” as shown on Figure 11 and seen in effect on Figure 31 below. Trace set up shown below, Figure 20.



The 'Edit Graph Trace' dialog box is shown. The 'Trace name' field contains 'IL (Phase)'. The 'Expression' field contains 'P1'. Below these are four parameter selection fields: 'P1:' is set to 'IL', 'P2:' is empty, 'P3:' is empty, and 'P4:' is empty. At the bottom left is a checkbox labeled 'Show data points?' which is unchecked. At the bottom right are 'OK' and 'Cancel' buttons.

Figure 20 - Parameters to show Phase Shift through the Inductor.

RLC Low Pass Filter and Attenuation Graph Set Up

Frequency graph parameters set up logarithmically as shown below, Figure 21.

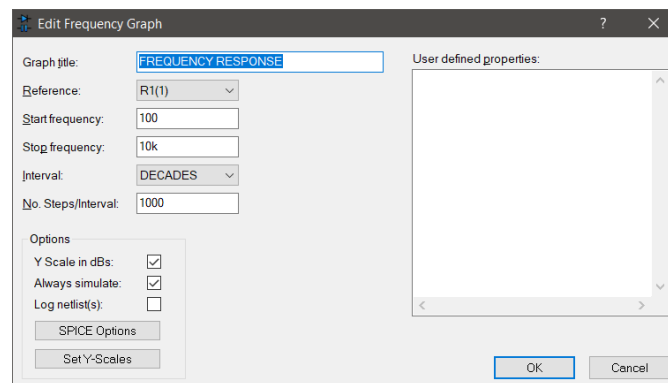


Figure 21 - Parameters for Frequency Graph, RLC Parallel Circuit.

Select L1(1) probe to show dB value across RLC parallel circuit as shown below, Figure 22.

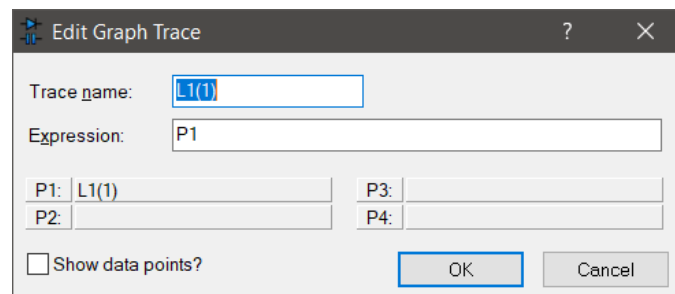


Figure 22 – Parameters to show dB Value across L1(1) Probe.

Current Transaction Graph Set Up

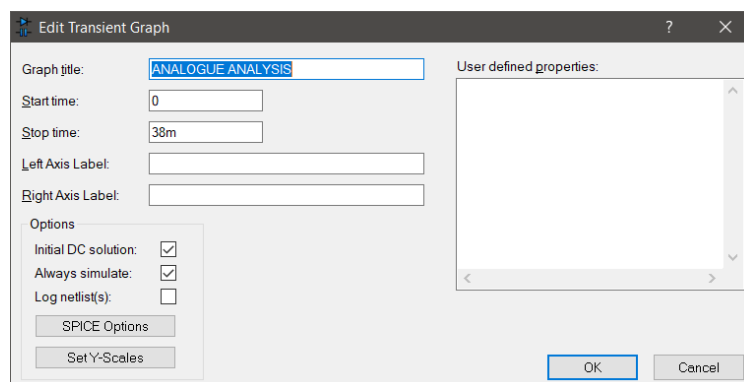
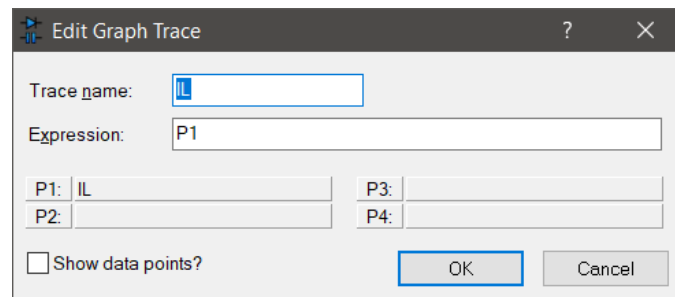


Figure 23 - Parameters for Analogue Graph, RLC Parallel Circuit

Select “IL” current probe to show current across inductor.

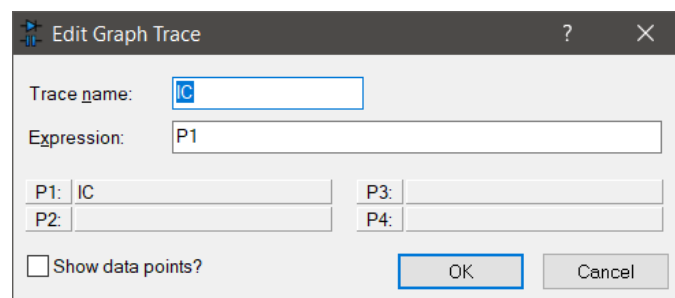


The 'Edit Graph Trace' dialog box is shown with the following settings:

- Trace name: IL
- Expression: P1
- P1: IL
- P2: (empty)
- P3: (empty)
- P4: (empty)
- ☐ Show data points?
- Buttons: OK, Cancel

Figure 24 - Parameters showing Current at Inductor.

Select “IC” current probe to show current across capacitor.



The 'Edit Graph Trace' dialog box is shown with the following settings:

- Trace name: IC
- Expression: P1
- P1: IC
- P2: (empty)
- P3: (empty)
- P4: (empty)
- ☐ Show data points?
- Buttons: OK, Cancel

Figure 25 - Parameters showing Current at Capacitor.

Results - Series Circuit

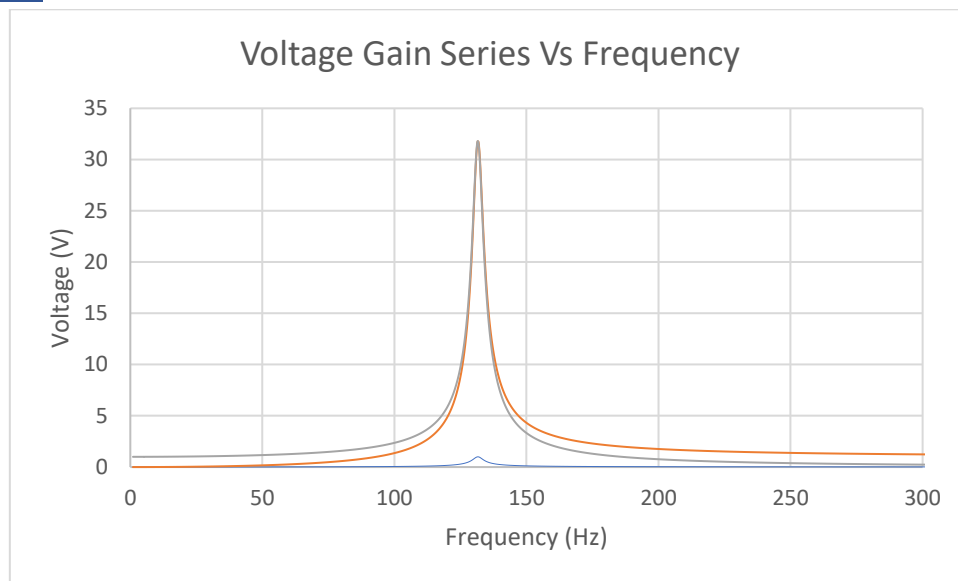


Figure 26 - Voltage Gain Across Each Component

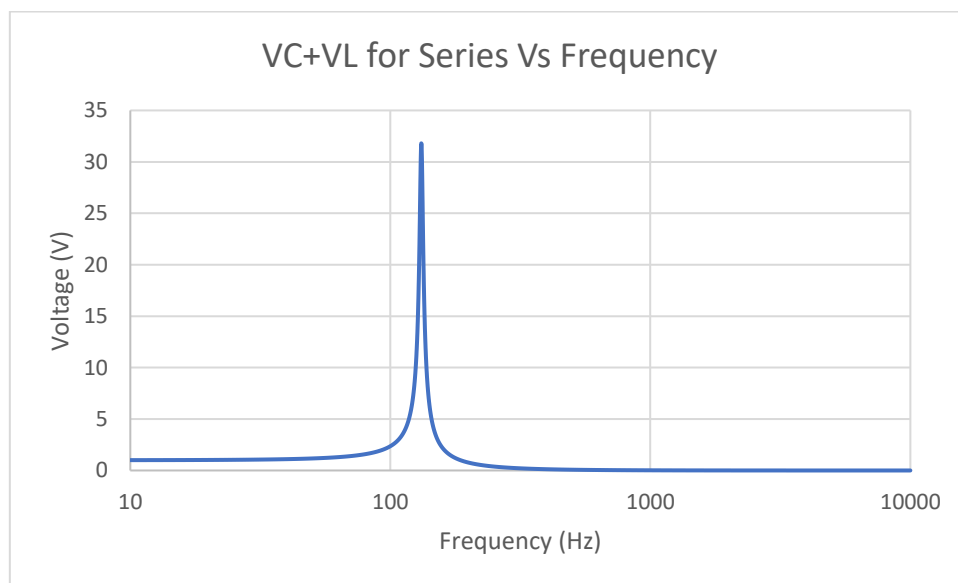


Figure 27 – Bandwidth and Q Factor on VC+VL graph.

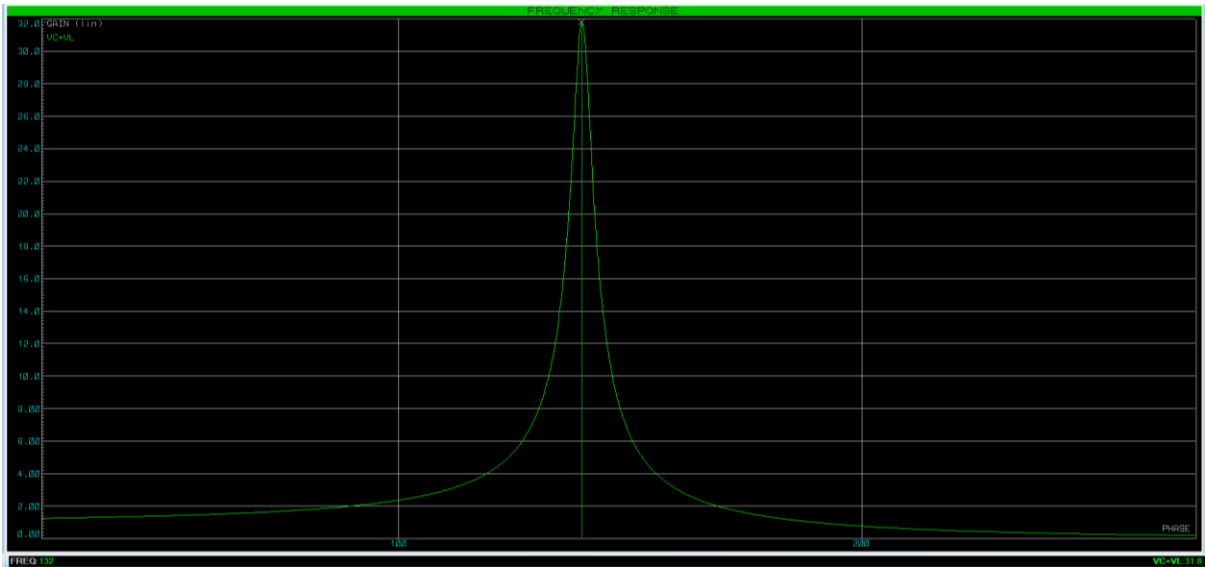


Figure 28 - VC+VL graph showing Resonant Frequency.

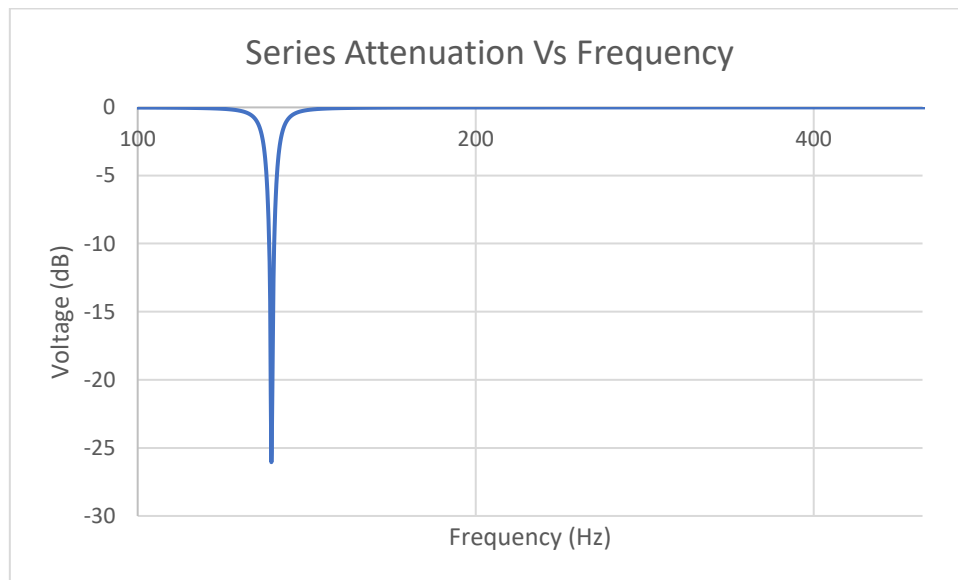


Figure 29 - RLC Band Stop Filter and Attenuation.

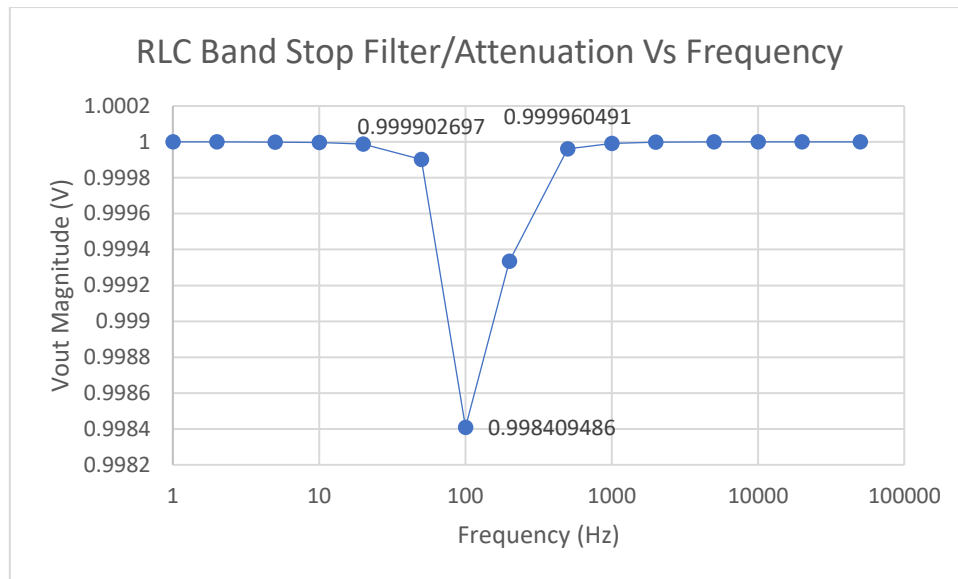


Figure 30 - RLC Band Stop Filter and Attenuation with Basic Theory.

Results – Parallel Circuit

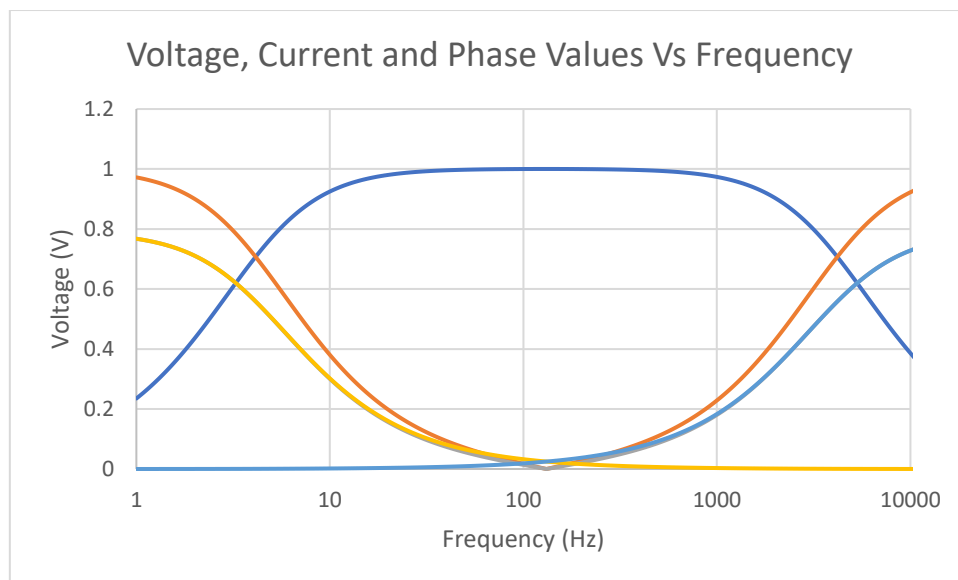


Figure 31 – Voltage and Current Across RLC Parallel Circuit.

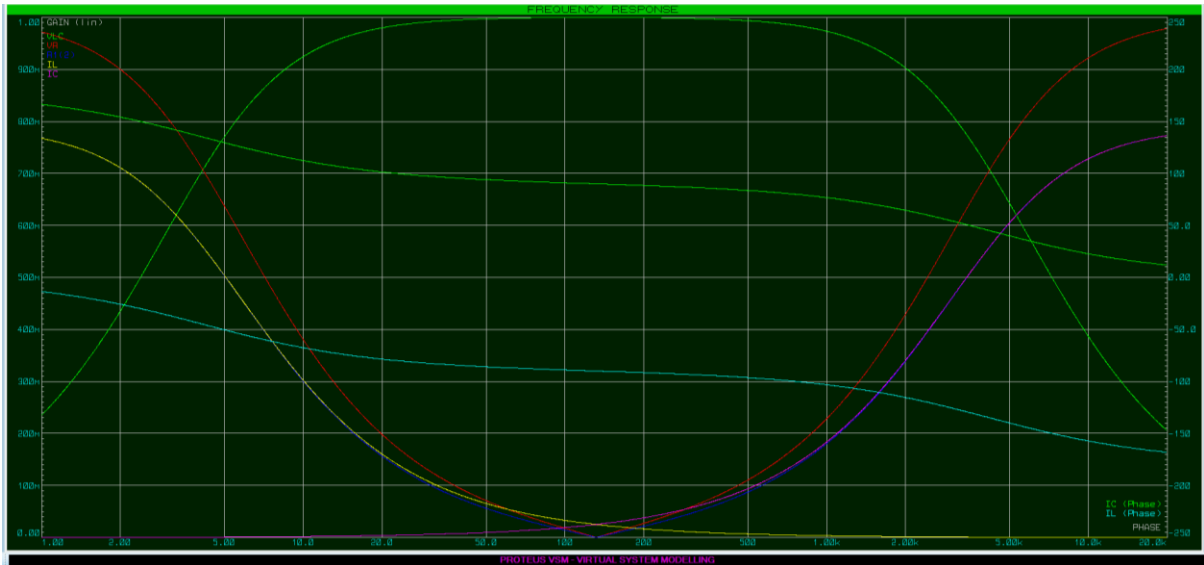


Figure 32 - Phase Across RLC Parallel Circuit.

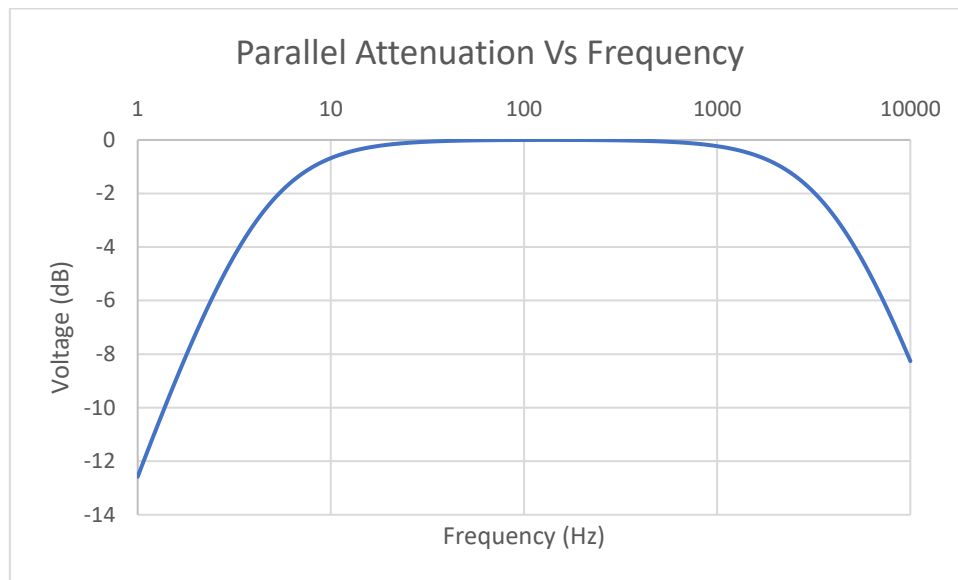


Figure 33 – RLC Wide Band Pass Filter and Attenuation Graph.

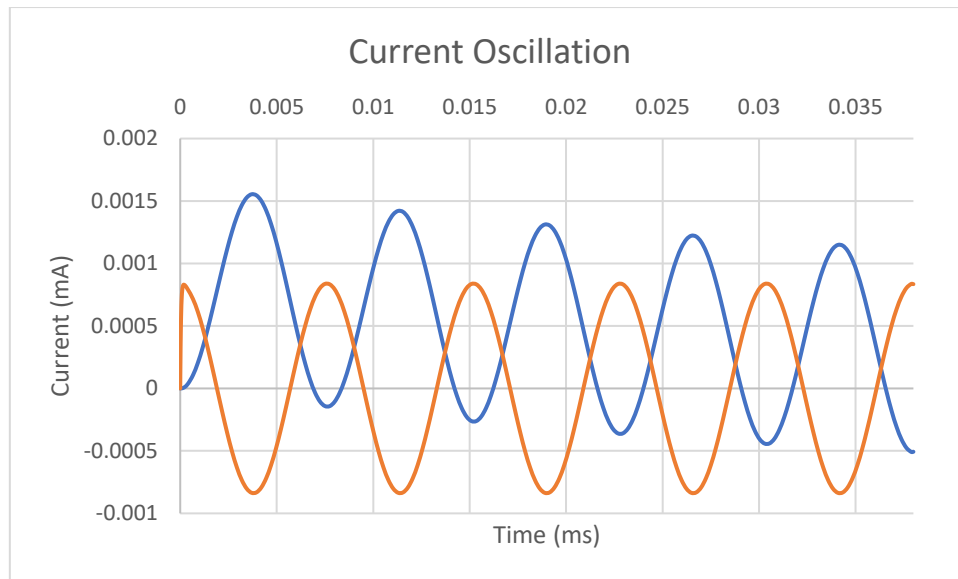


Figure 34 - Current Oscillations

Discussion

Voltage Gain Across Each Component

Figure 26 shows, from the 1-volt supply, at resonance the voltage gain on the inductor and capacitor is at 31.7 volts. This shows that they are equal. At resonance, the voltage gain across the resistor is at 999 millivolts. The increase in voltage at resonance is due to voltage magnification which can only happen to RLC series circuits.

This happens because current flows through the circuit and gets stored within the magnetic field of the inductor. Then, on the following half cycle the current stored will collapse and transfer to the capacitor allowing the component to charge. Oscillations between these components continue even shortly after the supply is cut.

VC+VL graph

Figure 29 above shows us a range of frequencies. From these frequencies, the bandwidth can be worked out. The equation below is used to calculate bandwidth and Q.

Bandwidth is measured between frequencies at an amplitude of 70.7%. By multiplying the peak by 0.707. A figure is given which allocates an accurate reading of the 70.7% region.

The 70.7% region is given the term Δf which stands for the “changed” variable.

The bandwidth of Δf is equal to $f_h - f_l$, where f_h stands for high band edge and f_l stands for low band edge.

$$\text{BW (Band Width)} = \Delta f = f_h - f_l = 133.7 - 129.51 = 4.19$$

By dividing the bandwidth by 2, and $\pm$ from f_h or f_l . The value 131.605 is given which is the centre resonant frequency, f_c .

$$f_c (\text{Centre Resonant Frequency}) = 131.605$$

From this Q can be worked out by the following transpose equation:

$$\text{BW} = f_c / Q \text{ then } Q = f_c / \text{BW} = 131.605 / 4.19$$

Equation 5 - Transposing for Q Factor.

$$Q = 31.41$$

The basic theory for resonant frequency and Q compares accurately with the data shown on Figure 27 above.

The basic theory for the resonant frequency is expressed as followed:

$$f_{res} = \frac{1}{2\pi\sqrt{LC}}$$

Equation 6 - Resonant Frequency

From this equation, f_{res} is equal to 131.63Hz.

The basic theory for the Q factor is expressed as followed:

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

Equation 7 - Q Factor.

From this equation, Q is equals to 31.82.

RLC Band Stop Filter and Attenuation

Attenuation is the gradual reduction in amplitude of the “signal when it passes through a medium that dissipates its energy.” [2]. There will always be attenuation as energy escapes in the form of sound which is why attenuation is also expressed in decibels(dBs).

Figure 29 shows low-level frequencies and high-level frequencies can pass through the circuit however the mid-level frequencies cannot as they are filtered out. This type of graph is known as a “Band Stop Filter” as it stops a specific frequency. “At low frequencies, the capacitor acts as an open circuit” [3], therefore at higher frequencies the inductor has the opposite effect. Leaving the mid-level frequencies to be blocked.

Figure 30 shows how basic theory attenuation compares to proteus data shown in Figure 29. The data represented compares accurately with the data provided by proteus.

RLC Wide Band Pass Filter and Attenuation

Figure 33 shows the formation of a band pass filter which allows many frequencies to pass through. Comparing this graph to Figure 29, the band pass filter allows a large amount of mid-level frequencies as well as a majority of high, and low frequencies.

Current Oscillation

Figure 34 shows the current oscillating between each other. This is due to the components being able to store energy. Similarly, to Figure 26 with voltage magnification. The capacitor charges up increasing the current being stored within an electric field. Then on the half cycle, the current is drawn to the inductor which then charges up increasing the current being stored within a magnetic field.

As shown in Figure 34, the current being stored in the capacitor remains the same throughout each cycle. However, as seen the inductor loses energy being stored as time passes. This is because the circuit is stabilizing at resonant frequency and the inductor and capacitor are equal.

Conclusion

In this experiment, it has been determined that frequency has a direct link to voltage gain. As frequency increases, so does voltage. Therefore, as seen the current drops proportionally to voltage.

It was also found that the basic theory for resonant frequency and Q were true to the data presented by proteus. Further validating the experiment, successful. Also, when comparing from Figure 29 and Figure 33, it can be shown that a higher Q has a smaller bandwidth, compared to a lower Q which will have a lower Q.

Overall, the results presented compared accurately with each other from basic theory to proteus data. Concluding our findings to be true.

Bibliography

- [1] S. Mosey, Composer, *Electrical & Electronic Principles Lectures (1:00:35 - 1:03:00)*. [Sound Recording]. Microsoft Streams. 2021.
- [2] G. E. N. a. A. K. Andrew Butteryfield, *A Dictionary of Computer Science (7ed.)*, Oxford University Press, 2016.
- [3] Administrator, "Electronics Hub," 26 01 2019. [Online]. Available: <https://www.electronicshub.org/band-stop-filter/>. [Accessed 12 04 2021].