

Electrical and Electronic Principles Assignment JLE 2011912 *by* Josh Luke Evans

Submission date: 08-Dec-2021 11:59AM (UTC+0000)

Submission ID: 165387542

File name:

27110_Josh_Luke_Evans_Electrical_and_Electronic_Principles_Assignment_JLE_2011912_387569_245416438.docx
(677.77K)

Word count: 3034

Character count: 16252

Lab Report on Resonance and its effects in an RLC Circuit

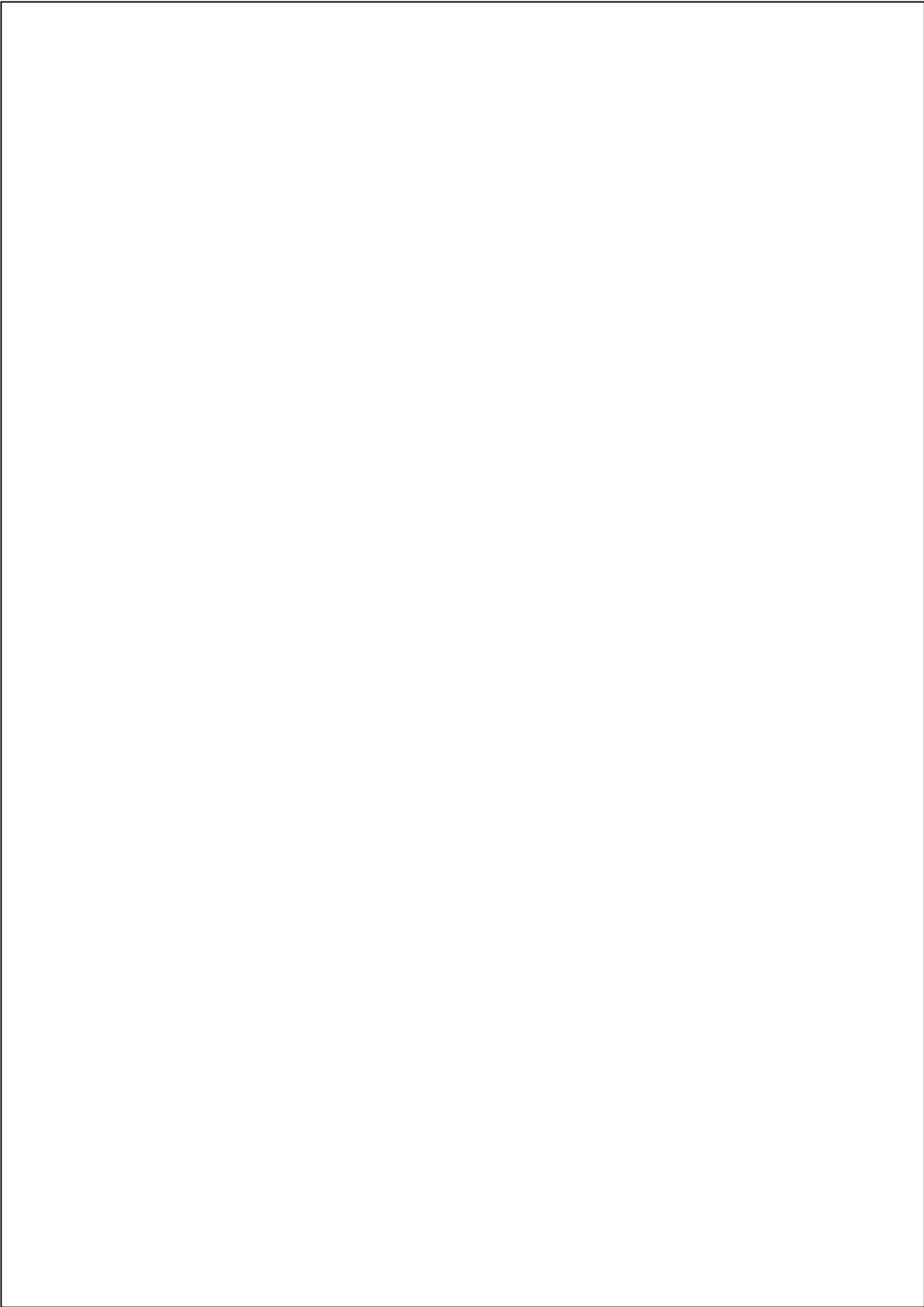
Author: Joshua Luke Evans (2011912)

Course: BSc Ordnance, Munitions, and Explosives – Level 4 Electrical and Electronic Principles

Faculty of Architecture, Computing and Engineering

Date of Submission: 8th December 2021

Word Count: 2436 (excluding appendices and references)



Declaration

The work of this report was completed under the supervision of Stephen Mosely. I declare that this report is the product of my own work and is not being submitted for any other degree, etc.

Signed: Joshua Evans (electronically on 08/12/2021)

Abstract

A lab study was conducted to develop practical measurement skills and data analysis through investigating resonant frequency effects within a circuit containing a resistor, inductor, and capacitor (also known as an RLC circuit). The experiment was initially conducted within the electronics simulation package, Proteus 8 Professional. It was then replicated in the lab using real components on a breadboard, connected to a function generator and an oscilloscope.

The results showed a higher peak inductor voltage and Q-factor in the simulated circuit compared with the physical circuit due to the original Proteus RLC circuit not accounting for additional resistances and different component values for capacitance and inductance. As a result, alterations were made to the Proteus circuit to reflect real-world conditions more closely, which lowered the inductor voltages and Q-factor, making the tests more comparable. The simulated circuits also showed a lower resonant frequency when compared with basic theory.

Contents

Declaration.....	1
Abstract.....	2
Table of Figures	4
1. Introduction.....	5
2. Experiment Setup.....	7
2.1. Proteus Setup	7
2.2. Physical RLC Circuit Setup	9
3. Results.....	10
4. Discussion	13
5. Conclusion.....	16
References.....	17
Annex A – Results Tables.....	18

Table of Figures

Figure 1 - Inductive and Capacitive Reactance in an RLC Circuit.	5
Figure 2 - RLC circuit generated in Proteus 8 Professional.	7
Figure 3 - Signal Generator module in Proteus 8 Professional.	7
Figure 4 - Oscilloscope module in Proteus 8 Professional displaying cursor measurements of input and output voltages.	8
Figure 5 - Adjusted Proteus circuit with sine wave generator for precise frequency inputs.	8
Figure 6 - RLC circuit produced on breadboard.	9
Figure 7 - Oscilloscope (top of image) measuring input and output voltages at a frequency of 20kHz (bottom of picture).	9
Figure 8 - Chart displaying the inductor voltages against frequency for a simulated and physical RLC circuit.	10
Figure 9 - Chart displaying the inductor voltage of the simulated RLC circuit including bandwidth markers.	11
Figure 10 - Chart displaying the inductor voltage of the physical RLC circuit, including bandwidth markers.	12
Figure 11 - Altered RLC circuit in Proteus, including additional resistances and measured component values.	13
Figure 12 - Graph to observe inductor voltage behaviour in different circuits. Scale adjusted for clarity purposes.	14

1. Introduction

A lab experiment investigating resonance and its effects on an RLC circuit was conducted to develop practical electronic skills and data analysis as part of the Electrical and Electronic Principles module of the Ordnance, Munitions and Explosives BSc course at the University of Wales – Trinity Saint David.

An RLC circuit is made up of a Resistor (R), an Inductor (L), and a capacitor (C). The inductor and capacitor can store an electrical charge through different methods: a capacitor stores electrical energy within an electrostatic field, whereas the inductor stores electrical energy within a magnetic field [1].

From the assignment question [2], the theoretical resonant frequency (f_R) could be calculated by finding the value where inductive reactance equals capacitive reactance. This would allow the resonant frequency to be located more accurately in the simulated and physical circuits.

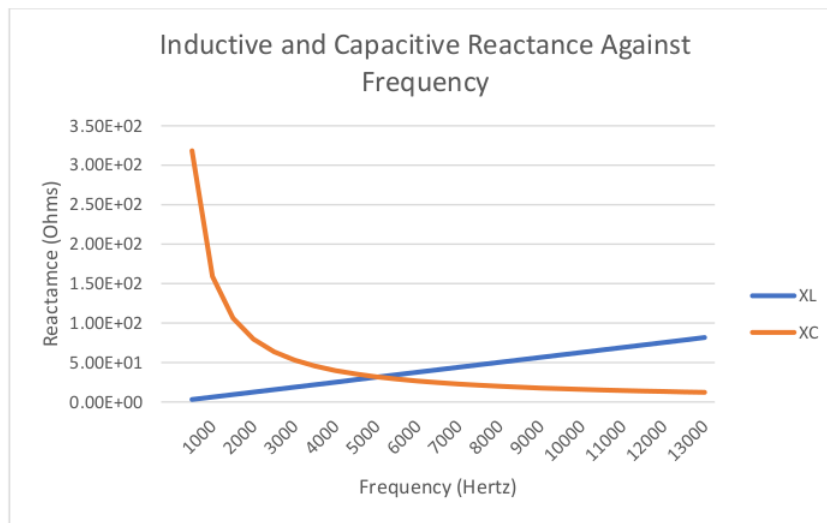


Figure 1 - Inductive and Capacitive Reactance in an RLC Circuit.

This equation can be used to find inductive reactance (X_L):

$$X_L = 2\pi fL$$

Where:

- f = Frequency (Hertz)
- L = Inductance (Henrys)

Capacitive reactance (X_C) can be calculated using the formula:

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

Where:

- C = Capacitance (Farads)

Therefore, when X_L is equal to X_C :

$$2\pi fL = \frac{1}{2\pi fC}$$

This equation can then be rearranged to find the frequency where inductive and capacitive reactance is equal, i.e., resonant frequency:

$$f_R = \frac{1}{2\pi\sqrt{LC}}$$

f_R could then be determined:

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

$$f_R = \frac{1}{2\pi\sqrt{1 \times 10^{-9}}}$$

$$f_R = \frac{1}{2\pi(31.6227766 \times 10^{-6})}$$

$$f_R = \frac{1}{198.6917653 \times 10^{-6}}$$

$$f_R = 5032.92 \text{ Hz}$$

The two reactive components cancel out at this frequency, influencing the circuit's behaviour. For example, in the parallel RLC circuit given in this case study, the combination of L and C can filter frequencies. This type of circuit has many typical applications, such as in AM radio receivers, for tuning in stations [3], and can also be found in oscillator circuits [4].

2. Experiment Setup

2.1. Proteus Setup

Figure 2 shows the setup that was used within Proteus 8 Professional. First, a circuit with a resistor ($1\text{k}\Omega$), an inductor (1mH), and a capacitor ($1\mu\text{F}$) was produced with a signal generator (far left of image) and oscilloscope (far right of image) connected.

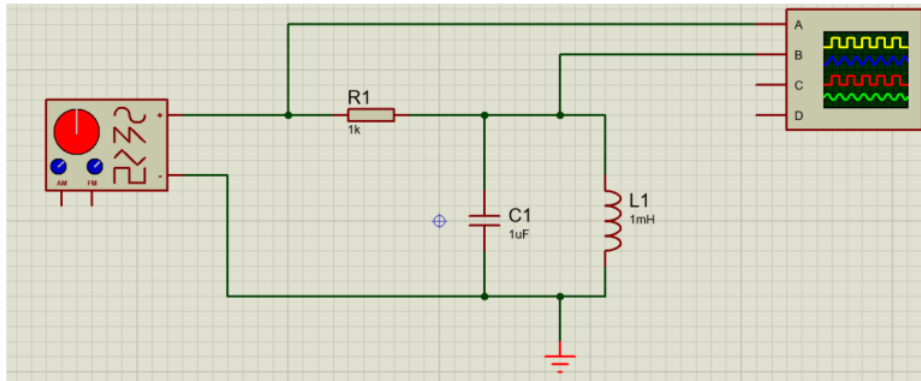


Figure 2 - RLC circuit generated in Proteus 8 Professional.

Once the component parameters were set, the simulation was run at 24 different frequencies between 100Hz and 20kHz, with an input voltage of 2V (peak-to-peak) (Figure 3). The inductor voltage (V_L) was then measured at each frequency using the cursor measurement function within the oscilloscope options (Figure 4).

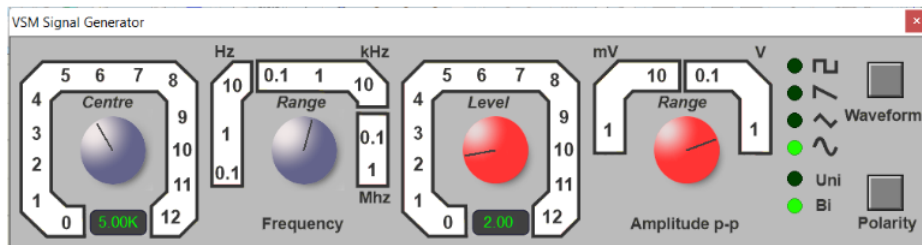


Figure 3 - Signal Generator module in Proteus 8 Professional.

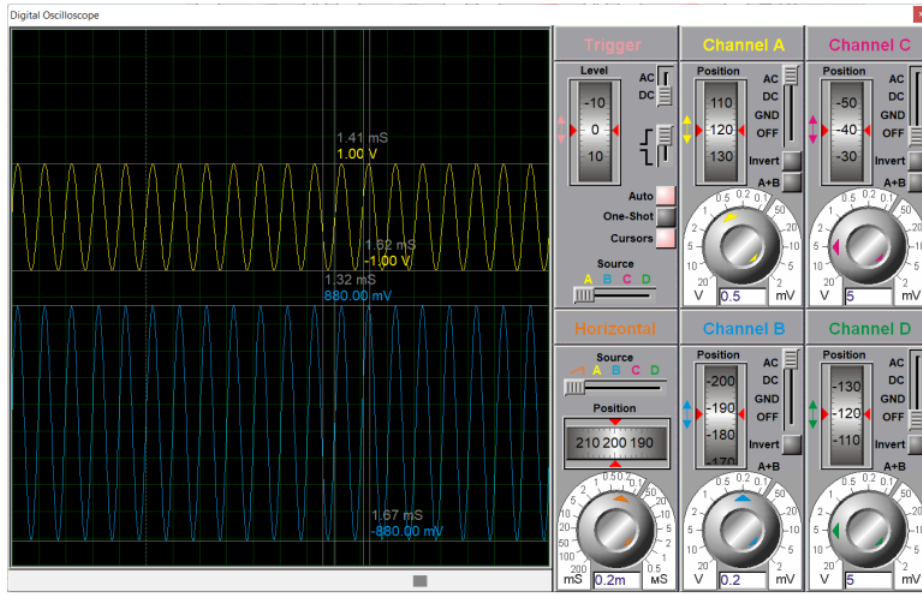


Figure 4 - Oscilloscope module in Proteus 8 Professional displaying cursor measurements of input and output voltages.

The signal generator module could not produce precise frequencies when measuring the theoretical resonant frequency. Therefore, the circuit was adjusted to replace the signal generator with a sine wave generator to get V_L measurements at a precise frequency. Furthermore, it was identified that max V_L was not present at 5032.92Hz. Consequently, to capture max V_L , the frequency was adjusted in the sine wave generator module until max V_L was obtained.

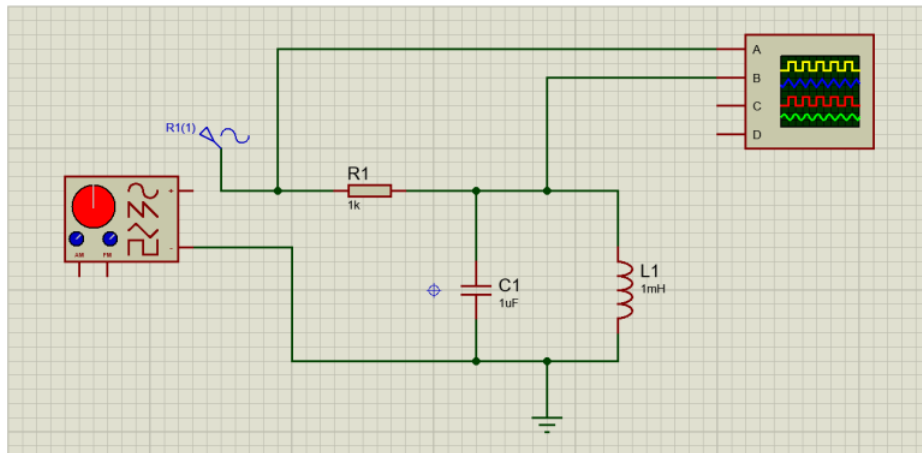


Figure 5 - Adjusted Proteus circuit with sine wave generator for precise frequency inputs.

2.2. Physical RLC Circuit Setup

An RLC circuit was produced on a breadboard (Figure 6). It was connected to a function generator to supply the input voltage and frequency, and an oscilloscope was used to measure V_L at each frequency interval (Figure 7).

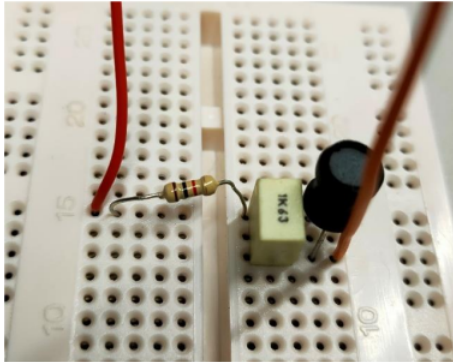


Figure 6 - RLC circuit produced on breadboard.

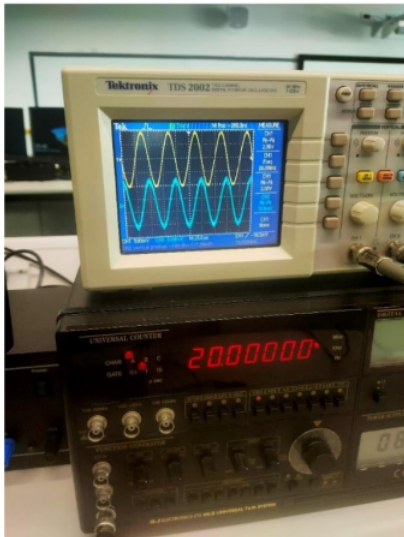


Figure 7 - Oscilloscope (top of image) measuring input and output voltages at a frequency of 20kHz (bottom of picture).

The resistor had a resistance of $1\text{k}\Omega$ and a 5% tolerance (indicated by the brown-black-red-gold banding on the resistor). The capacitor had a capacitance of $1\mu\text{F}$ and a tolerance of 10%, with a working voltage of 63V (indicated by the "1K63" code on the capacitor casing). The inductor had an inductance of 1mH.

The physical RLC circuit was tested twice, as results from the first test indicated a fault with the component as the V_L values were higher than the Proteus results throughout. Therefore, the repeated test was carried out using different components and a different function generator and oscilloscope, which produced more credible results.

3. Results

The first results gathered are from the Proteus simulation (see Table 2). A peak V_L of 1.76V was experienced at a frequency of 4961Hz. The second and third series of results (Table 3 and Table 4) are from the physical RLC circuit tests. The first experiment had a max V_L of 2.92V at a frequency of 5032.354Hz, yet as previously indicated in section 1.1, there were validity issues with this set of measurements, and therefore results have not been included for comparison at this stage. The second set of measurements revealed a max V_L of 0.3V, captured at 4961.87Hz, 5000.488Hz, and 5032.646Hz. The comparison of V_L lines for the Proteus experiment and the second physical experiment can be seen in Figure 8.

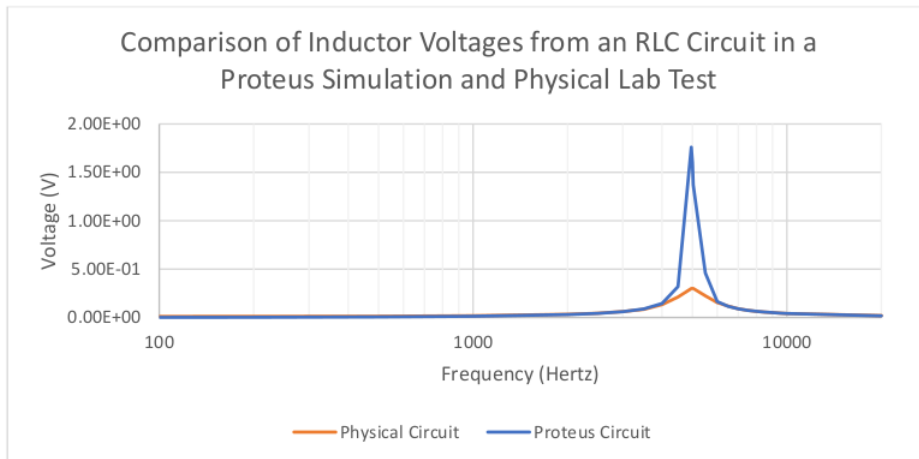


Figure 8 - Chart displaying the inductor voltages against frequency for a simulated and physical RLC circuit.

The Q-Factor – which is the current magnification factor within a parallel RLC circuit and the voltage magnification factor within a series RLC circuit [5] [6] [7] – was then derived for both circuits using the results data in Microsoft Excel (Figure 9 and Figure 10). The low band edge (f_L) and high band edge (f_H) were found where the maximum power decreased by half (at around 70.7% of the peak V_L), either side of f_R . With this data, the bandwidth (BW) could be calculated for each circuit using the formula: [6]

$$BW = F_H - F_L$$

This equation could then find the Q-Factor:

$$Q = \frac{F_R}{BW}$$

Therefore, for the Proteus circuit:

$$BW = 5100 - 4795$$

$$BW = 305\text{Hz}$$

$$Q = \frac{4961}{305}$$

$$Q = 16.266$$

And for the physical circuit:

$$BW = 5585 - 4500$$

$$BW = 1085\text{Hz}$$

$$Q = \frac{5032}{1085}$$

$$Q = 4.638$$

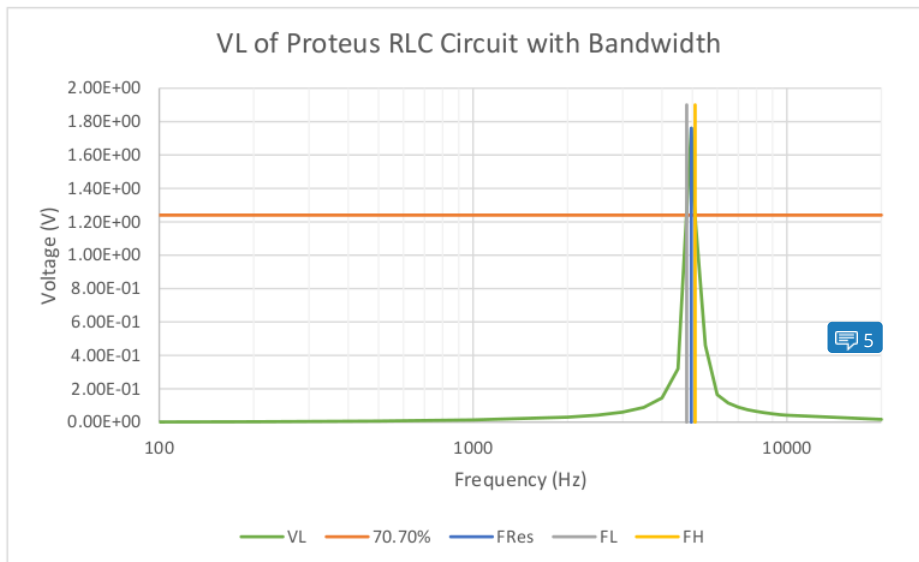


Figure 9 - Chart displaying the inductor voltage of the simulated RLC circuit including bandwidth markers.

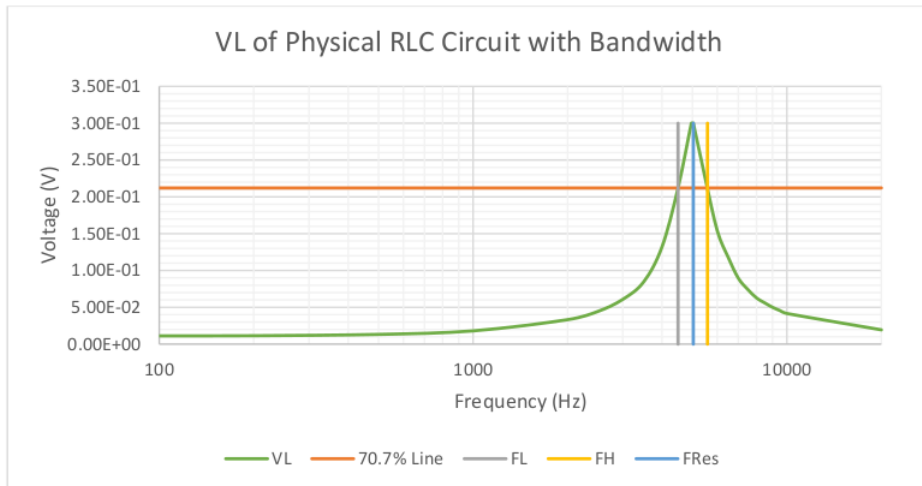


Figure 10 - Chart displaying the inductor voltage of the physical RLC circuit, including bandwidth markers.

4. Discussion

There is a considerable difference in the results gathered between the Proteus and the physical circuits. Namely, the Proteus simulation displayed a greater V_L by 1.46V, and its Q-factor was over three times higher than that of the equivalent physical RLC circuit. The main reason for this difference is that Proteus simulates the circuit in a perfect world – in which it does not account for additional factors that are present in reality. For example, the only resistance accounted for in the Proteus circuit came from the resistor. However, in the real circuit, there were additional resistances introduced by the function generator, the inductor, and the internal resistance of the wires. Adding these additional resistances to the RLC circuit in Proteus should mean that the peak inductor voltage and Q-factor will be lower.

Moreover, the components used in the real circuit have tolerances that were not accounted for in Proteus. As mentioned in Section 1.1, the resistor had a tolerance of 5%, and the capacitor had a tolerance of 10%. Example components were measured after the lab tests were conducted to collect actual values for each (Table 1).

Table 1 - Measured component values used in altered Proteus circuit

Component	Values
Resistor	979 Ω
Capacitor	1.064 μ F
Inductor	0.994mH with an internal resistance of 7.32 Ω

These values were put back into the Proteus circuit (Figure 11), and the test was re-run to observe any changes in the results (Figure 12).

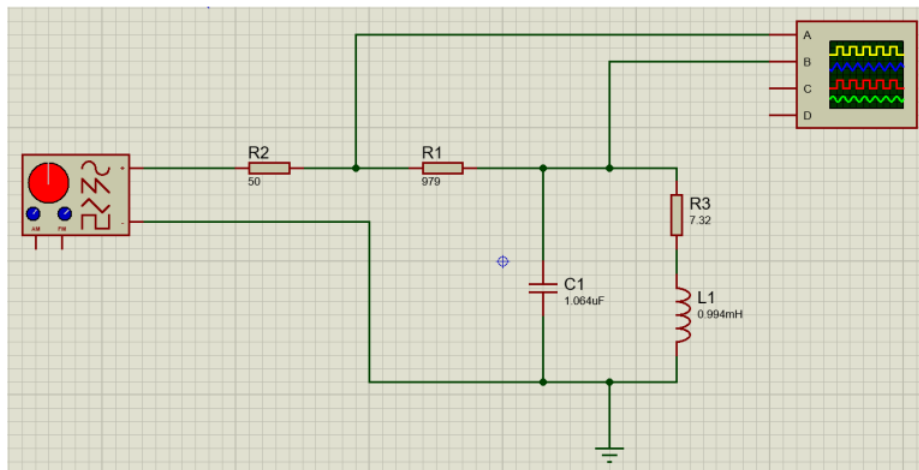


Figure 11 - Altered RLC circuit in Proteus, including additional resistances and measured component values.

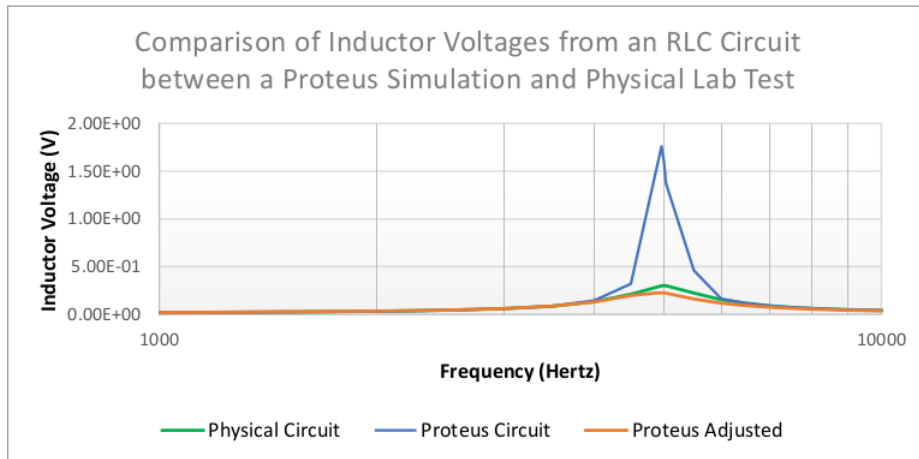


Figure 12 - Graph to observe inductor voltage behaviour in different circuits. Scale adjusted for clarity purposes.

As demonstrated in Figure 12, the addition of measured component values and unaccounted resistances has changed the V_L line significantly. The peak V_L was measured at 225mV at a frequency of 5000Hz. The bandwidth was 1300Hz, which resulted in a Q-factor of 3.846. Therefore, the Q-factor was lower than the physical RLC circuit – let alone the original Proteus simulation. This finding could be accounted for by the measured components being different from those used in the physical circuit. The component tolerances could make up for the 17.08% difference in Q-factor between the adjusted Proteus simulation and the physical RLC circuit.

Another consideration for the Q-factor difference could be the method of determining bandwidth from the data. The f_L and f_H were gathered visually by locating where the V_L line intersected the 70.7% line on either side of the resonant frequency, introducing human error into the result, which could have resulted in the altered Proteus simulation being lower than the physical circuit. Alternatively, the Q-factor for the real RLC circuit could have been overestimated due to the same reasoning.

A further observation from the results is that the resonant frequencies slightly differed between all experiment iterations. The two physical tests demonstrated V_L s that were at or near the peak across a range of two different measurements: ~4961Hz to ~5032Hz. The altered Proteus circuit also displayed peak V_L at a range of frequencies but was slightly lower at 4890Hz to 5000Hz. Seeing peak V_L across a more extensive frequency range is expected at a lower Q-factor because the circuit's bandwidth is wider, meaning the peak V_L effectively plateaus for longer before decreasing. Max V_L could have been more accurately obtained by increasing the frequency intervals for taking measurements. This also would have changed the profile of the V_L lines in Figure 8, Figure 9, Figure 10 and Figure 12 to have more rounded peaks rather than the sharp peaks presented. The conventional rounded peak can be seen across various studies and other resources [8] [9].

Similarly, the first Proteus simulation only displayed max V_L at a frequency of 4961Hz. This adds credence to the previous statement as the Q-factor for this circuit was much higher, indicative of a sharper peak. However, it is unclear why f_r is not closer to the theoretical f_r calculated in Section 1. One possibility is that the circuit design in Proteus is affecting the measurements; however, it is not clear if anything has been misdesigned.

A general point of discussion surrounding the results from the physical RLC experiments is that the function generator was challenging to set accurate frequencies and the oscilloscope readings were also difficult to measure. The measured frequency intervals seen in Table 3Table 4 were intended to match the intervals in the Proteus simulation to be directly comparable. Due to the sensitivity of the function generator, frequencies were set as close as possible without spending too much time on each reading. However, this does not affect the V_L line or any other results. On the other hand, the oscilloscope readings constantly changed, making it difficult to take V_L measurements. This could have affected the results captured, particularly around the resonant frequency, as data could have been recorded at the bottom or top of the range for a given frequency. Therefore, the peak V_L and resonant frequency could be inaccurate for the circuits with lower Q-factors.

5. Conclusion

In conclusion, it was initially found that the RLC circuit designed in Proteus had a higher Q-factor than the physical RLC circuit and a higher peak V_L . However, upon investigation, it was discovered that the Proteus simulation had not accounted for additional resistances and component tolerances. Therefore, once the Proteus circuit had been adjusted to consider these additional factors, the results showed a lower Q-factor than the physical circuit and a lower peak V_L .

Furthermore, it was found that the resonant frequency was slightly different across all iterations of the lab study; however, the physical RLC circuits that were tested were closer to the resonant frequency calculated from basic theory, whilst the Proteus circuits demonstrated a slightly lower resonant frequency. Finally, the behaviour of V_L around the resonant frequency dependant on Q-factor was also observed as a peak V_L was more difficult to obtain with a lower Q-factor, demonstrated by the max V_L being acquired across a range of frequencies, whilst a higher Q-factor was easier to measure.

References

- [1] S. Mosey, "Electrical Electronic Principles L4," UWTSD, Swansea, 2021.
- [2] S. Mosey, "Level 4 Assessment Specification - Electrical & Electronic Principles," University of Wales - Trinity Saint David, Swansea, 2021.
- [3] P. Horowitz and W. Hill, "1.8 Putting it all together - an AM Radio," in *The Art of Electronics*, Third ed., New York, Cambridge University Press, 2021, pp. 55-56.
- [4] D. Youmbi Fouego, E. D. Dongmo and P. Wofo, "Powering RLC Load by an array of self-sustained oscillators," *Chaos, Solitons and Fractals*, vol. 104, pp. 222-227, 2017.
- [5] J. Bird, "18.6 Parallel Resonance and Q-factor," in *Bird's Electrical and Electronic Principles and Technology*, 7 ed., New York, Routledge, 2022, pp. 367-368.
- [6] M. Stephen, "Q Factor," UWTSD, Swansea, 2016-17.
- [7] J. Bird, "Q-factor," in *Bird's Electrical and Electronic Principles and Technology*, New York, Routledge, 2022, pp. 346-347.
- [8] K. L. Cristiano, D. A. Triana, R. Ortiz and A. F. Estupiñán, "Teaching Forced Damped Oscillator Using RLC Circuit Through Inverse Modeling," *arXiv:1908.01891v2 [physics.ed-ph]*, 8 August 2019.
- [9] P. Horowitz and W. Hill, "1.7.14 Resonant Circuits," in *The Art of Electronics*, Third ed., New York, Cambridge University Press, 2021, pp. 52-54.

Annex A – Results Tables

Table 2 – Results from original RLC circuit in Proteus. * Resonant frequency measured for this circuit.

Frequency (Hertz)	Voltage Input (V_{in}) (Volts)	Inductor Voltage (V_L) (Volts)
100	2	1.30E-03
200	2	2.60E-03
500	2	6.40E-03
1000	2	1.33E-02
2000	2	3.03E-02
2500	2	4.25E-02
3000	2	6.00E-02
3500	2	8.85E-02
4000	2	1.45E-01
4500	2	3.20E-01
4961*	2	1.76E+00
5000	2	1.60E+00
5032.92	2	1.37E+00
5500	2	4.60E-01
6000	2	1.65E-01
6500	2	1.15E-01
7000	2	9.00E-02
7500	2	7.40E-02
8000	2	6.40E-02
8500	2	5.60E-02
9000	2	5.00E-02
9500	2	4.50E-02
10000	2	4.15E-02
20000	2	1.68E-02

Table 3 – Results from physical RLC circuit (test one) - * Resonant frequency measured for this circuit

Frequency (Hertz)	Input Voltage (V_{in}) (Volts)	Inductor Voltage (V_L) (Volts)
100.14	2.04	1.14E-01
199.96	2.04	1.15E-01
500.13	2.04	1.27E-01
1000.42	2.04	1.84E-01
2000.15	2.04	3.36E-01
2500.951	2.04	4.48E-01
3000.145	2.04	6.04E-01
3500.231	2.04	8.64E-01
4000.08	2.04	1.26E+00
4500.14	2.04	2.08E+00
4961.574	2.04	2.88E+00
5000.248	2.04	2.90E+00
5032.354*	2.04	2.92E+00
5500.71	2.04	2.28E+00
5999.889	2.04	1.56E+00
6499.898	2.04	1.18E+00
6999.717	2.04	9.12E-01
7500.789	2.04	7.68E-01
8000.92	2.04	6.48E-01
8499.694	2.04	5.68E-01
8999.294	2.04	5.12E-01
9500.211	2.04	4.60E-01
10004.39	2.04	4.24E-01
20006.71	2.04	1.84E-01

Table 4 – Results from physical RLC circuit (test two) - * Resonant frequency measured for this circuit

Frequency (Hertz)	Input Voltage (V_{in}) (Volts)	Inductor Voltage (V_L) (Volts)
100.0144	2	1.12E-02
200.2771	2	1.14E-02
500.124	2	1.32E-02
1000.859	2	1.80E-02
2000.797	2	3.32E-02
2499.4	2	4.44E-02
3000.312	2	6.08E-02
3500.867	2	8.48E-02
3999.912	2	1.32E-01
4500.471	2.04	2.12E-01
4961.87*	2.04	3.00E-01
5000.488*	2.04	3.00E-01
5032.646*	2.06	3.00E-01
5500.078	2.02	2.24E-01
6000.254	2	1.54E-01
6499.898	2	1.18E-01
7000.454	2	8.96E-02
7500.722	2	7.44E-02
7999.963	1.98	6.28E-02
8500.421	1.98	5.60E-02
9000.044	1.96	5.00E-02
9500.356	1.96	4.56E-02
10001.1	1.94	4.16E-02
20000	2	1.94E-02

Table 5 – Results from adjusted RLC circuit in Proteus (with measured component values and additional resistances) - * Resonant frequency measured for this circuit

Frequency (Hertz)	Input Voltage (V_{in}) (Volts)	Inductor Voltage (V_L) (Volts)
100	2	1.43E-02
200	2	1.43E-02
500	2	1.55E-02
1000	2	1.95E-02
2000	2	3.38E-02
2500	2	4.50E-02
3000	2	6.15E-02
3500	2	8.70E-02
4000	2	1.30E-01
4500	2	1.98E-01
4890*	2	2.25E-01
5000*	2	2.25E-01
5032.92	2	2.23E-01
5500	2	1.61E-01
6000	2	1.17E-01
6500	2	9.20E-02
7000	2	7.50E-02
7500	2	6.30E-02
8000	2	5.50E-02
8500	2	4.90E-02
9000	2	4.40E-02
9500	2	4.05E-02
10000	2	3.70E-02
20000	2	1.53E-02

Electrical and Electronic Principles Assignment JLE 2011912

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

75/100

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10



Comment 1

The signal generator module in proteus is very precise as it is software. Do you mean it could not produce the exact frequency you wanted?

PAGE 11



Comment 2

I suspect the instrument was set wrong.

PAGE 12



Comment 3

I think an input attenuation setting was wrong on the oscilloscope - set to X1 instead of X10.



Comment 4

Cutoff frequencies?

PAGE 13



Comment 5

May have been better to change the horizontal axis limits to zoom in on the area of interest.

PAGE 14

PAGE 15

PAGE 16

PAGE 17



Comment 6

You could take multiple readings and average - even include error bars to show significance of your data, this would mitigate this issue.

PAGE 18



Comment 7

You could have found the resonant frequency practically by adjusting the frequency until a maxima is observed on the oscilloscope.

PAGE 19



Comment 8

Name is the wrong way around. Should be "Mosey, S."



Comment 9

Excellent set of references.

PAGE 20

PAGE 21

PAGE 22

GRADING FORM: SMU GENERIC_SMOSEY

JOSH LUKE EVANS**75.15****ENGAGEMENT WITH LITERATURE***including reading, referencing, academic conventions and academic honesty*

Outstanding knowledge of research-informed literature embedded in the work. Outstanding selection of relevant and credible sources. High-level referencing skills consistently and professionally applied.

4.5**KNOWLEDGE & UNDERSTANDING***Knowledge of the basic underlying concepts and principles of a subject.*

Highly detailed knowledge and understanding of the main theories/concepts, and a critical awareness of the ambiguities and limitations of knowledge.

24**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.



Thoroughly logical work, supported by evaluated evidence. High quality analysis, developed independently Ability to investigate contradictory information and identify reasons for contradictions. Strong, persuasive, conclusions.

22.5

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



A very good application of a range of methods, materials, tools and/or techniques. Evidence of some creativity.

20.4

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 professionally and, confidently in a suitable format. Work is coherent, very fluent and is presented professionally.

3.75