

Assignment 1 electronics

by Joshua Warren Ede

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RLC circuits and resonant frequency: An investigation

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Abstract

This report details an experiment examining the frequency response of an LC or tank circuit. The experiment contains two parts; a real circuit built from simple components in a classroom environment and a simulated circuit created using Proteus 8 professional. Both the real and simulated experiments show that the peak voltage output, the indicator for the frequency response, is highest either on or very close to the resonant frequency, but there is a marked difference between the two peak values with the simulation providing a response an order of magnitude greater than the real components. This report will then discuss these results explaining using conventional electronics theory as to how this difference could occur. Furthermore, as part of the discussion the simulation is rerun using values for the components closer to those observed in the real world as opposed to their stated values e.g. adjusting the resistance of the resistors from 1,000ohms to 979ohms, noting that the simulated peak this time is much closer to that observed in the real-world experiment.

1) Introduction

The experiment comprised of assembling a circuit using an inductor, a capacitor, a resistor, a power source and an oscilloscope for measuring. The basic components of the circuit, e.g. the capacitor, inductor and resistor and the arrangement of the inductor and capacitor conform with the design of a RLC circuit, otherwise known as tank or tuned, circuits [1]. One of the first uses of the RLC circuit was as a tuner for radio devices and similarly with the onset of television the RLC circuit continued to be utilised in this fashion albeit for the newer device [2]. However, as the RLC circuit is essentially a way of selecting certain frequencies, it has wide-scale applications even in advanced electronics such as in radio telescopic observatories [3].

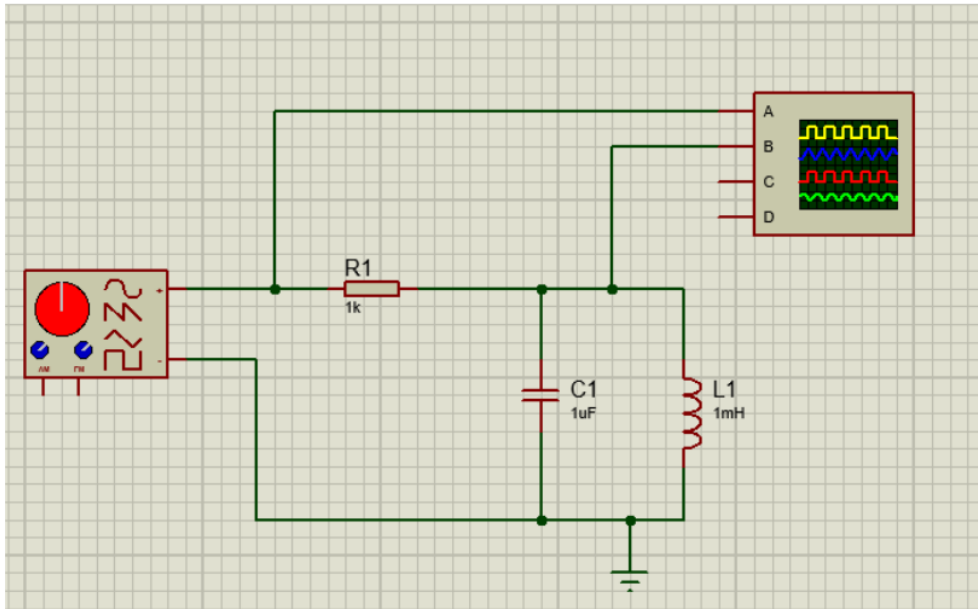


Figure 1: RLC, tank or tuned, circuit, taken from Proteus.

The ability to select particular frequencies using the RLC circuit is due to capacitive and inductive reactance [4]. To better understand this a definition of reactance should be given:

Reactance is “the opposition to the flow of alternating current” [5].

The formula for capacitive reactance is:

$$X_C = \frac{1}{2\pi f C} \text{ Eqn. No.}$$

[6, p. 287]

Where X_C is capacitive reactance in Ohms, C is the capacitance in Farads and f is the frequency in Hertz. The formula shows that as capacitance of the capacitor increases then capacitive reactance decreases. However, more importantly for the RLC circuit is the fact that as frequency increases the capacitive reactance also decreases [3, p. 42]. Relating this to the definition, this means that as the frequency increases the opposition to the flow of current decreases. In this way high level frequencies are able to pass through the circuit and low-level frequencies are blocked [3].

The formula for inductive reactance is:

$$X_L = 2\pi fL$$

[6, p. 283]

Where X_L is inductive reactance in Ohms, L is the impedance of the inductor in Henrys and f is the frequency in Hertz. For an inductor therefore, if the impedance increases then the inductive reactance also increases and more importantly for the RLC circuit if the frequency increases then the inductive reactance also increases [3, p. 44]. Relating this to the definition, if the frequency increases the opposition to the flow of current also increases. In this way low level frequencies are able to pass through the circuit, but high-level frequencies are blocked [3].

By taking the two formulae together it is possible to see that by changing the frequency it is possible to get capacitive and inductive reactance to be equal.

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

Rearranged:

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

[3, p. 53]

Where f_0 denotes resonant frequency in Hertz.

In a parallel RLC circuit it is also important to consider impedance. Impedance can be defined as the overall resistance to the flow of a current in a circuit including both reactance and resistance [7]. The impedance of the parallel RLC circuit will approach infinity at resonance [3]. This is because the total impedance for a parallel LC circuit could be worked out as:

$$Z_{LC} = \frac{j}{\left(\frac{1}{2\pi fL}\right) - 2\pi fC}$$

[3, p. 52]

This makes sense logically as by the definitions of both inductors and capacitors their reactance is dependent on frequency, but in opposite directions. At this point the current being drawn from the power source is only effected by the resistor in the circuit making it very small and because the impedance of the inductor and capacitor combined in parallel is infinite it effectively creates an open circuit for the voltage, meaning that at resonant frequency the voltage should begin to approach a similar level to that of the generator source [3] [8]. Therefore, in the parallel RLC circuit the only frequencies that can cross the circuit are those at resonance as all others are blocked by either capacitive or inductive reactance. In this way the parallel RLC circuit acts as a band-pass filter [3]. Furthermore, to test whether the above statement is true the resonant frequency could be worked out mathematically for the RLC circuit and then the voltage output can be measured at this point. If the above theory is correct there should be a significant increase in the voltage output at resonance where the circuit is effectively open [3] [8].

This report will now proceed to test the theory based on the equations and assumptions above using the following circuit:

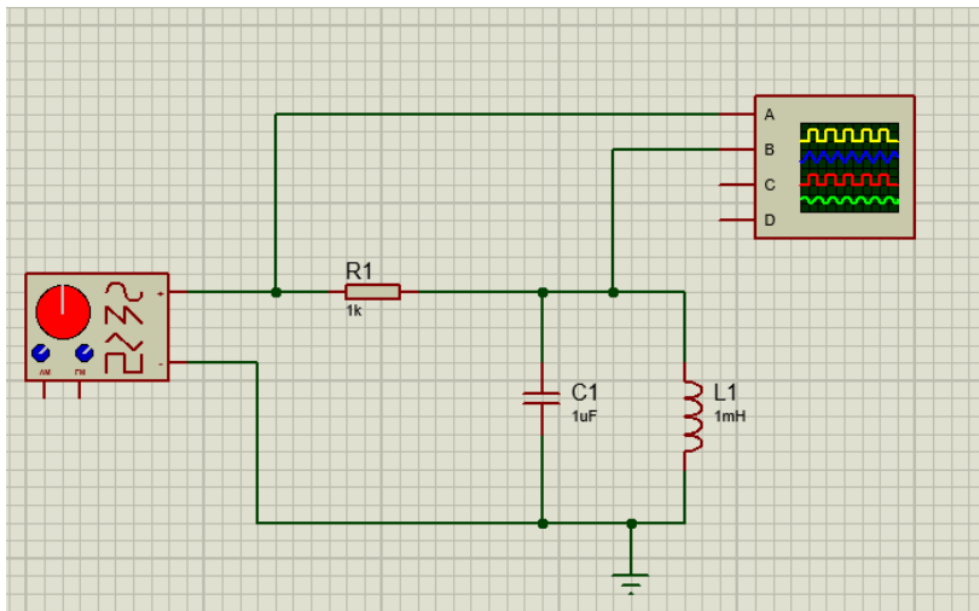


Figure 2: Parallel RLC circuit as setup for experiment with the resistor at 1000 ohms, the capacitance at 1 microfarad and the inductance at 1 millihenry, the voltage is supplied by the generator to the left and an oscilloscope is on the right to observe changes in wave formation.

Following the experimental design and results there will be a discussion noting any discrepancies or observations made from the results, with a conclusion offered at the end of the report.

2) Experimental design

The experimental design was governed by the parameters set out as part of research brief, namely that the peak-to-peak voltage should be at 2volts at the frequency of 100Hz and that this should be measured across a range of frequencies in both the simulated and real parallel RLC circuit. The range provided in the brief was between 100 and 20000 Hz and the circuit was laid out according to the diagram, and with values for the components, illustrated in figure 3.

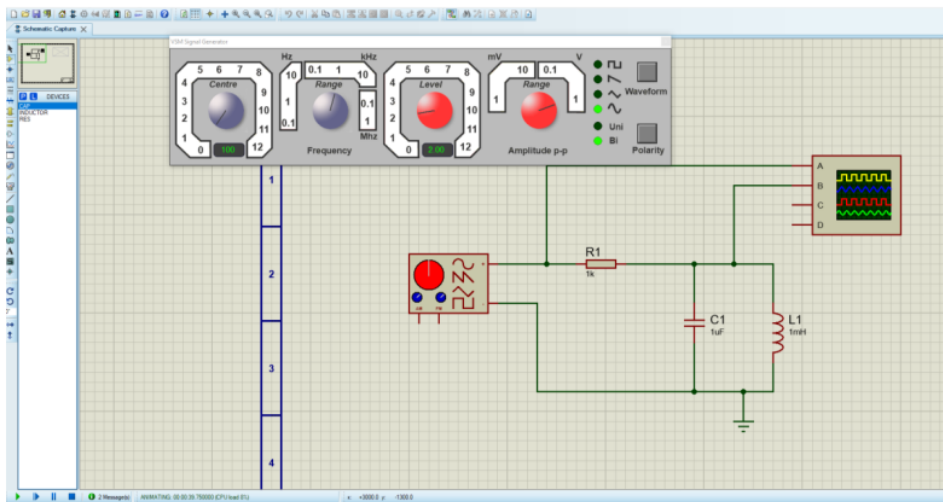


Figure 3: Screenshot showing initial values used in the experimental setup.

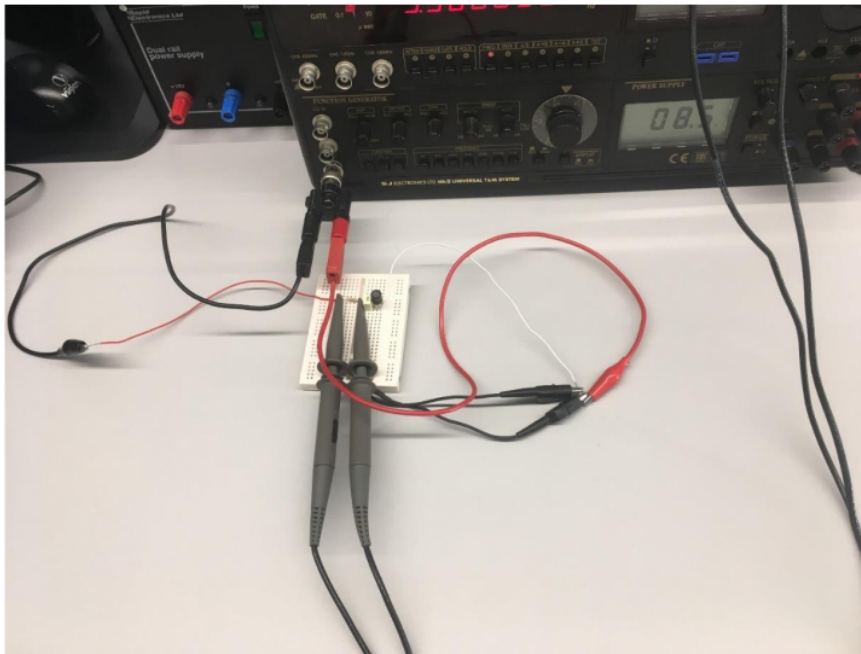


Figure 4: Picture showing the experimental setup using real components.

To determine a suitable scale for plotting results a choice was made between the time required to take results both in the simulation and in the real experiment and to provide a meaningful discussion about the resonant frequency. It was initially thought that by doubling the frequency between 100-8000Hz and then taking a reading at 10000 and 20000 Hz that the results should indicate a trend that followed the theoretical principles outlined in the introduction. However, it was revealed through the simulated experiment that this did not provide the granularity to show the resonant frequency so instead this was worked out mathematically using the formula:

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

[3, p. 53]

Taking L to be 1mH and C to be 1 μ F the resonant frequency was derived to be 5032.92121Hz, thus the scale for taking measurements was refined so that the results would provide a clearer conclusion. The results of these measurements were then recorded in excel and the experiment was repeated in the real-world using components provided in the laboratory, see figure 4 for setup. To take a point at the resonance frequency itself the circuit was modified in order to input a sine generator that could be set to the exact frequency provided by the equation. See the diagram below for the placement and modification of the circuit in proteus.

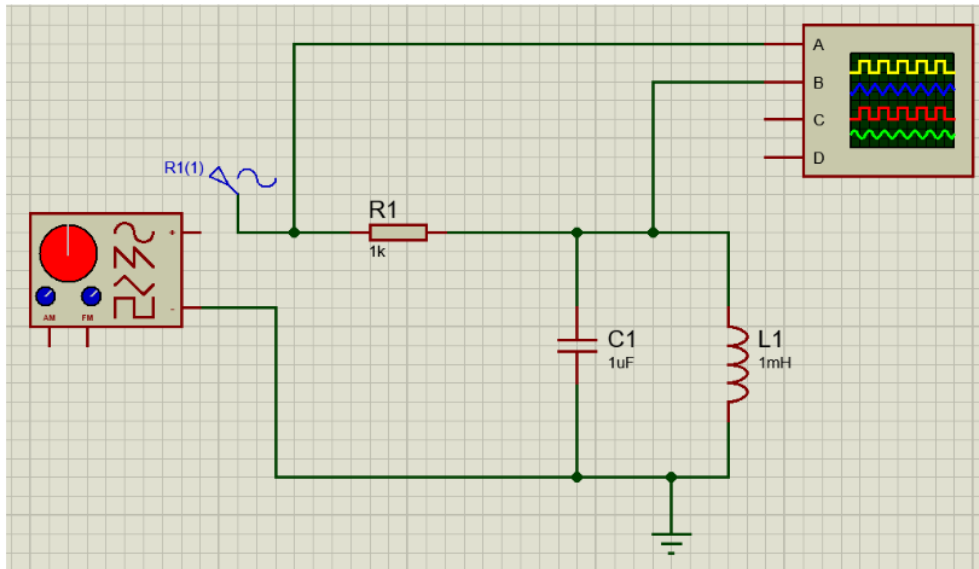


Figure 5: Screenshot of the circuit in proteus with the sine generator, sine generator frequency was set to 5032.92121Hz to represent the resonant frequency.

3) Results

The results from both the simulated and real-world experiments are shown by the graphs below. The full table of results is included in Annex A for reference. The results are shown on graphs created in excel.

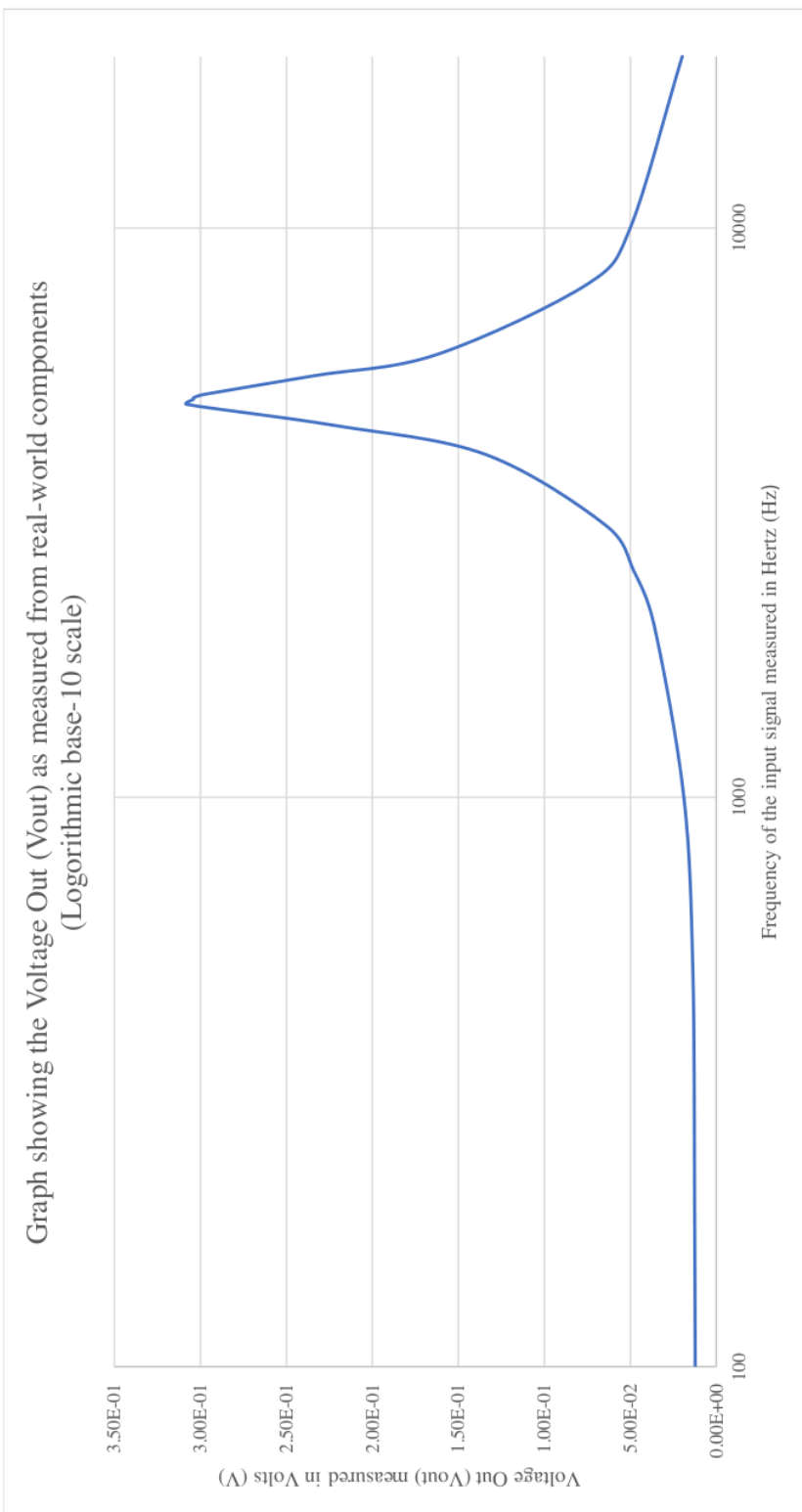


Figure 6: Results of Voltage Out measured using real world components and plotted in excel in a logarithmic scale.

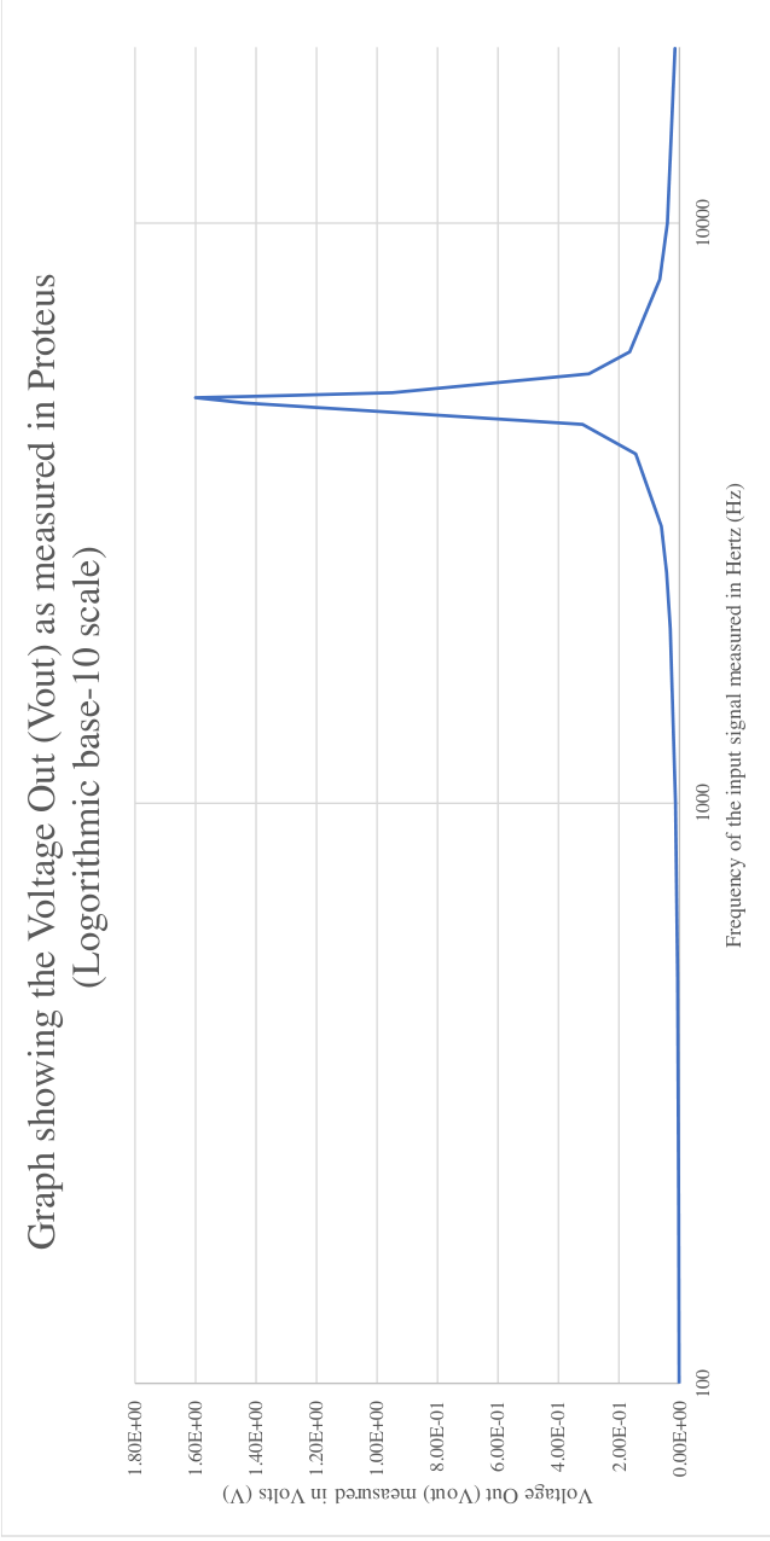


Figure 7: Results of Voltage measured using proteus circuit simulation software and plotted in excel with a logarithmic scale.

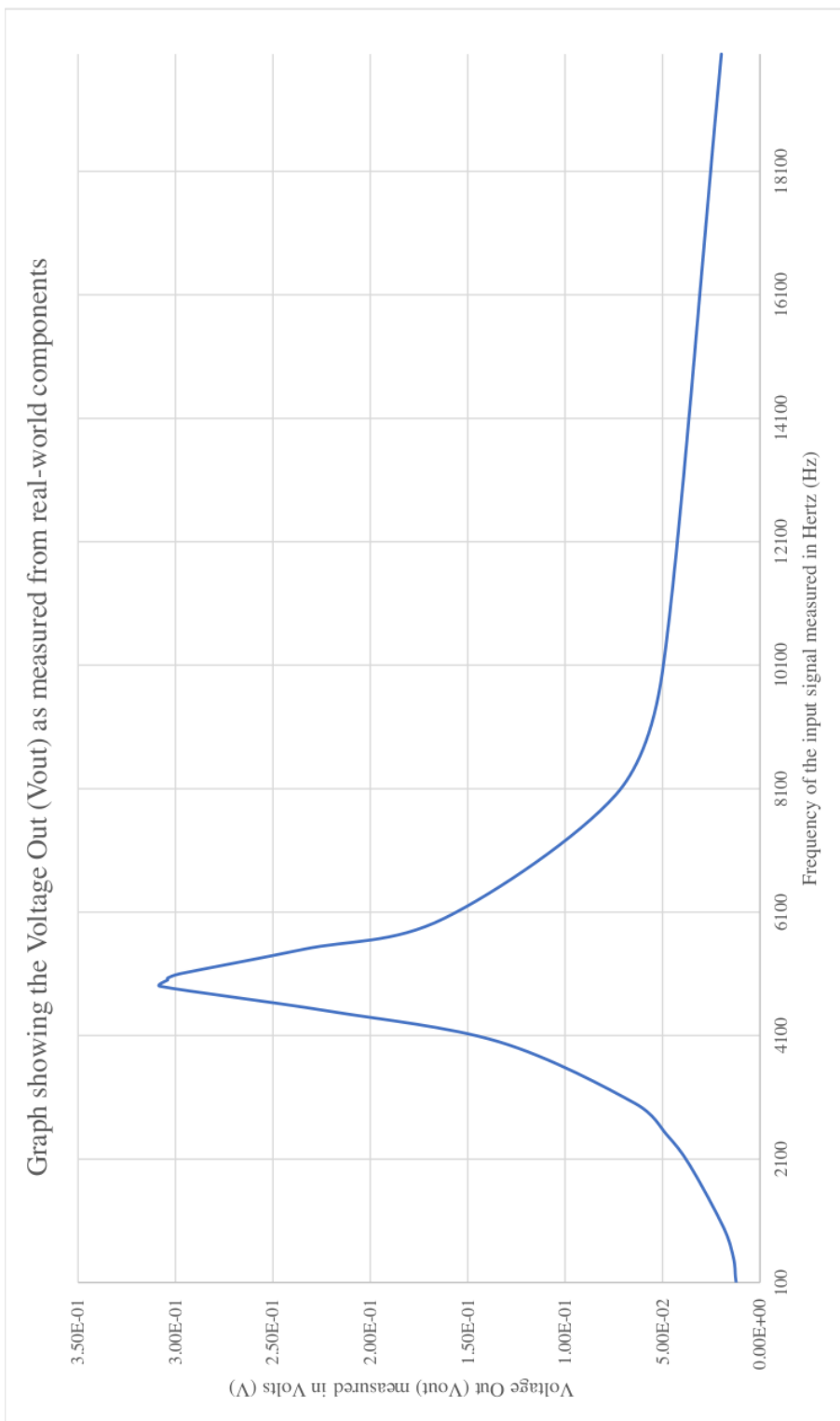


Figure 8: Graph showing the voltage out across the range of frequencies specified in the assignment brief.

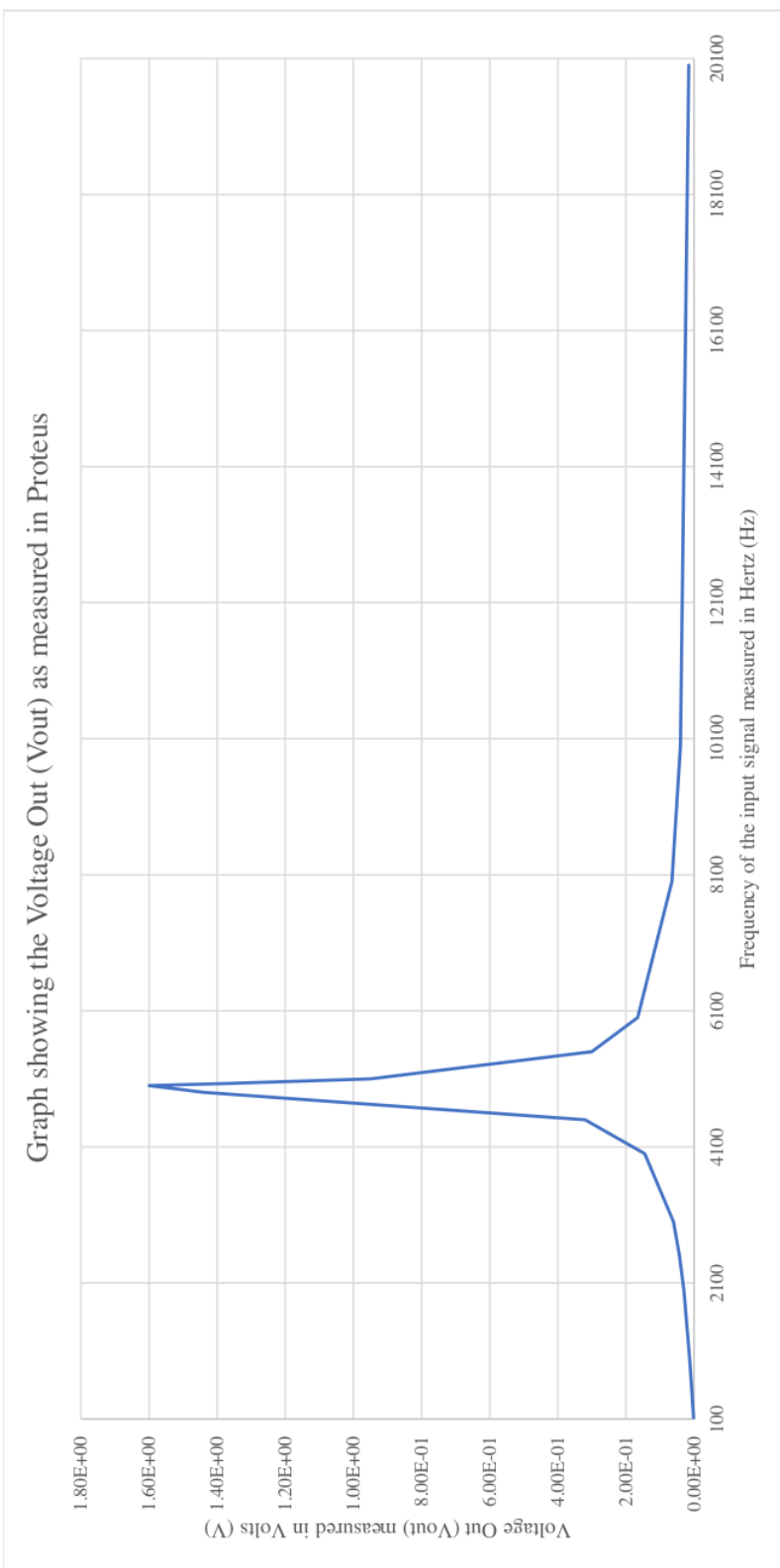


Figure 9: Graph showing the voltage out across the range of frequencies specified in the assignment brief.

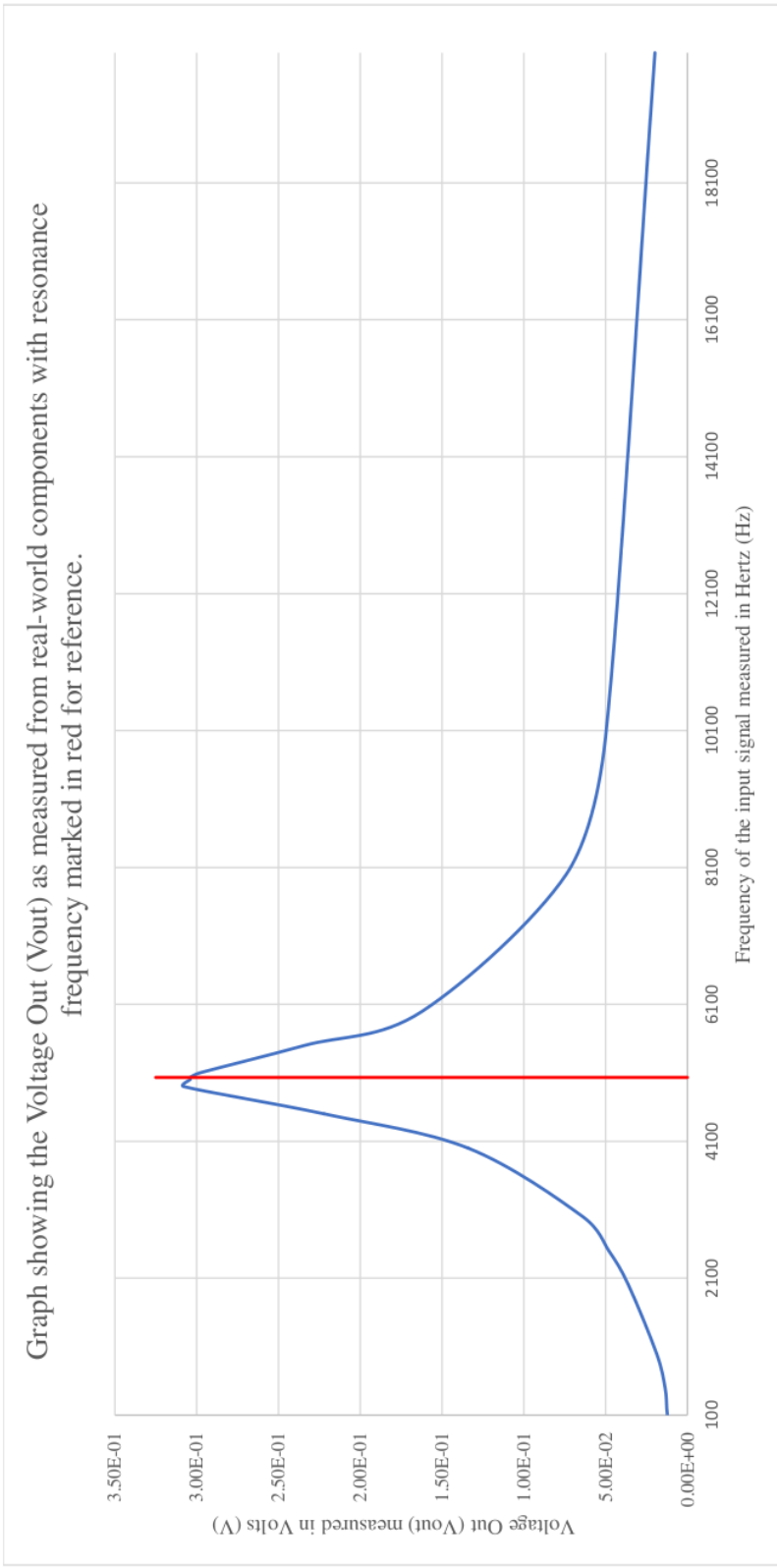


Figure 10: Graph showing the voltage out (Vout) for real world components with resonance frequency marked.

Graph showing the Voltage Out (Vout) as measured in Proteus with resonance frequency marked in red for reference.

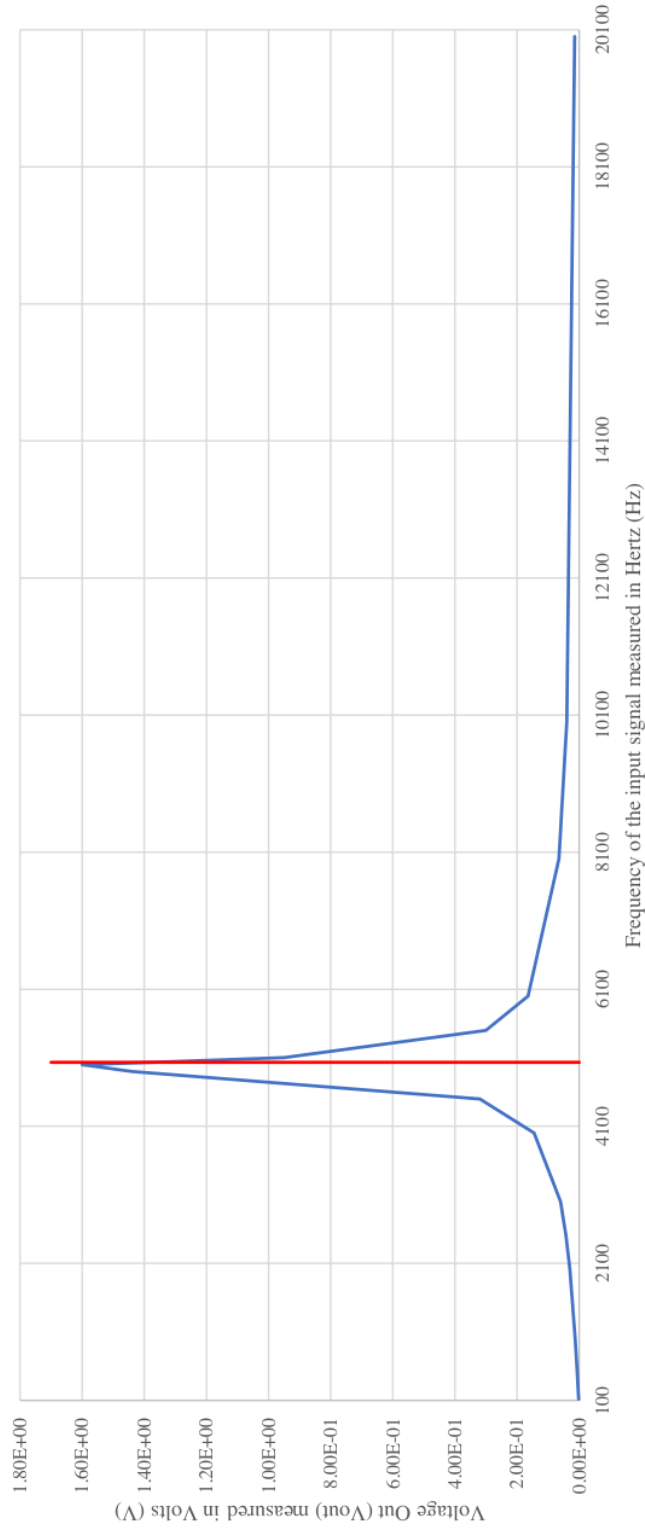


Figure 11: Graph showing the voltage out (Vout) as measured in proteus with resonance frequency marked.

The results clearly support the theory established by the equations from the introduction, however there are some interesting observations, and these shall be outlined further in the discussion.

4) Discussion

The figures shown in the results and the table included in Annex A all appear to confirm that the voltage out at resonance frequency approaches the generated voltage source as expected from the theory. However, there are discrepancies between the values as indicated in the table below. To explain this there needs to be a discussion of Q-factor, the real components and finally open circuit voltage.

Table 1: Table showing the voltages in and out for both real-world components and proteus at resonance.

Voltage at source (real)	Voltage at source (proteus)	Voltage out at resonance (real)	Voltage out at resonance (proteus)
2.18V	2.00V	0.304V	1.38V



Therefore, there must some discussion as to how these differences occur.

4.1) Q-factor

In the results section it is possible to see that the peak of the voltage out relative to the voltage in for both the real-world components and for proteus conform to the result expected from the theory, see figure 10. for the real components, and figure 11. for proteus. However, in the graph shown in figure 12. the peaks and gradients for the slopes for the results are quite different between the real-world components and the results taken in simulation. The differences between the values can be partially explained by Q-factor. Q-factor is essentially a way of measuring the peak in the response and is worked out as the peak frequency divided by the width of the band at -3dB, which equates the half power of that frequency [3] [7].

$$Q = f_0 / \Delta f$$

[3, p. 53]

Where f_0 is equal to the resonant frequency and Δf is the difference between the frequency taken at 7.707 or -3dB [5] [7]. The Q factor for both the real and proteus simulated circuits is shown in table 2.

Table 2: Table showing the different Q Factors obtained for real world components and the proteus simulation, note Q factor has no units as it is a ratio.

Q Factor for real world components	Q factor for simulated components
4.453913	16.94915

Whilst Q factor explains the difference in the two results it does not explain why proteus and the real-world should differ in this way. In order to do with it is necessary to consider some of the assumptions made during the introduction and experimental design.

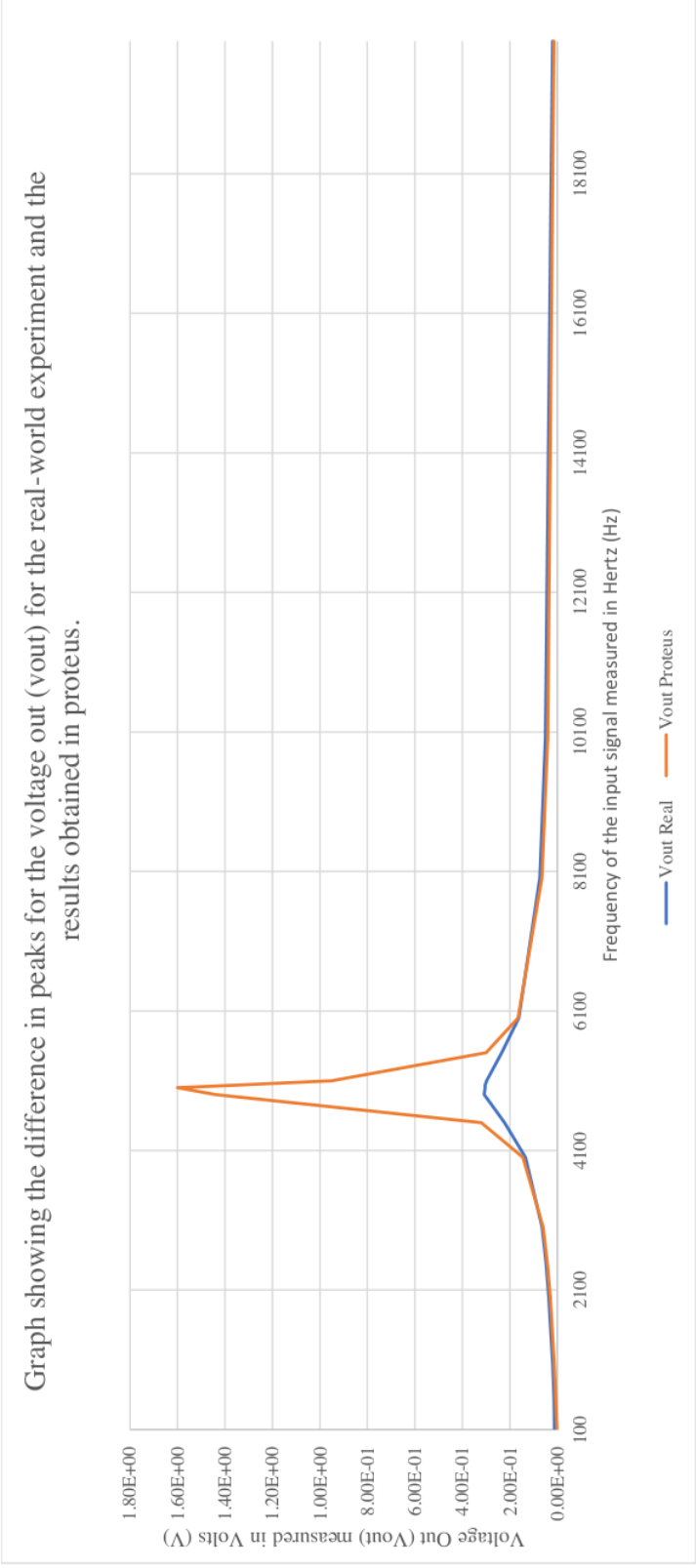


Figure 12: Graph showing the difference in peak heights for voltage out between the real-world components and proteus.

4.2) Assumptions and real-world component values.

In the introduction it was noted that the capacitive reactance in the capacitor and the inductive reactance in the inductor are related to frequency.

Formula for capacitive reactance:

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

[6, p. 287]

Formula for inductive reactance:

$$X_L = 2\pi fL$$

[6, p. 283]

Furthermore, in both cases these values rely on the capacitance shown by C, for the capacitor and the inductance shown by L for the inductor. These values are measured in Farads and Henrys respectively. In the experimental design the values given for the components used were 1mH for the inductor and 1 μ F for the capacitor. In the real-world experiment although these were the stated values on the side of the components, in actuality none of the components used were fully at the values given on the side of the component. The values obtained for this discussion were provided after the initial experiment design and are listed at [10].

For the inductor in the real-world the number of turns of the coil of wire within component, the spacing of those turns, the resistance of wire within and the core used all effect the inductance even though these differences may overall only offer a small reduction [6] [11]. The actual value for the inductor used, once checked was 0.994mH. Similarly, the construction of the capacitor will account for small differences between the component values and the measured results. Additionally, the dialectic between the plates used in the capacitors construction also provides some differences between stated and measured values [9]. The actual value for the capacitor used, once checked was 1.064 μ F.

Another difference between the components used in the real-world experiment and in the simulation is the internal resistance of the wires used and within the supply voltage. These were not simulated at in proteus initially, but when checked amounted to 7.32Ohms in the wires and 500Ohms in the supply voltage. Finally, the resistance of the resistor placed in series with the inductor was not quite at 1000Ohms again this is due to its construction therefore its true value was 979Ohms. In order to explore the effect that this had on the circuit and the results a comparative circuit was designed in proteus so that the adjusted real-world values could be modelled in the simulation.

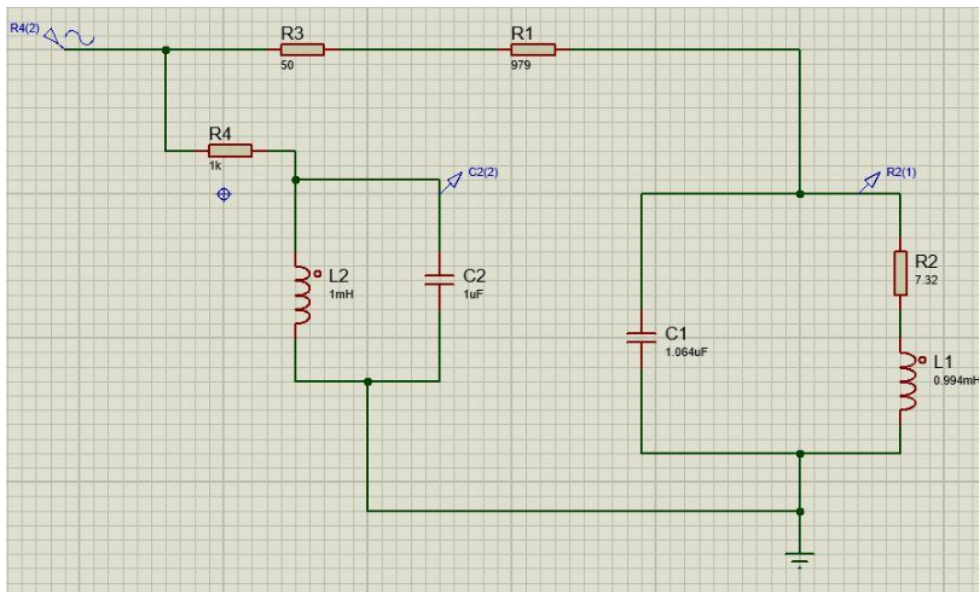


Figure 13: Comparative circuit design to see the difference in peak caused by losses in real world components.

This time when the simulation was rerun the frequency response peak for the adjusted components was far closer to that observed in the real world creation of the experiment, see fig. 14. Furthermore, the peak occurred at a slightly different value, indicating that the mathematical formula used to derive the resonant frequency in the introduction is also slightly incorrect due to the observed real world values. This observation is borne through the results obtained during the experiment and can be seen in the table of results Annex A, along with the figs. 10 and 11 showing where the mathematical resonant frequency should occur along the curve of the results obtained.

4.3) Open Circuit Voltage

According to the theory in the introduction the inductor and capacitor should reach such a high impedance that they effectively cause the circuit to behave as if it had two open terminals in place of the aforementioned components [3]. However, in the results obtained the voltage out never quite returns to this level and this is due to Thévenin's theorem, which is outside of the discussion of this report, however even without reaching the levels of the input voltage it should still be clear that relative to other frequencies there is a considerable difference between the output voltage at resonant frequency and other values [3].

Graph showing the difference in voltage output as measured in the initial simulation and the simulation adjusted for real component values

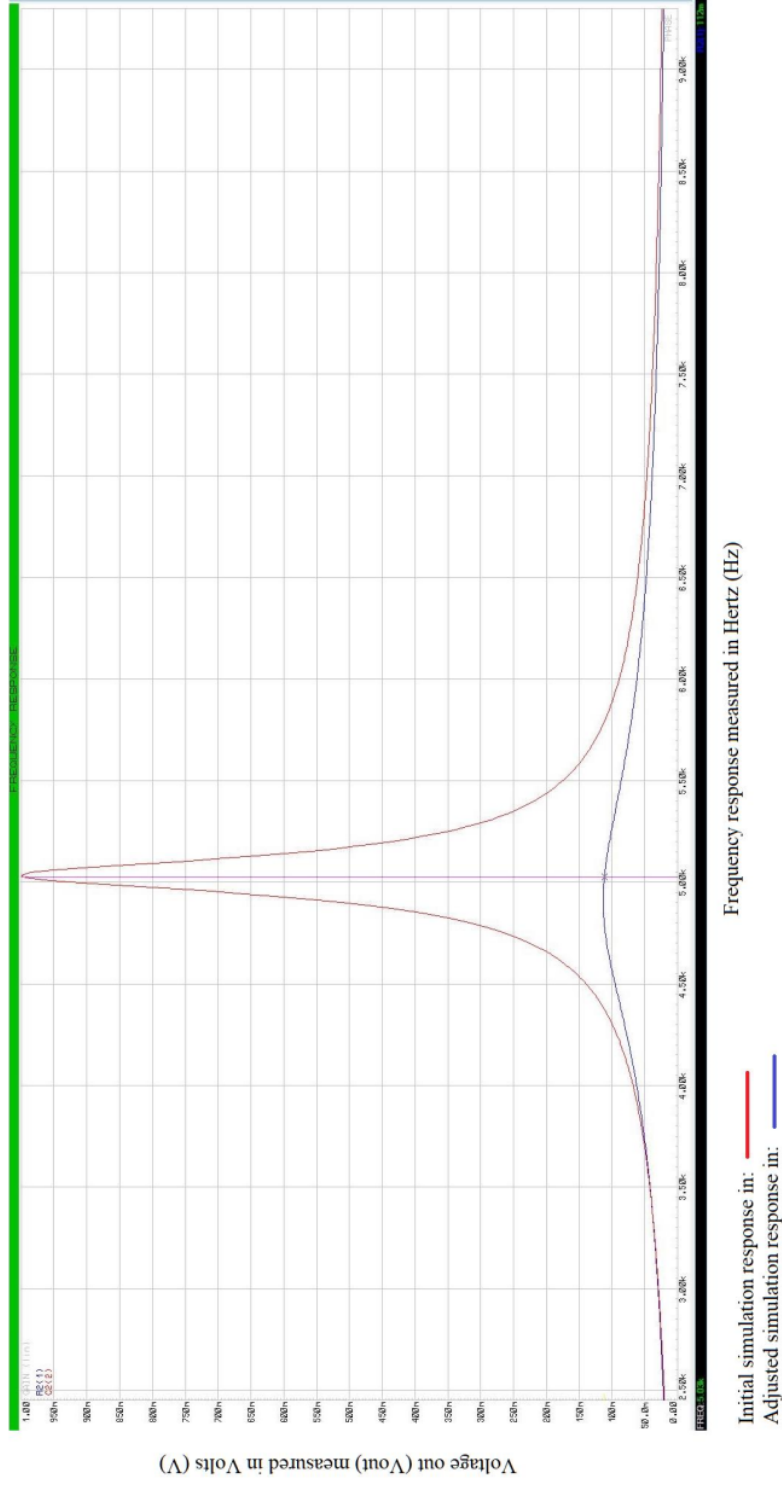


Figure 14: Graph showing the difference in peaks between the initial simulation and the simulation adjusted for real-world component losses.

5) Conclusion

This report has shown how an RLC circuit acts as a band pass filter. In the introduction the report has outlined the mathematical formulae of resonant frequency and related this to the components within an RLC circuit. The introduction also related these findings to the voltage output, which could be measured as part of an experiment. The experiment has been conducted utilising both real-world and simulated components in order to prove the mathematical formula and also to note differences between simulated and real-world components. Finally, it can be stated that despite the effects of Q-factor, the peak voltage output for a RLC circuit does occur at resonant frequency and that outside of this frequency there is a considerable drop in voltage output. These features of the parallel RLC circuit make it suitable for its wide utilisation as a band-pass filter as it creates a narrow field in which frequencies are able to pass through the circuit as suggested by the equations listed in the introduction.

References

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Annex A

Table 3: Table of results obtained during the experiments

Freq	Vin Real	Vout	Vin Proteus	Vout Proteus	Peak real	f	70.7% line
100	2.08	1.22E-02	2.00E+00	1.30E-03	70.70%	100	2.18E-01
200	2.08	1.26E-02	2.00E+00	2.60E-03		20000	2.18E-01
500	2.08	1.36E-02	2.00E+00	6.40E-03			
1000	2.08	1.88E-02	2.00E+00	1.30E-02		FL	FL
2000	2.16	3.60E-02	2.00E+00	3.00E-02		4450	3.00E-01
2500	2.16	4.80E-02	2.00E+00	4.25E-02		4450	0.00E+00
3000	2.16	6.40E-02	2.00E+00	6.00E-02			
4000	2.16	1.34E-01	2.00E+00	1.45E-01		FH	FH
4500	2.18	2.22E-01	2.00E+00	3.20E-01			
4900	2.18	3.08E-01	2.00E+00	1.44E+00		5580	3.00E-01
5000	2.18	3.04E-01	2.00E+00	1.60E+00		5580	0.00E+00
5032.92	2.18	3.04E-01	2.00E+00	1.38E+00			
5100	2.18	2.98E-01	2.00E+00	9.50E-01		BW	1130
5500	2.16	2.34E-01	2.00E+00	3.00E-01		Fr	5032.92121
6000	2.16	1.62E-01	2.00E+00	1.65E-01		Q	4.453912575
8000	2.16	7.40E-02	2.00E+00	6.50E-02			
10000	2.16	5.00E-02	2.00E+00	4.00E-02	Peak proteus		
20000	2.16	1.98E-02	2.00E+00	1.50E-02	70.70%	f	70.7% line
						100	1.13E+00
						20000	1.13E+00
						FL	FL
						4780	1.40E+00
						4780	0.00E+00
						FH	FH
						5075	1.40E+00
						5075	0.00E+00
						BW	295
						Fr	5000
						Q	16.94915254

Assignment 1 electronics

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

70/100

PAGE 1

PAGE 2

PAGE 3

PAGE 4

QM

Eqn. No.

You should include an equation number to allow you to identify the equation in your text e.g. "this can be calculated using equation 2".

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14

**Comment 1**

I think this table could have been structured better. 2 rows: Vsrc, Vout; and 2 columns: simulated, practical.

Maybe even adding a third row with the loss or dB attenuation.

**Comment 2**

It isn't the equation that is incorrect, it was the component values used that were incorrect.

**Ref Qual**

You should try to use more high quality reference sources, such as textbooks from reputable academic publishers and articles from peer reviewed journals.

**Ref Qual**

You should try to use more high quality reference sources, such as textbooks from reputable academic publishers and articles from peer reviewed journals.

GRADING FORM: SMU GENERIC_SMOSEY

JOSHUA WARREN EDE

69.90

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.

4.2

KNOWLEDGE & UNDERSTANDING

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



Excellent knowledge and understanding of the main concepts and key theories.

22.5

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; synthesis and evaluation. Ability to communicate ideas and evidence accurately and convincingly. Sound, convincing conclusions No mention of Q factor

18.6

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. Very good consideration of the context of the application, with perceptive use of examples, where relevant. Evidence of some innovation and 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 with an exceptionally high level of professionalism. Work is exceptionally coherent, very fluent and is presented professionally.

4.2