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Resonance Lab Report

ACDA4006

L4 – Electrical and Electronic
Principles

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Electrical and Electronic
Engineering Degree Apprenticeship

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Abstract

In this experiment, the frequency response of an RLC (resistor, inductor and capacitor) circuit was tested using both software simulation (Proteus) and a practical measurement using a breadboard. The circuit contained a 1k Ω resistor, 1mH inductor and a 1 μ F capacitor. A sinusoidal input signal of 2V peak to peak was applied, and the output voltage was measured over a frequency range of 100Hz to 20kHz. The attenuation was calculated in decibels using the formula below:

$$A = 20 \log_{10} \left(\frac{V_{out}}{V_{in}} \right)$$

The simulated resonant frequency was found to be approximately 5000Hz, compared to the theoretical value of 5033Hz. It was found that the practical breadboarded circuit produced a resonant frequency of approximately 5200Hz. The simulated Q factor, using the half amplitude method, was calculated to be approximately 16.4, while the practical circuit's Q factor was approximately 1.26. The results showed that even though the practical response had a much lower amplitude and wider bandwidth, it followed the same general resonant trend of the simulation.

Introduction

An RLC circuit is an electrical circuit containing a resistor, conductor and capacitor. These circuits are commonly used in applications where frequency selection is required, such as filters, tuning circuits, oscillators and signal-processing systems [1], [2].

The behaviour of inductors and capacitors changes with frequency. The reactance of an inductor increases as frequency increases and is calculated [1]:

$$X_L = 2\pi fL$$

The reactance of a capacitor decreases as frequency increases and is calculated [1]:

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

Resonance occurs when the inductive reactance and capacitive reactance are equal in magnitude [1], [3]:

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

The Q factor describes how "sharp" or selective the resonant peak is. A high Q factor indicates a narrow, sharp peak. While a low Q factor indicates a broader, less selective response [2], [4]:

The Q factor can be calculated from the graph [4]:

$$Q = \frac{f_r}{f_2 - f_1}$$

Where f_r is the resonant frequency, f_1 is the lower half-amplitude frequency and f_2 is the upper half-amplitude frequency.

In standard filter theory, Q is normally calculated using the -3dB half-power points [4]. However, this assignment brief asks for the voltage across the inductor to be reduced to half of maximum voltage, so the half amplitude method has been used in the main analysis.

Simulation Setup

The circuit was first built in Proteus, using the following component values:

Component	Value
Resistor (R)	1k Ω
Inductor (L)	1 mH
Capacitor (C)	1 μ F

Table 1: Simulated Circuit component values



The signal generator was set to:

$$V_{in} = 2V_{pk-pk}$$

The frequency was varied from 100Hz – 20kHz. At each frequency the output voltage was measured and the attenuation calculated:

$$A = 20 \log_{10} \left(\frac{V_{out}}{V_{in}} \right)$$

Decibel calculations are most used when analysing frequency response as they allow large changes in voltage ratio to be shown more clearly when plotted on a graph [1], [2].

The frequency was adjusted more closely around the resonant peak to improve accuracy of the resonant frequency and half-amplitude points.

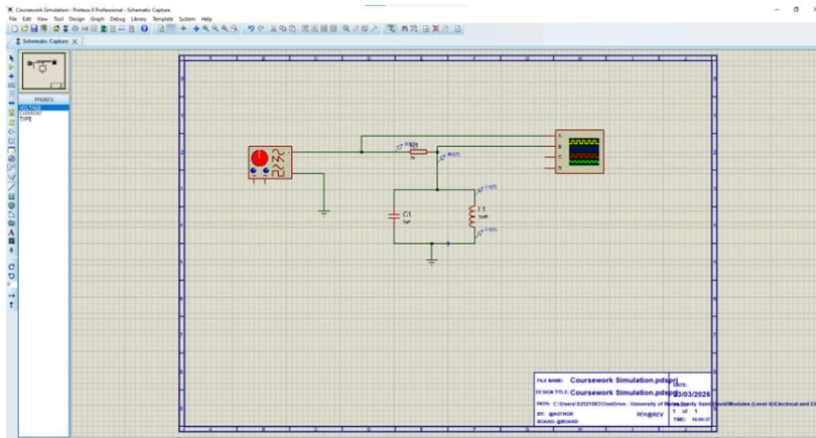


Figure 1: Drawing of simulated circuit on Proteus

Practical Breadboard Setup

The circuit was then built physically on a breadboard using the same nominal component values as the simulation. A signal generator was used to apply a 2Vpk-pk sinusoidal input signal. The output voltage was measured using an oscilloscope while the frequency was increased from 100Hz to 20kHz.

Additional readings were taken around the expected resonant frequency, especially between 4800Hz and 5400Hz, to allow the resonant peak to be identified more accurately. The practical readings were recorded in the same format as the simulated readings so that the simulated and practical results could be compared directly.

Practical oscilloscope measurements can be affected by probe loading and the way the measuring instrument interacts with the circuit under test [5], [6]. Therefore, practical results may not exactly match the simulation, especially when measuring small voltages or high-impedance points.

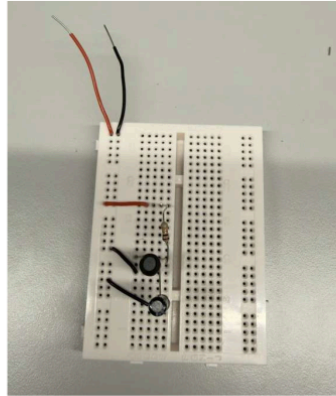


Figure 2: Breadboarded RLC Circuit

Theoretical resonant Frequency

The theoretical resonant frequency was calculated using [1], [3]:

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

Substituting the component values:

$$C = 1\mu F = 1 \times 10^{-6} F$$
$$f_r = \frac{1}{2\pi\sqrt{0.001 \times 1 \times 10^{-6}}}$$
$$f_r = 5032.9 Hz$$

Therefore:

$$f_r \approx 5033 Hz$$

The theoretical resonant frequency of the circuit was approximately 5033Hz.

Simulation Results

The simulation results showed a clear resonant peak at approximately 5000Hz. The maximum simulated output voltage was:

$$V_{out(max)} = 1.93V$$

This occurred at:

$$f_r = 5000Hz$$

Frequency (Hz)	Vin	Vout	Amplitude
100	2	0.0013	-63.74173287
500	2	0.0025	-58.06179974
1000	2	0.0132	-43.60912129
2500	2	0.042	-33.55561411
3000	2	0.059	-30.60355968
4000	2	0.138	-23.22301819
4500	2	0.285	-16.92370271
4800	2	0.665	-9.564167007
4900	2	1.105	-5.153354353
5000	2	1.93	-0.309453733
5100	2	1.4	-3.0980392
5200	2	0.81	-7.850899536
5300	2	0.56	-11.05683937
5400	2	0.42	-13.55561411
6000	2	0.18	-20.91514981
7000	2	0.095	-26.46612781
10000	2	0.042	-33.55561411
20000	2	0.017	-41.41162149

Table 2: Simulation results

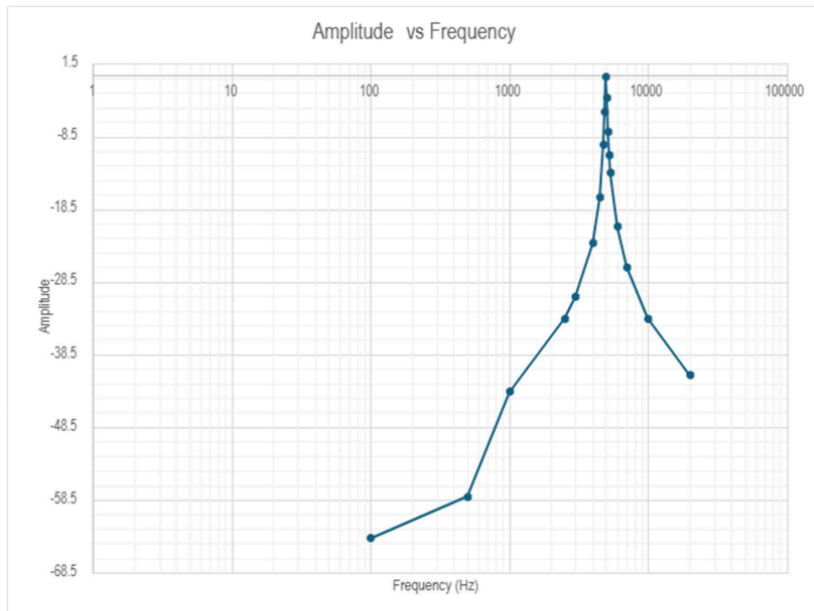
The attenuation at resonance was:



$$A = 20\log_{10}\left(\frac{1.93}{2}\right)$$

$$A = -0.31dB$$

This shows that the output voltage at resonance was almost equal to the input voltage.



Graph 1: Logarithmic graph of simulated results



Practical Breadboard Results

The breadboard circuit also showed a resonant peak, but the measured output voltage was much lower than in the simulation. The maximum practical output voltage was:

$$V_{out(max)} = 0.0196V$$

This occurred at:

$$f_r = 5200Hz$$

Frequency (Hz)	Vin	Vout	Amplitude
100	2	0.00184	-60.7242435
500	2	0.00256	-57.8558006
1000	2	0.0026	-57.721133
2500	2	0.0046	-52.7654433
3000	2	0.0068	-49.3704217
4000	2	0.011	-45.1927462
4500	2	0.0146	-42.7335428
4800	2	0.017	-41.4116215
4900	2	0.0178	-41.0121999
5000	2	0.0184	-40.7242435
5100	2	0.0188	-40.5374429
5200	2	0.0196	-40.1754785
5300	2	0.0194	-40.2645653
5400	2	0.019	-40.4455279
6000	2	0.0166	-41.6184382
7000	2	0.0114	-44.8825029
10000	2	0.0056	-51.0568394
20000	2	0.00288	-56.8327502

Graph 3: Practical breadboard results



The breadboard result showed a much broader and lower-amplitude response than the simulation. This suggests that the practical circuit had greater losses and damping compared to the simulated circuit.

Resonant Frequency Comparison

The theoretical, simulated and practical resonant frequencies are compared in Table 4.

Method	Resonant Frequency
Theory	5033Hz
Simulation	5000Hz
Practical Breadboard	5200Hz

Table 4: Resonant Frequency Comparison

The difference between the theoretical and simulated resonant frequencies was:

$$5033 - 5000 = 33\text{Hz}$$

The percentage difference was:

$$\frac{33}{5033} \times 100 = 0.66\%$$

The difference between the theoretical and practical resonant frequencies was:

$$5200 - 5033 = 167\text{Hz}$$

The percentage difference was:

$$\frac{167}{5033} \times 100 = 3.32\%$$

The practical resonant frequency was slightly higher than both the theoretical and simulate values, but it was still reasonably close. Small differences are expected as real components have varying tolerances and are not ideal [1], [2].

Q Factor Calculations

Simulated Q Factor

The maximum simulated output voltage was:

$$V_{out(max)} = 1.93V$$

The half-amplitude voltage was:

$$V_{hal} = \frac{1.93}{2}$$

$$V_{half} = 0.965V$$

Using interpolation from the simulation data:

$$f_1 \approx 4868Hz$$

$$f_2 \approx 5174Hz$$

The bandwidth (BW) was:

$$BW = f_2 - f_1$$

$$BW = 5174 - 4868$$

$$BW = 306Hz$$

The Q factor was calculated using [4]:

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

$$Q = \frac{5000}{306}$$

$$Q \approx 16.4$$

Therefore, the simulated Q factor using the half amplitude method was approximately:

$$Q \approx 16.4$$

Practical Breadboard Q Factor

The maximum practical output voltage was:

$$V_{out(max)} = 0.0196V$$

The half amplitude voltage was:

$$V_{half} = \frac{0.0196}{2}$$

$$V_{half} = 0.0098V$$

Using interpolation from the breadboard results:

$$f_1 \approx 3714Hz$$

$$f_2 \approx 7828Hz$$

The bandwidth was:

$$BW = f_2 - f_1$$

$$BW = 7828 - 3714$$

$$BW = 4114Hz$$

The practical Q factor was:

$$Q = \frac{5200}{4114}$$

$$Q \approx 1.26$$

Therefore, the practical breadboard Q factor was approximately:

$$Q \approx 1.26$$

Comparison of Results

Result	Theory	Simulation	Practical Breadboard
Resonant Frequency	5033Hz	5000Hz	5200Hz
Maximum Output Voltage	N/A	1.93V	0.0196V
Lower half amplitude	N/A	4868Hz	3714Hz
Upper half amplitude	N/A	5174Hz	7828Hz
Bandwidth	N/A	306Hz	4114Hz
Q factor	N/A	16.4	1.26

Table 5: Overall comparison of theory simulation and practical results



The simulated resonant frequency was very close to the theoretical value. The practical resonant frequency was slightly higher but still followed the same general behaviour. The main difference was that the practical circuit had a much lower maximum output voltage and a much wider bandwidth.

Discussion

The simulation results show a clear resonant response. The voltage increased as the frequency approached 5000Hz, reached a maximum at resonance, then decreased as the frequency moved above resonance. This is expected as resonance occurs when the inductive and capacitive resistances are equal in magnitude [1], [3].

The theoretical resonant frequency was calculated as 5033Hz, while the simulated resonant frequency was 5000Hz. The percentage difference was only 0.66%, showing strong agreement between theory and simulation. The small difference is likely due to the chosen measurement points, as the exact resonant frequency may lie between recorded frequencies.

The practical breadboard circuit produced its resonant frequency at 5200Hz. This was slightly higher than the theoretical value, with a percentage difference of approximately 3.32%. This difference is reasonable for a practical circuit because real components have tolerances. For example, the actual value of the capacitor or inductor may not be exactly equal to the value used in the simulation.

The practical Q factor was much lower than the simulated Q factor. The simulated Q factor was approximately 16.4, while the practical Q factor was approximately 1.26. This shows that the practical circuit had a much wider bandwidth and a much less selective response. A lower Q factor usually means that the circuit has more damping or losses [4].

The practical output voltage was also much lower than the simulated output voltage. The maximum simulated output voltage was 1.93V, while the maximum breadboard output voltage was only 0.0196V.

This is a significant difference. Possible reasons include internal resistance, poor connections, oscilloscope probe loading, signal generator output impedance and measurement point differences. Oscilloscope probes can affect the circuit being measured as the probe becomes part of the measurement system and can load the circuit [5], [6].

The practical circuit still showed a peak around the expected resonant frequency, but the response was much flatter and lower in amplitude. This suggests that the practical circuit was more heavily damped compared to the simulated circuit. In a simulator, components are often treated as ideal unless additional resistance or parasitic effects are added. In a real breadboard circuit, these non-ideal effects are always present [1], [2].

It is also important to note that the assignment uses the half amplitude method for determining f_1 and f_2 . This means that the voltage is reduced to half of the maximum value. In decibels, this is a reduction of:

$$20\log_{10}(0.5) = -6.02dB$$

However, standard Q factor calculations normally use the -3dB half power points, where the voltage is approximately $0.707V_{max}$ [4]. Therefore, the calculated Q factor depends on whether the half amplitude or half power method is used. In his report, the half amplitude method was used as it was what the assignment brief requested.

Conclusion

In this experiment, the resonant frequency and Q factor of an RLC circuit were investigated using both simulation and a practical breadboard circuit. The aim was to observe how the output voltage changed as the input frequency was varied, and to compare the simulation and practical results with theoretical calculations.

The theoretical resonant frequency was calculated as 5033Hz. The simulation gave a resonant frequency of 5000Hz, which only had a 0.66% difference from the theoretical value. This shows that the simulation closely resembled the expected theoretical behaviour of an RLC circuit.

The practical breadboard circuit gave a resonant frequency of 5200Hz, a 3.32% difference from the theoretical value. This indicates that the practical circuit followed the same general frequency response as the simulation, although the peak occurred at a slightly higher frequency.

Using the half amplitude method, the simulated factor was approximately 16.4, with the practical Q factor was approximately 1.26. This shows that the practical circuit had a much wider bandwidth and lower selectivity than the simulated circuit. The lower practical Q factor indicates that the breadboarded circuit has greater damping and losses compared to the ideal simulated RLC circuit.

The maximum simulated output voltage was 1.93V, whereas the maximum practical output voltage was only 0.0196V. This large difference shows that the practical circuit did not behave exactly like the simulation in terms of output amplitude. Possible reasons could include component tolerances, internal resistance of inductor, breadboard contact resistance, oscilloscope probe loading, signal generator output impedance and measurement uncertainty.

Overall, the experiment demonstrated that RLC circuits produce a resonant response at a specific frequency. The simulation closely matched the theoretical resonant frequency, while the practical circuit showed the same general trend but with lower amplitude and a wider response. This confirms that theoretical calculations and simulations are useful for predicting circuit behaviour, but practical measurements are affected by real-world component and measurement limitations.

References

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FINAL GRADE

GENERAL COMMENTS

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GRADING FORM: EEP

IWAN EVANS

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ENGAGEMENT WITH LITERATURE

Marks for engagement with literature skills will be gained through the use of information collected from appropriate reference material embedded in mainly the introduction, but also in the discussion and conclusion sections of your report. This reference material should be used to explain concepts and to support arguments in the discussion of your results.



Engagement with a wide range of literature is demonstrated through the use of textbooks, manufacturer application notes, and other relevant sources to support discussions of RLC resonance, Q factor, and measurement effects, strengthens the theoretical foundation. Consistency of IEEE referencing should also be checked, and key explanations such as probe loading, inductor resistance, and component tolerance should be more explicitly linked to both cited sources and the measured data.

2.8

KNOWLEDGE AND UNDERSTANDING

Marks for knowledge and understanding skills will be given for the accuracy of your description of the concepts and principles of resonance and how this relates to the experimental setup used.



Excellent knowledge and understanding are demonstrated through a clear explanation of resonance, attenuation, bandwidth, and Q factor. The theoretical, simulated, and practical resonant frequencies are compared effectively. However, some equations are missing. To improve, the Q-factor calculation method should be applied consistently throughout.

23

COGNITIVE AND INTELLECTUAL

Marks for cognitive and intellectual skills will be given for the quality and validity of your interpretation of the experimental results gathered.

You should consider the differences between the simulated and experimental and explain possible causes for them.



Excellent evaluation of the underlying concepts and principles is demonstrated through a clear comparison of theoretical, simulated, and practical results, including resonant frequency, bandwidth, and Q factor. Relevant factors such as component tolerances, internal resistance, breadboard losses, signal generator impedance, and oscilloscope loading are discussed effectively. However, the large difference between the simulated and practical output voltages requires deeper research.

20

PRACTICAL SKILLS

Marks for practical skills will be given for your use of the available tools, models and techniques to explain your results and their relationship to the theory of the concepts.



Good application of taught methods, materials, tools, and techniques is demonstrated through both Proteus simulation and breadboard testing. Component values, input voltage, frequency range, data tables, and graphs are clearly presented, while additional measurements around the resonance point and interpolation of half-amplitude values demonstrate good data-analysis practice.

24

TRANSFERABLE SKILLS FOR LIFE

Marks for transferable skills for life and professional practice will be given for the structure, coherence, presentation and overall quality of your report.



A good level of structure and coherence is demonstrated through clear sections covering the setup, theory, results, Q-factor calculations, comparison, discussion, conclusion, and

3.2

references. The comparison table effectively communicates the key findings, while the conclusion provides a clear summary of the main results. However, spelling, grammar, and formatting issues reduce the professionalism of the work. It is evident from the coursework that the student demonstrates the ability to design circuits using Proteus, measure the output, analyse the circuit, and present the findings in a report.