

Resonance

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TIME SUBMITTED	05-FEB-2019 05:47PM (UTC+0000)	WORD COUNT	4492
SUBMISSION ID	100285715	CHARACTER COUNT	32839

Resonance

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05/11/18 - 16/11/18

Abstract

A study was undertaken into the resonance reaction of a resistor, inductor, capacitor (RLC) circuit where a simulation on Proteus was compared to a practical build of the same circuit. The circuits were subjected to changes in the frequency of the input voltage to measure when resonance occurred. Resonance is where a circuit's reactance from the inductor and capacitor cancel out to produce a large current flow or voltage drop in compensation. The results for bandwidth, resonant frequency and quality (Q) factor were compared between the calculated, simulated and practical results.

Large differences in the results from the simulated and practical experiment were found for all the values studied. These differences can mostly be attributed to the differences in the ideal component values used by the simulation software and the "real-world" values of the components used in the practical experiment.



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1 Introduction

1.1 Objective

The purpose of this work was to explore the resonance produced in a circuit containing three passive devices; a resistor, inductor and capacitor, RLC circuit, when connected to an alternating current (A.C) power supply.

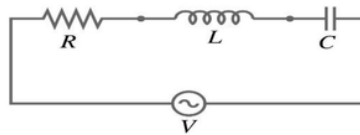


Figure 1 Circuit Diagram for RLC Series Circuit [1]

1.2 Background Theory

1.2.1 Direct Current Circuits

In circuits with a direct current (D.C) flowing through them, all the impedance to the flow of current occurs in the form of resistance. The resistance is generated by components, such as resistors, the wires and external factors such as temperature.

The resistance in a circuit can be calculated using Ohm's Law, where the voltage of a circuit is directly proportional to the produce of the current and resistance.

$$V = IR$$

Equation 1 Ohm's Law [2, p. 4]

1.2.2 Alternating Current Circuits

In a circuit containing A.C, as well as resistance impeding the flow of the current, there is an opposition to changes in the way in which the current flows: this is the reactance of the circuit. Reactance is a reaction to the change in the flow of the A.C current and proportional to the frequency of the circuit. The frequency is number of full cycles completed by the circuit within one second. [3]

As the voltage in an A.C circuit is a sinusoidal waveform, the input voltage of an A.C circuit is often defined as the effective or root mean square voltage (VRMS). This is the equivalent to a D.C voltage that produces the same heating effect in the circuit [4]. This notation will be used through this report to describe the supply voltage.

1.2.3 Reactance

Reactance can be inductive or capacitive, inductive reactance is generated a magnetic field which arises from the change in the flow of the electric current. The magnetic field in turn produces a voltage which acts against the direction of the original current producing a drop in the voltage across the device. As can be seen from Equation 2, there is a direct, linear relationship between frequency and inductive reactance.

$$X_L = 2\pi fL$$

Equation 2 Inductive Capacitance [2, p. 45]

Capacitive reactance arises from the change in the electric field formed between two charged surfaces such as in a capacitor. [5] It takes work to move the current across the insulate material between the plates of a capacitor. This work cannot be done instantly and so a reactance is created

which is out of phase with the alternating current. This reactance has an inverse relationship to the frequency of the current, so it blocks D.C and passes A.C [6].

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

Equation 3 Capacitive Inductance [2, p. 42]

Capacitive and inductive reactance both act 90° out of phase with the voltage and 180° out of phase with one another. The phase shift is created by the reactive nature of the devices. When a capacitor is charging, the voltage increases and the current decreases; the opposite is true for discharging. For an inductor, when charging the voltage decreases and the current increases before swapping over to discharge. And so, in each device, when the voltage is at a maximum, the current is at a minimum and vice versa creating a 90° out of phase relationship for current and voltage and an 180° out of phase relationship with one another. [7]

1.2.4 Impedance

The RLC circuit contained both inductive and capacitive reactance which can be combined to find the total reactance of the circuit (X).

$$X = X_L - X_C$$

Equation 4 Total Reactance

As there were both capacitive and inductive components to the circuit, the phase shift was not be 90° as for a purely capacitive or inductive circuit. The phase difference was, instead, somewhere between 0 and 90° depending on the relative values of X_L and X_C



For an RLC circuit, both resistance and reactance had to be taken into account by finding the impedance of the circuit (Z).

$$Z = \sqrt{R^2 + X^2}$$

Equation 5 Impedance of a Circuit [2, p. 48]

1.2.5 Resonance

For RLC circuits, resonance is where the circuit suddenly passes a large current and this occurs at a particular frequency, the resonant frequency, for which the inductive reactance and capacitive reactance cancel out, because they have equal magnitudes but are 180° out of phase [8], leaving the impedance dependent solely on the resistance of the circuit [6].

$$X_L = X_C$$

Equation 6 Reactance at Resonance

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

Equation 7 Resonant Frequency [2, p. 53]

Where the current can't be increased from the supply, there is instead a voltage drop. At frequencies lower than the resonance frequency, f_{res} , capacitive impedance dominates the circuit, at resonance, resistance dominates the circuit and at frequencies higher than f_{res} , inductive reactance dominates the circuit. [9]

Electrical resonance is a feature that is utilised for numerous different devices especially in signal processing and communications, such as tuning devices in radio receivers. Series circuits also be used to produce voltage magnification [10].

Resonance is important because it causes circuits to respond more favourably to particular frequencies and to discriminate against signals of other frequencies [8] which is the behaviour required for tuning devices.

1.2.6 Bandwidth

Bandwidth for an RLC circuit is the range of frequencies that will cause resonant like behaviour. The narrower the bandwidth, the more selective the circuit to signal frequencies. As can be seen in Equation 9 Quality Factor Equation 9, the bandwidth is inversely proportional to the Quality factor, so a smaller bandwidth produces a higher quality factor.

The bandwidth can be measured from a frequency-voltage graph by calculating 70.7% of the input voltage and drawing a straight line across the graph to find the points this line crosses the frequency-voltage curve. These points correspond to lower and higher frequency values (f_l and f_h). The bandwidth is the difference between these two frequency values.

$$BW = f_h - f_l$$

Equation 8 Bandwidth Equation

1.2.7 Q Factor

For the simulated and practical circuits, the Q factor was calculated as a method of comparing the results of the two circuits. Q factor is an indication of the efficiency of a circuit by providing a quantitative measure of the relationship between the stored energy (energy within capacitors and inductors) with the rate of energy use (energy used in resistors) in the circuit. A circuit with a high Q factor is more selective on the frequency that it responds to [8].

As the Q factor of an RLC circuit depends on the total resistance in the circuit, the added resistance from the inductor can have a large effect on the quality factor if it is of a similar order of magnitude of the resistor in the circuit.

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

Equation 9 Quality Factor [11]

For capacitors the Q-factor is equal to the inverse of losses within the capacitor, which are frequency and temperature dependant.

$$Q = \frac{X_c}{ESR}$$

Equation 10 Q Factor of Capacitors [12]

Where ESR is a single resistance representative of the sources of resistance in the equivalent circuit, which can be seen in Figure 10 Capacitor Equivalent Circuit [12].

1.2.8 Equivalent circuits

Whilst ideal components have only resistance, capacitance or inductance, real components can each contain a mixture of resistance, inductance and capacitance.

Each of the passive components used in the experiment are more complicated than they first seem. A resistor has a capacitance and inductance value as well as resistance. A capacitor also has a resistance value known as the equivalent series resistance (ESR) which is dependent on the operating frequency of the circuit. Inductors also have capacitance and resistance values.

Looking at an RLC circuit diagram is looking at a generalised Thevenin's theorem circuit in reverse. Instead of representing a complex circuit by single sources of resistance, capacitance and inductance, the simple looking RLC circuit can be expanded to view each of the components as an equivalent circuit generating their own resistance, capacitance and inductance.

Figure 2 below shows a schematic for an equivalent RLC circuit where each of the three main components is broken down into its constituent parts.

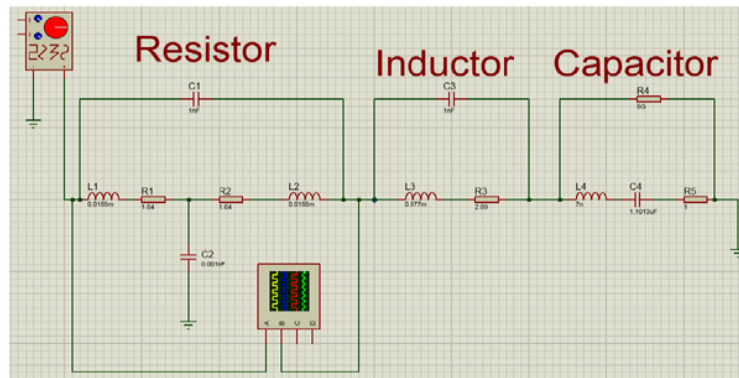


Figure 2 Total Equivalent Circuit

2 Materials

- Oscilloscope
- Probe
- Breadboard
- 3.3Ω resistor
- 1.0mH inductor
- 1.0μF capacitor
- Signal generator
 - A.C Power supply
- Proteus 8.8 Demonstration
- Circuit diagram

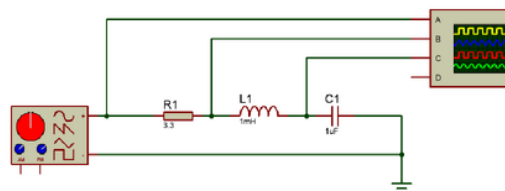


Figure 3 Circuit diagram provided in Experiment Brief

3 Experimental Procedure

3.1 Simulation Experiment

A model circuit was built using Proteus version “8.8 Demonstration” by following the drawing provided in the experiment brief (see Figure 3). The signal generator was set have an output of 4VRMS at 100 Hz. This was reduced from the value of 12VRMS stated in the experimental brief to match the requirements of the components that were to be used in the latter half of the experiment. This allowed for better comparison between the results of the simulation and practical experiments. By running the simulation, measurements of the peak to peak $V_C + V_L$ voltage, where V_L is the voltage across the inductor and V_C is the voltage across the capacitor, could be measured on the oscilloscope. Once the values for V_R , the voltage across the resistor, and $V_L + V_C$ had been noted down in a table, the frequency was adjusted to the next desired level and the measurements repeated. As it had been calculated previously that the expected resonant frequency would occur at 5.0 kHz, measurements were taken more frequently between 4.5 kHz and 5.5 kHz than below 4.5 kHz and above 5.5 kHz. This was to allow for better resolution of the determination of the resonant frequency and bandwidth in the analysis. This process of changing the frequency of the signal generator and then running the simulation to gather measurements was repeated up to a value of 10 kHz.

3.2 Practical Experiment

The circuit was then built using supplied components on a breadboard, with the components having manufacturer quoted values the same as those used in the simulation. Once the circuit had been built and checked, the signal generator was set to 4VRMS at 100 Hz. The earth clip of the probe was attached to the circuit and the probe used measure the voltage across the capacitor and inductor, $V_C + V_L$ by attaching the probe to the leg of the capacitor. The voltage of the resistor, V_R , was measured by moving the probe to a leg of the resistor. Measurements were initially taken at the same levels as in the simulation, however at 10 kHz the $V_C + V_L$ voltage was still much lower than the input voltage so more measurements were taken in large jumps up to 100 kHz where the voltage value returned to near input voltage levels.

The components were then measured using a multi-meter to find the real values of the components opposed to the manufacturer stated values.

4 Results

4.1 Raw Results

Frequency	Simulation Results		Practical Results	
	V_R	$V_L + V_C$	V_R	$V_L + V_C$
Hz	V	V	V	V
100	4.00	4.0	4.00	3.800
200	4.00	4.0	4.00	3.100
500	4.00	4.0	4.00	1.800
1000	4.00	4.0	4.00	1.000
2000	4.00	4.0	4.00	0.465
4500	4.00	3.5	4.20	0.064
4600	4.00	3.3	4.20	0.052
4700	4.00	2.8	4.20	0.050
4800	4.00	2.3	4.20	0.040
5000	4.00	0.8	4.10	0.032
5100	4.00	1.8	4.10	0.026
5200	4.00	2.6	4.10	0.010
5300	4.00	3.0	4.10	0.010
5400	4.00	3.4	4.10	0.012
5500	4.00	3.5	4.10	0.015
6000	4.00	3.8		
7000	4.00	4.0		
8000	4.00	4.0		
9000	4.00	4.0		
10000	4.00	4.0	4.10	0.120
20000			4.10	0.750
30000			4.00	1.800
40000			4.00	2.200
50000			4.00	1.800
60000			4.00	2.400
70000			4.00	2.500
100000			4.00	3.200

Table 1 Results of Experiments

4.2 Graphs

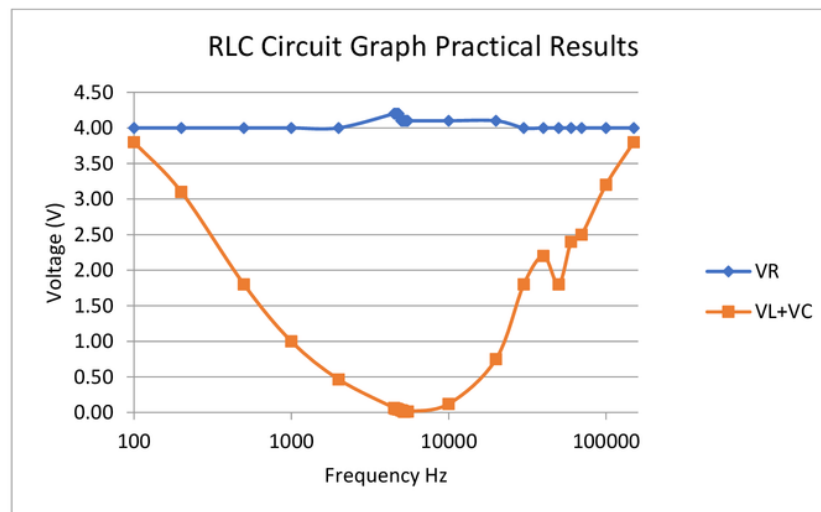


Figure 4 Practical Experiment Results

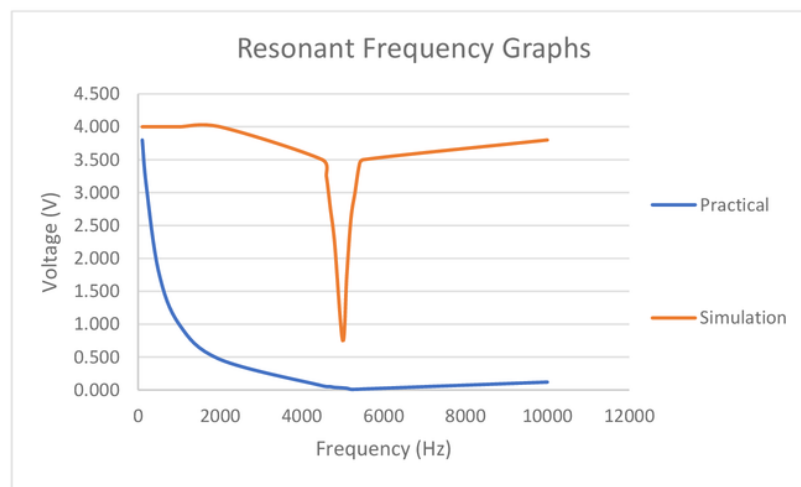


Figure 5 Resonant Frequency Results

It can be seen from the graphs that the practical experiment produces very different results to the simulation.

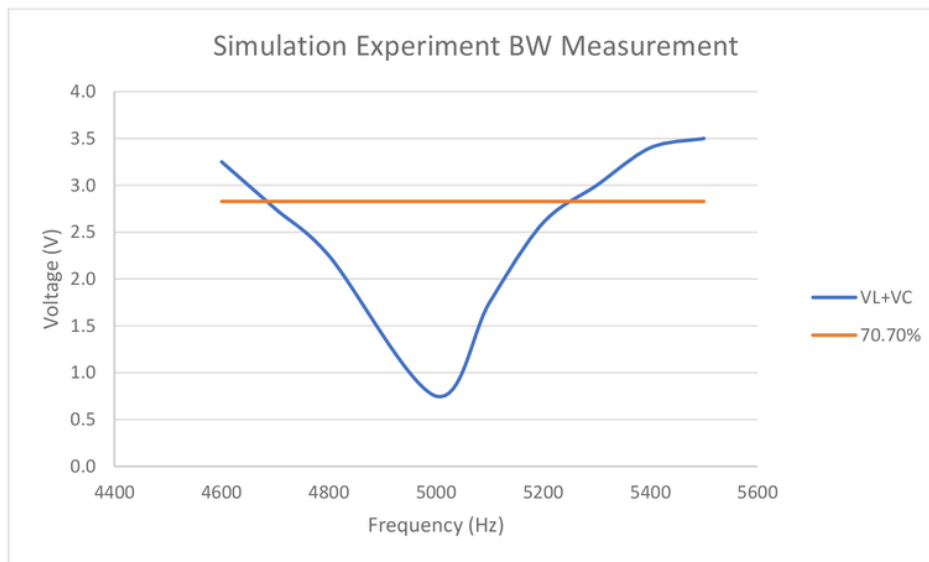


Figure 6 Simulation Experiment Bandwidth Measurement

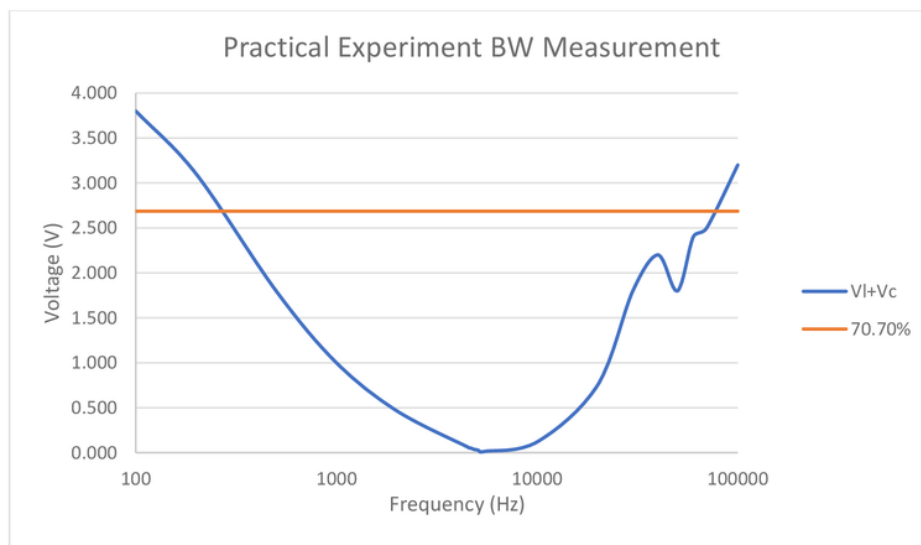


Figure 7 Practical Experiment Bandwidth Measurement

It can be seen from Figure 6 Simulation Experiment Bandwidth MeasurementFigure 6 & Figure 7 that the recovery time of the practical circuit's voltage has greatly affected the bandwidth of the circuit.

4.3 Calculations

4.3.1 Resonant Frequency

4.3.1.1 Calculation

As measured, from the components the capacitor had an inductance which affected the calculations for the resonant frequency.

$$L_T = L_1 + L_2$$

Equation 11 Inductors in Series [2]

Equation 7 was used with Table 2 to calculate the expected resonant frequency for the practical and simulation.

4.3.1.1.1 Simulation:

$$f_{res} = \frac{1}{2\pi\sqrt{(1.0 \times 10^{-3})(1.0 \times 10^{-6})}}$$

$$f_{res} = 5,033\text{Hz}$$

The capacitor had an inductance of 0.007mH and the inductor had an actual inductance of 0.997mH. As the capacitor and inductor were in series, their inductances were added together (Equation 11) to give a total inductance of 1.004mH to calculate the resonant frequency of the practical circuit.

4.3.1.1.2 Practical:

$$f_{res} = \frac{1}{2\pi\sqrt{(1.004 \times 10^{-3})(1.013 \times 10^{-6})}}$$

$$f_{res} = 5,023\text{Hz}$$

4.3.1.2 Bandwidth Measurement:

Using the values measured from the graphs for bandwidth (14) and an adaption to Equation 8 it was possible to use these values to calculate the resonance frequencies of the circuits.

4.3.1.2.1 Simulation:

$$f_{res} = f_l + \frac{BW}{2}$$

$$f_{res} = 4700 + \frac{600}{2} = 5,000\text{Hz}$$

4.3.1.2.2 Practical:

$$f_{res} = f_l + \frac{BW}{2}$$

$$f_{res} = 500 + \frac{69500}{2} = 35,250\text{Hz}$$

The resonant frequency measured from the graph of the simulation results matched, within experimental errors, the expected resonant frequency from the calculation with the stated component values. The resonant frequency measured from the practical experiment results graph was significantly different to that expected from the calculations using the measured component values.

4.3.2 ESR

The gradient of the line for the ESR of the inductor and capacitor should have been approximately equal to the Q factor of the circuit. For this graph the gradient was 10.026 which was similar to the calculated Q factor of 9.6 from the component stated values.

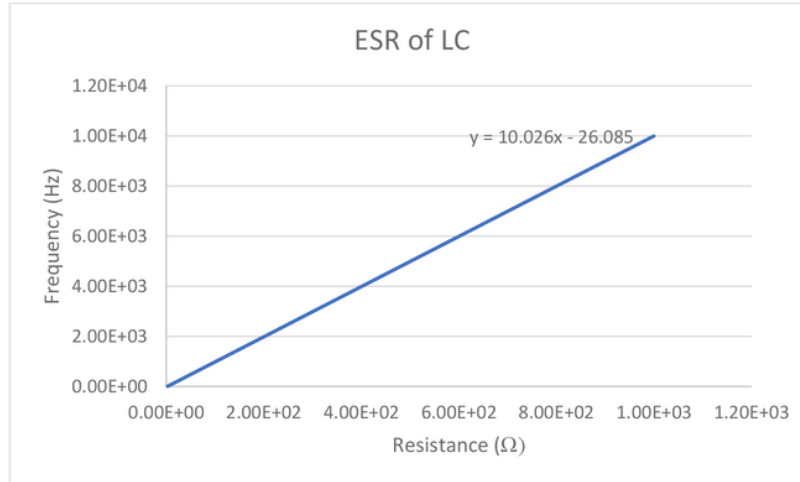


Figure 8 ESR of LC

Using this value of Q in Equation 9 gave a bandwidth of 502Hz.

$$BW = \frac{f_{res}}{Q} = \frac{5033}{10.026} = 502 \text{ Hz}$$

4.3.3 Bandwidth

The bandwidth of the two circuits was measured from Figure 6& Figure 7 by finding where the 70.7% of the maximum voltage line crossed the frequency response curve.

4.3.3.1 Simulation:

Using Equation 8, with $f_l = 4700 \text{ Hz}$, $f_h = 5300 \text{ Hz}$

$$BW = 5300\text{Hz} - 4700\text{Hz} = 600\text{Hz}$$

4.3.3.2 Practical:

Using Equation 8, with $f_l = 500 \text{ Hz}$, $f_h = 70000 \text{ Hz}$

$$BW = 70000\text{Hz} - 500\text{Hz} = 69500\text{Hz}$$

4.3.4 Q Factor

4.3.4.1 From component Values:

$$\text{Using Equation 9, } Q = \frac{1}{R} \sqrt{\frac{L}{C}}$$

$$Q = \frac{1}{3.3} \sqrt{\frac{1.0 \times 10^{-3}}{1.0 \times 10^{-6}}} = 9.6$$

Equation 12 Ideal Components & stated Values

$$Q = \frac{1}{2.89} \sqrt{\frac{0.977 \times 10^{-3}}{1.013 \times 10^{-6}}} = 10.7$$

Equation 13 Ideal Components & measured Values

$$Q = \frac{1}{2.89 + 2.89} \sqrt{\frac{1.004 \times 10^{-3}}{1.013 \times 10^{-6}}} = 5.5$$

Equation 14 Real Components with Measured Values

4.3.4.2 From Simulation:

Using Equation 9, $Q = \frac{f_{res}}{BW}$ where $f_{res} = 5,033\text{Hz}$ and $BW = 600\text{ Hz}$

$$Q = \frac{5033}{600} = 8.4$$

4.3.4.3 From Practical:

$Q = \frac{f_{res}}{BW}$ where $f_{res} = 5,023\text{Hz}$ and $BW = 69500\text{ Hz}$

$$Q = \frac{5023}{69500} = 0.07$$

The measured values were very different to those expected from using the equivalent circuit model and measured values to calculate the resonant frequency and Q factor.

4.3.5 Expected Voltage drop

Using the adapted version of Ohm's Law (Equation 1) for impedance, $V = IZ$, the current of the circuit before resonance was calculated. At resonance, the resistance dropped meaning the current wants to increase but is unable, consequently, the voltage drops in accordance with Ohm's Law.

4.3.5.1 Ideal Components

$$I = \frac{V}{Z} = \frac{4}{\sqrt{(R^2 + X^2)}} = \frac{4}{\sqrt{R^2 + \left(2\pi fL - \frac{1}{2\pi fC}\right)^2}}$$

Equation 15 Adapted Ohms Law for Reactance [2]

$$I_{Sim} = \frac{4}{\sqrt{3.3^2 + \left(2\pi 5033(1 \times 10^{-3}) - \frac{1}{2\pi 5033(1 \times 10^{-6})}\right)^2}} = 1.21A$$

Equation 16 Current circuit wants to draw at Resonance

$$I_{sim} = \frac{4}{\sqrt{3.3^2 + \left(2\pi 1000(1 \times 10^{-3}) - \frac{1}{2\pi 1000(1 \times 10^{-6})}\right)^2}} = 0.026A$$

Equation 17 Current circuit draws normally

$$V = IR = 0.026 \times 3.3 = 0.09V$$

Equation 18 Voltage during Resonance

4.3.5.2 Real Components with Measured Values

$$I_{prac} = \frac{4}{\sqrt{(2.89 + 2.89)^2 + \left(2\pi 5023(1.004 \times 10^{-3}) - \frac{1}{2\pi 5023(1.013 \times 10^{-6})}\right)^2}} = 0.69A$$

Equation 19 Practical Experiment: Current circuit wants to draw at Resonance

$$I_{prac} = \frac{4}{\sqrt{(2.89 + 2.89)^2 + \left(2\pi 1000(1.004 \times 10^{-3}) - \frac{1}{2\pi 1000(1.013 \times 10^{-6})}\right)^2}} = 0.027A$$

Equation 20 Practical Experiment: Current Circuit draws normally

$$V = IR = 0.027 \times (2.89 + 2.89) = 0.15V$$

Equation 21 Practical Circuit Voltage during Resonance

The two expected voltages at resonance are an order of 10 different from one another. These are different to the minimum voltage displayed in the graphs calculated from the results of the simulation and practical experiments.

5 Analysis

During this experiment the reactions of a simulated and a practical circuit to changes in the frequency of the A.C current was investigated.

Graphs of the voltage across the inductor and capacitor against the frequency of the A.C input were plotted in excel and compared (Figure 4 & Figure 5). The graphs showed significant differences in their shape, minimum voltage and central frequency (resonant frequency). These differences were more than expected from the differences in using ideal components in the simulation and real-world components in the practical experiment.

Using these graphs to calculate the bandwidth for the circuits, consequently, led to different results than those expected from theory. Using the ESR graph of the LC part of the circuit to calculate the bandwidth gives a value similar to that obtained in the simulation experiment but 1000th of the result measured from the practical experiment.

In the practical experiment, the voltage took a long time to recover creating a very large bandwidth and low Q Factor value. This was probably due to cumulation of numerous factors that affected the circuit resistance. The components used didn't have the values stated by the manufacturer but were instead built to a stated tolerance, the actual values of the components were measured to account for this. Each component has a combination of resistance, inductance and capacitance and in the case of the capacitor, the internal resistance (ESR) can change with frequency. The other parts of the circuit also add to the total resistance, capacitance and inductance: each of the wires used has a resistance, the probe has a capacitance, the signal generator will also introduce errors. The competence of the person performing the experiment will also have had an effect for example, how steady their hands were when making the connection, how well the earthing clip had been placed, the minimisation of wires in the building of the circuit.

The slow recovery of the voltage in the practical circuit led to the value for the resonant frequency calculated using the bandwidth to be significantly different to that calculated using the measured values of the components. The resonant frequency of the circuit measured from the component values is probably more accurate as this fitted with when the circuit started to show resonant behaviour.

The large bandwidth and consequently large measured resonant frequency of the practical circuit can all be summed up by the Q factor values measured. The expected Q factor for an ideal circuit was calculated and measured to be between 10.7 and 8.4, the variance of which can be explained by experimental errors. Taking into account the resistance of the inductor and the inductance of the resistor produces a Q Factor of 5.5. This was unsurprising as the Q Factor was heavily dependent on the resistance of the circuit and taking account of the resistance in the inductor doubles the resistance of the circuit. This expected value is still two orders of magnitude larger than the Q Factor found from the practical experiment's voltage frequency graph. This difference was greater than can be expected from additional resistance in the wires and breadboard and was most likely due to other experimental errors or damaged equipment.

The last part of the circuit investigated was the voltage drop caused at resonance. At resonance, the circuit tries to pass a large current as the inductance has been reduced. The current can't be produced, and so to follow Ohm's Law, the circuit instead experiences a corresponding voltage drop. The voltage read during the experiment was larger than the calculations suggested it should be, this could be tied to the Q Factor, where a larger resistance than expected appeared to be present in the

circuit, but could also be a factor of the measurements around the resonant frequency being too coarse to observe the absolute minima.

5.1 Experimental Errors

Experimental errors could have been introduced at all points of the experiment: some of these could be accounted for, such as measuring the actual values of the components rather than using the stated values. Errors in reading the graphs to find the bandwidth could resolve the differences seen between the Q Factor calculated using the component values (9.3) and the Q factor measured from the frequency voltage graph of the simulation results (8.4). These relate to Bandwidths of 526 Hz and 600 Hz respectively which can be accounted for by the line drawing function of Excel and the human error from measuring the points of intersection. Other sources of error include, the reading of the oscilloscope in both the practical and simulation experiments which depending on the voltage per division settings, could have produced an error of up to $\pm 0.25V$ on all the measurements.

The scope probe in the practical experiment, would have had small effect on the capacitance and inductance in the circuit, this would however be small compared to the other errors as the scope is designed to have very small impact.

At resonance, the circuit is supposed to produce a large current flow, however the output impedance of the signal generator in the practical prevents the generation of this much current and instead produces a voltage drop which could skew the results.

5.2 Recommendations

The simulation could be improved, to better represent the practical, by using the measured values of the components which were used in the practical experiment. It could have been improved further by re-drawing the circuit using the equivalent circuit to account for all the sources of resistance, capacitance and inductance.

To measure a more precise value for the Q factor, more measurements could be taken around the expected resonant frequency.

Repeating the simulation with components of different tolerances could be undertaken to confirm the resistance of the inductor had the biggest effect of all the components on the Q factor.

6 Conclusions

It was impossible to match simulations to practical work perfectly, there are always some differences arising from the variable quality of components and user capability.

Simulations can be a good guide and make a good starting point to predict what a practical circuit will do, but should not be taken as absolute truth.

The Q Factor of the practical circuit was affected by resistance in the circuit that couldn't be accounted for in the simulation.

The large bandwidth of the practical circuit would have decreased its selectivity in response to certain frequencies which if it had been part of a larger system could have had a large effect on the system as a whole.

7 References

- [1] AUGUSTANA COLLEGE, "LECTURE 25," 8 2 2018. [ONLINE]. AVAILABLE: [HTTP://HELIOS.AUGUSTANA.EDU/~DR/102/LECTURES/25.HTML](http://helios.augustana.edu/~dr/102/lectures/25.html). [ACCESSED 26 1 2019].
- [2] P. HOROWITZ AND W. HILL, THE ART OF ELECTRONICS, 3 ED., VOL. 1, CAMBRIDGE: CAMBRIDGE UNIVERISTY PRESS, 2015.
- [3] EDITORS OF ENCYCLOPEDIA BRITANNICA, "FREQUENCY (PHYSICS)," ENCYCLOPEDIA BRITANNICA, 28 3 2017. [ONLINE]. AVAILABLE: [HTTPS://WWW.BRITANNICA.COM/SCIENCE/FREQUENCY-PHYSICS](https://www.britannica.com/science/frequency-physics). [ACCESSED 26 1 2019].
- [4] EDITORS OF LEARNING ABOUT ELECTRONICS, "RMS VOLTAGE AND CURRENT-EXPLAINED," LEARNING ABOUT ELECTRONICS, 2018. [ONLINE]. AVAILABLE: [HTTP://WWW.LEARNINGABOUELECTRONICS.COM/ARTICLES/RMS-VOLTAGE-AND-CURRENT-EXPLAINED.PHP](http://www.learningaboutelectronics.com/articles/rms-voltage-and-current-explained.php). [ACCESSED 26 1 2019].
- [5] THE EDITORS OF ENCYCLOPEDIA BRITANNICA, "REACTANCE," ENCYCLOPEDIA BRITANNICA, 26 4 2013. [ONLINE]. AVAILABLE: [HTTPS://WWW.BRITANNICA.COM/TECHNOLOGY/REACTANCE](https://www.britannica.com/technology/reactance). [ACCESSED 26 1 2019].
- [6] TEXAS INSTRUMENTS, "UNDERSTANDING BASIC ANALOGUE-PASSIVE DEVICES," TEXAS INSTRUMENTS, 1999.
- [7] EDITORS OF ELECTRONICS TUTORIALS, "AC INDUCTORS," ELECTRONICS TUTORIALS, [ONLINE]. AVAILABLE: [HTTPS://WWW.ELECTRONICS-TUTORIALS.WS/INDUCTOR/AC-INDUCTORS.HTML](https://www.electronics-tutorials.ws/inductor/ac-inductors.html). [ACCESSED 26 1 2019].
- [8] R. NAVE, "RESONANCE," HYPER PHYSICS, [ONLINE]. AVAILABLE: [HTTP://HYPERPHYSICS.PHY-ASTR.GSU.EDU/HBASE/ELECTRIC/SERRES.HTML](http://hyperphysics.phy-astr.gsu.edu/hbase/electric/serres.html). [ACCESSED 31 1 2019].
- [9] ELECTRICAL4U, "RESONANCE IN SERIES RLC CIRCUIT," 8 10 2018. [ONLINE]. AVAILABLE: [HTTPS://WWW.ELECTRICAL4U.COM/RESONANCE-IN-SERIES-RLC-CIRCUIT/](https://www.electrical4u.com/resonance-in-series-rlc-circuit/). [ACCESSED 26 1 2019].
- [10] ELPROCUS, "GUIDE ON RESONANT RLC CIRCUITS WORKING AND APPLICATIONS," ELPROCUS, 2013. [ONLINE]. AVAILABLE: [HTTPS://WWW.ELPROCUS.COM/GUIDE-ON-RESONANT-RLC-CIRCUITS-WORKING-AND-APPLICATION/](https://www.elprocus.com/guide-on-resonant-rlc-circuits-working-and-application/). [ACCESSED 31 1 2019].
- [11] S. MOSEY, "Q FACTOR (QUALITY FACTOR)," UWTSD, SWANSEA, 2016-17.
- [12] VISHAY ROEDERSTEIN, "FILM CAPACITORS," VISHAY ROEDERSTEIN, 2017.
- [13] S. MOSEY, COMPONENTS USED IN ASSIGNMENT, SWANSEA: UWTSD, 2018.
- [14] EDITORS OF MERRIAM-WEBSTER, "RESONANCE," MERRIAM-WEBSTER, 14 1 2019. [ONLINE]. AVAILABLE: [HTTPS://WWW.MERRIAM-WEBSTER.COM/Dictionary/RESONANCE](https://www.merriam-webster.com/dictionary/resonance). [ACCESSED 26 1 2019].

8 Appendix

8.1 Measured Values of Components from Practical Experiment [13]

Component	Stated Value	Measured Resistance	Measured Inductance	Measured Capacitance
		Ω	mH	μF
Resistor	3.3Ω	2.89	0.0137	N/A
Inductor	1mH	2.89	0.977	N/A
Capacitor	$1\mu F$	1kHz = 5.09189×10^{-5}	0.007	1.013
		10kHz = 7.63784×10^{-4}		

Table 2 Component Values

8.2 Equivalent circuit diagrams

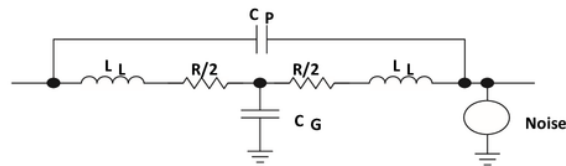


Figure 9 Resistor Equivalent Circuit [6]

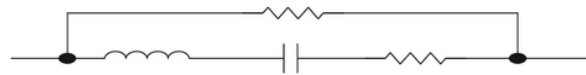


Figure 10 Capacitor Equivalent Circuit [6]



Figure 11 Inductor Equivalent Circuit [6]

Resonance

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GENERAL COMMENTS

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Instructor

PAGE 1

PAGE 2



Comment 1

Nice abstract. All required info in one place.

PAGE 3

PAGE 4

PAGE 5



Comment 2

generated BY a magnetic field



Comment 3

dielectric?

PAGE 6



Comment 4

'would not be'?

PAGE 7



Comment 5

something wrong with the reference to this equation

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73.25

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

3.9

referencing skills, consistently applied.

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.



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, justifiable recommendations.

21.6

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



An advanced application of a range of methods, tools and techniques. The context of the application is well considered, with extensive use of relevant examples. Creativity evident throughout.

21.6

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.

3.65