

OME_Resonance_Atkins

by Stuart Atkins

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1. Resonance

By Stuart Atkins (Student Number 1809912)

Practical Laboratory Experiment conducted on 14th January 2019

2. Abstract

The purpose of the experiment was to determine how the frequency of an RLC circuit affects the voltage across the inductor and capacitor, and how this compares with a simulation of the same circuit. The results showed that for both the practical experiment and the simulation the voltage across the inductor and capacitor was at its lowest at the point of resonant frequency. The Q (Quality) Factor for the simulation was similar to the calculated Q Factor, but the Q Factor for the practical experiment was much lower, due to resistive losses not taken into account in the simulation. The inductance and capacitance in an RLC circuit is directly related to the frequency input and at a specific frequency (known as resonance) they cancel each other out. Simulating circuits is a good way to see how different components may affect a circuit and its behaviour, but it is important to conduct a practical experiment to establish effects on the circuit by resistance, temperature etc.  1

3. Introduction

The aim of the experiment was to measure the peak to peak voltage across passive components (an inductor and capacitor) at a different range of frequencies in an RLC circuit in series. The experiment was also simulated on Proteus Design Suite and the results compared.

Series Resonance circuits are commonly in use within electrical and electronic circuits and are considered to be very important. Common uses can be found in equipment such as in AC mains filters, noise filters and also in radio and television tuning circuits [1].

An RLC circuit is created when a voltage supply is connected to a resistor, an inductor and a capacitor in series. These three components use energy rather than produce it and have a linear relationship between voltage and current [2]. An example of an RLC circuit can be seen in *Figure 1*.

The impedance (Z) of a series RLC circuit is defined as opposition to the flow of current due to resistance in the circuit (R), inductive reactance (X_L), and capacitive reactance (X_C). If the reactance from the inductor is greater than the capacitor's reactance, then the RLC circuit has a lagging phase angle and if the capacitive reactance is greater than the inductive reactance, the RLC circuit has a leading phase angle. If $X_L = X_C$ (both the inductive and capacitive reactances have the same value) then the circuit behaves as a purely resistive circuit [2].

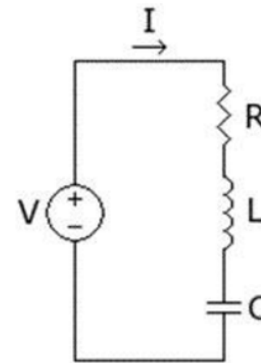


Figure 1 - RLC Circuit [3]

The combination of resistance, inductive reactance, and capacitive reactance is defined to be impedance. A version of Ohm's law shows the relationship between Current, voltage, and impedance in an RLC circuit, as seen below:

$$I_0 = \frac{V_0}{Z} \text{ or } I_{\text{rms}} = \frac{V_{\text{rms}}}{Z}. \quad [4]$$

Here I_0 is the peak current, V_0 is the peak source voltage, and Z is the impedance of the circuit. In order to establish an equation for impedance we must look at the relationship between the different components and the source voltage [4].

2

Current is known to be the same across all parts of a circuit at all times due to conservation of charge, therefore the currents in R, L, and C are determined to be equal and in phase. The voltage across the resistor (V_R) is in phase with the current, the voltage across the capacitor (V_C) follows behind the current by a quarter of a cycle and the voltage across the inductor (V_L) leads the current by a quarter of a cycle. According to Kirchhoff's loop rule, the total voltage around the circuit (V) is also the source voltage [4].

As V_R is in phase with the current, V_C follows by 90° and V_L leads by 90° , this means that V_L and V_C are 180° out of phase and cancel, although not entirely unless they have the same value. Since the peak voltages are not in phase, the peak voltage of the source cannot be worked out by adding up the peak voltages across R, L, and C. The actual relationship is:

$$V_0 = \sqrt{V_{0R}^2 + (V_{0L} - V_{0C})^2}, \quad [4]$$

In the formula above, V_{0R} is the peak voltage across the resistor, V_{0L} is the peak voltage across the inductor and V_{0C} is the peak voltage across the capacitor. By substituting in definitions for the different reactances, and Ohm's law, the equation simplifies to leave the expression for impedance (Z):

$$Z = \sqrt{R^2 + (X_L - X_C)^2}, \quad [4]$$

In a series RLC circuit, as the frequency is increased, the reactance value of an inductor increases linearly, meaning inductive reactance is positive and is directly proportional to frequency ($X_L \propto f$). For a capacitor, if the frequency is increased the capacitive reactance decreases. As the frequency reaches infinity, the capacitor's reactance reduces almost to zero, causing it to act like a perfect conductor with 0Ω . But as the frequency approaches zero, the capacitor's reactance rapidly increases up to infinity causing it to act like a very large resistance, acting like an open circuit. This means that capacitive reactance is inversely proportional to frequency ($X_C \propto f^{-1}$). At a high frequency X_L is high, and at a low frequency X_C is high. This means that there is an intermediate frequency point where the value of X_L is the same as the value of X_C . Electrical resonance occurs when the two reactants, which are opposite and equal, cancel each other out as $X_L = X_C$. In a series resonant circuit, this is known as the resonant frequency (f_r) and can be calculated as follows [1]:

$$X_L = X_C$$

Substituting the definitions of X_L and X_C ,

$$2\pi f_0 L = \frac{1}{2\pi f_0 C} \quad [1]$$

Transforming this equation to determine resonant frequency;

$$f_0 = \frac{1}{2\pi\sqrt{LC}}, \quad [1]$$

In a circuit containing an inductor and capacitor, the energy is stored in two different ways. For the inductor, energy is stored in a magnetic field when current is applied to it, whereas when a capacitor is charged the energy is stored in an electric field [2].

The magnetic field in the inductor is created when current flows through it, which is provided by the capacitor discharging. Similarly, the capacitor is charged by the current produced by the collapsing of the magnetic field of the inductor, creating an electrical field and this action repeats, causing electrical energy to fluctuate between the magnetic field and the electric field. At resonant frequency, the reactance of the inductor becomes equal to the reactance of the capacitor which causes the electrical energy to fluctuate between the electric field of the capacitor and magnetic field of the inductor [2].

The Quality Factor (Q Factor) of a circuit describes how under-damped a resonator is. The higher the Q factor the less damping there is. In an RLC circuit damping is caused by the loss of energy in resistive components. Therefore, the higher the Q Factor, the more efficient the circuit is [5].

4. Materials and Methods

Bread Board - A solderless plug board that is reusable and used for prototyping in electronics.

Jumper wires – Wires used to connect components within a circuit.

Resistor - A resistor is an electrical component that limits or regulates the flow of electrical current in an electronic circuit.

Inductor - A passive electronic component that stores energy in the form of a magnetic field.

Capacitor – A passive electronic component that consists of two conducting plates separated by an insulating material.

Signal generator – Used to provide a specific input to the circuit.

Oscilloscope - A laboratory instrument commonly used to display and analyse the waveform of electronic signals [6].

5. Experimental Procedure

There were two parts to the assignment, a simulation model and a laboratory experiment.

In order to complete the simulation, the following circuit (*Figure 2*) was created using Proteus Design Suite;

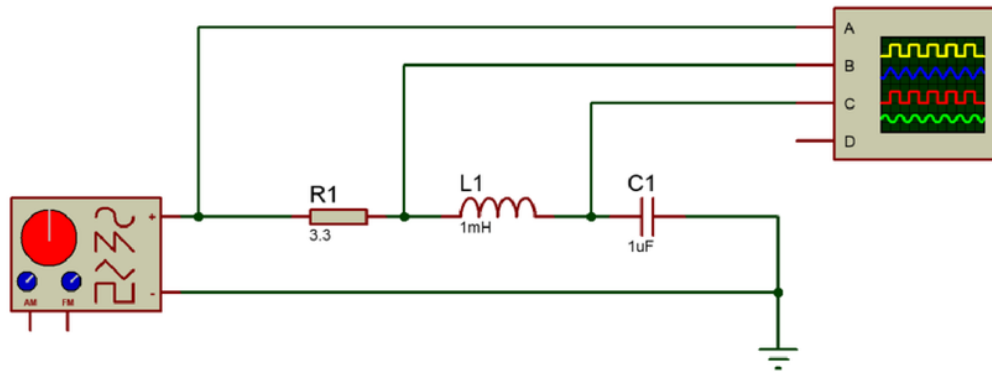


Figure 2 - Showing RLC circuit created on Proteus Design Suite

The input voltage on the signal generator was set to 4v and the frequency at 100hz. Using the oscilloscope, the voltage peak to peak was measured from peak to trough of the waveform and recorded in an excel spreadsheet. The frequencies were then increased gradually, with measurements taken at each frequency.

By plotting the output voltages against frequency, the behaviour of the circuit can be seen as different frequencies were applied. In order to establish a more accurate resonant frequency, the frequencies between 4500-5500hz, were measured at smaller intervals.

For the laboratory experiment an RLC circuit in series was set up. To do this, a breadboard, a 3.3 Ohm resistor, a 1mH inductor and a 1uF capacitor were used. The three passive components were put in series on the breadboard and connected using wires. The input to the circuit was supplied by the signal generator and the oscilloscope probes were connected to the circuit to measure across the inductor and capacitor. A 4V peak to peak input voltage and a 100Hz sine wave was applied to the circuit from the signal generator.

The peak to peak voltage was measured from the oscilloscope by measuring from the peak of the wave to the trough. As with the simulation, the frequency was then increased at the same intervals, and the voltages were measured and recorded in the excel spreadsheet.

6. Results

Table 1 - Showing Inductor and Capacitor Reactances for different frequencies

Frequency (Hz)	XL (Ohms)	XC (Ohms)	Frequency (Hz)	XL (Ohms)	XC (Ohms)
100	0.628318531	1591.549431	5900	37.07079331	26.97541408
200	1.256637061	795.7747155	6000	37.69911184	26.52582385
500	3.141592654	318.3098862	6200	38.9557489	25.67015211
1000	6.283185307	159.1549431	6400	40.21238597	24.86795986
2000	12.56637061	79.57747155	6800	42.72566009	23.40513869
3000	18.84955592	53.0516477	7000	43.98229715	22.73642044
3500	21.99114858	45.47284088	7500	47.1238898	21.22065908
3800	23.87610417	41.88287976	8000	50.26548246	19.89436789
4000	25.13274123	39.78873577	8500	53.40707511	18.72411095
4200	26.38937829	37.89403407	9000	56.54866776	17.68388257
4400	27.64601535	36.17157798	10000	62.83185307	15.91549431
4500	28.27433388	35.36776513	11000	69.11503838	14.46863119
4600	28.90265241	34.59890067	12000	75.39822369	13.26291192
4700	29.53097094	33.86275385	13000	81.68140899	12.24268793
4800	30.15928947	33.15727981	14000	87.9645943	11.36821022
4900	30.78760801	32.48060063	15000	94.24777961	10.61032954
5000	31.41592654	31.83098862	16000	100.5309649	9.947183943
5100	32.04424507	31.20685159	17000	106.8141502	9.362055476
5200	32.6725636	30.60671983	18000	113.0973355	8.841941283
5300	33.30088213	30.02923455	20000	125.6637061	7.957747155
5400	33.92920066	29.47313761	30000	188.4955592	5.30516477
5500	34.55751919	28.93726238	40000	251.3274123	3.978873577
5600	35.18583772	28.42052555	50000	314.1592654	3.183098862
5700	35.81415625	27.92191984	100000	628.3185307	1.591549431
5800	36.44247478	27.44050743			

Table 1 shows the calculated Inductance (XL) and Capacitance (XC) for the different frequencies that measurements were taken for. These were calculated using the equations for XL and XC and the given values of L and C (1mH and 1uF respectfully). This supports the theory that inductive reactance is low at low frequencies and increases as the frequency increases, and the capacitor reactance is high at low frequencies and reduces as the frequency increases. This data is shown in graph form in Figure 3.

Table 2 - Showing voltage measurements for different frequencies, for both the Simulation and the Experiment

	Lab Experiment	Proteus Simulation		Lab Experiment	Proteus Simulation
Frequency (Hz)	VL+VC (V)		Frequency (Hz)	VL+VC (V)	
100	4	4	5900	0.74	3.86
200	4	4	6000	0.85	3.88
500	3.9	4	6200	0.95	3.9
1000	3.6	4	6400	1.08	3.95
2000	3	4	6800	1.3	4
3000	2	4	7000	1.4	4
3500	1.5	4	7500	1.7	4
3800	1.15	4	8000	1.9	4
4000	0.95	4	8500	2.1	4
4200	0.75	3.9	9000	2.25	4
4400	0.57	3.6	10000	2.5	4
4500	0.49	3.5	11000	2.75	4
4600	0.41	3.35	12000	2.9	4
4700	0.32	2.85	13000	3	4
4800	0.27	2.1	14000	3.15	4
4900	0.23	0.9	15000	3.2	4
5000	0.23	0.6	16000	3.3	4
5100	0.26	1.8	17000	3.35	4
5200	0.3	2.6	18000	3.4	4
5300	0.35	3.1	20000	3.5	4
5400	0.41	3.4	30000	3.75	4
5500	0.48	3.55	40000	3.85	4
5600	0.54	3.68	50000	3.95	4
5700	0.61	3.75	100000	4	4
5800	0.68	3.8			

Table 2 shows the voltage measured across the inductor and capacitor for the different frequencies. It shows that at very low and very high frequencies the voltage across the inductor and capacitor is close to the source voltage. When the frequency nears 5000Hz the voltage across the inductor and capacitor is at its lowest. This data is also displayed in the graph below (*Figure 4*).

Figure 3 - Graph showing Reactance vs Frequency

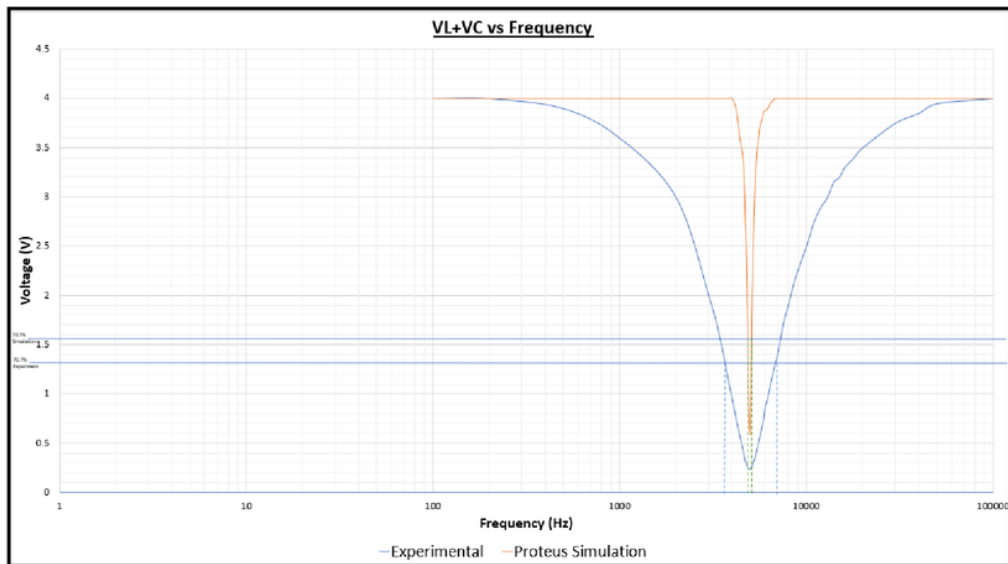
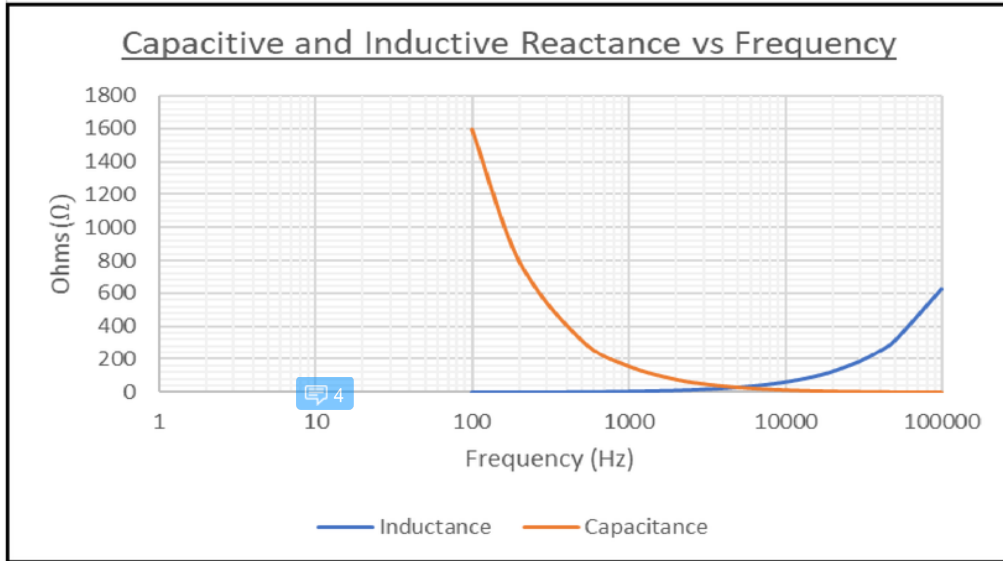


Figure 4 - Graph showing VL + VC against frequency for both the Lab Experiment and the Simulation

From the graph (*Figure 4*) the resonant frequency is determined to be 5000Hz. The Q factor can be determined from the graph by using the following formula:

$$Q \text{ Factor} = \text{Resonant Frequency} / \text{Bandwidth}$$

The bandwidth was established by reading the upper and lower frequency values, where the plotted line on the graph for both the simulation and lab experiment crosses the point at which the magnitude is 70.7%.

$$\text{The bandwidth for the practical experiment} = 6900 - 3700 = 3200$$

$$Q \text{ Factor} = 5000 / 3200 = 1.56$$

$$\text{The bandwidth for the simulation results} = 5200 - 4750 = 450$$

$$Q \text{ Factor} = 5000 / 450 = 11.1$$

Below are calculations for both the given values and the actual measured values for the components used in the experiment.

Given values –

Resistor – 3.3 Ohms

Inductor – 1 mH

Capacitor – 1 uF

Measured values –

Resistor – 2.89 Ohms

Inductor – 0.977 mH

Capacitor – 1.013 uF

Given values for RLC

Resonant Frequency

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

$$Fr = \frac{1}{2\pi\sqrt{0.001 \times 0.000001}}$$

$$= 5032.92\text{Hz}$$

Circuit current

$$I = \frac{V}{R}$$

$$I = \frac{4}{3.3} = 1.21\text{A}$$

Measured values for RLC

$$Fr = \frac{1}{2\pi\sqrt{0.000977 \times 0.000001013}}$$

$$= 5059.04\text{Hz}$$

$$I = \frac{4}{2.89} = 1.38\text{A}$$

Inductor reactance (X_L) at resonance

$$X_L = 2\pi fL \quad X_L = 2\pi \times 5032.92 \times 0.001$$

$$= 31.623\Omega$$

Capacitor reactance (X_C) at resonance

$$X_C = \frac{1}{2\pi fC} \quad X_C = \frac{1}{2\pi \times 5032.92 \times 0.000001}$$

$$= 31.623\Omega$$

$$Q \text{ Factor} = \frac{X_L}{R} \quad Q \text{ Factor} = \frac{31.623}{3.3} = 9.58$$

$$\text{Band Width} = \frac{fr}{Q} \quad \frac{5032.92}{9.58} = 525.36\text{Hz}$$

$$X_L = 2\pi \times 5059.04 \times 0.000977$$

$$= 31.056\Omega$$

$$X_C = \frac{1}{2\pi \times 5059.04 \times 0.000001013}$$

$$= 31.056\Omega$$

$$Q \text{ Factor} = \frac{31.056}{2.89} = 10.75$$

$$\frac{5059.04}{10.75} = 470.61\text{Hz}$$

The results show that the voltage across the inductor and capacitor changes depending on the frequency applied. At very low and very high frequencies the voltage across the inductor and capacitor is close to source voltage, but as we get closer to the resonant frequency, the voltage decreases. This is because at resonant frequency, the X_L and X_C (reactances of the inductor and capacitor) have the same value and therefore cancel each other out meaning the series impedance for the two components is at its lowest. As $Z = V/I$ (and current remains the same throughout the circuit) when the impedance drops, as does voltage. This is supported by the graph (*Figure 3*). This graph shows the inductive and capacitive reactances for the different frequencies, using the given values for L and C . They have both been plotted on the graph and it can be seen that they cross at the same point as resonant frequency. This is the point at which X_L and X_C have the same value and cancel each other out.

The resonant frequency is calculated using the formula as 5032.92Hz for the given component values and 5059.04Hz for the measured values, and this is very similar to the resonant frequency determined from the graph. The resonant frequency established by the graph was determined to be 5000Hz which differs from the calculations by <1%, which shows that the experiment was conducted successfully. For both the simulation and the experiment the intervals between the chosen frequencies were 100hz, at and around the resonant frequency. If I had taken more measurements at this point, say for example taking

measurements every 10Hz, the peaks of the graph would have been closer to the calculated resonant frequency.

The calculated Q factor using theory is 9.58 for the given component values and 10.75 for the measured values. This is very similar to the Q factor determined from the graph for the simulation, which was 11.1. The Q factor of the lab experiment was 1.56 which is much lower and the peak of the graph has a much larger bandwidth. This Q Factor is much lower because in the real-world, components within a circuit have resistive losses causing energy to be lost. Ideal components in a simulation do not suffer from resistive losses and therefore are considered to be highly efficient. For example, in an ideal capacitor the two plates are perfectly insulated from each other. However, in a real-world capacitor the insulation comes from the dielectric between the two plates which has a finite resistance. This allows a small current to flow between the two plates [5]. The inductor used in the practical experiment has a component resistance of 2.89 ohms, which is a considerable resistance. The simulation would not take this into account, whereas in the experiment this resistance would affect the efficiency of the circuit and therefore reduce the Q Factor. Another factor to consider is that in the practical experiment, external equipment was connected to the RLC circuit, such as the oscilloscope. The oscilloscope has its own internal circuitry and wiring which means resistance occurs, which is not something that is taken into account for the oscilloscope within the simulation.

There were a number of other factors and variables that may have affected the accuracy of the results. Taking a peak to peak voltage measurement from the screen of the oscilloscope was difficult and ensured knowledge of how to use the different ranges/positions to get more accurate readings. This also became difficult when the peak of the wave signal 'spiked' and made it more difficult to identify the position of the peak. Also, when adjusting the input frequency, it was difficult to get the exact frequency required due to the sensitivity of the dial. I did not encounter any anomalies in my results so it is likely that I did not make any major errors in taking measurements but there is always the possibility of human error. I have since learnt that the oscilloscope has a built-in function that displays the pk to pk voltage as a figure. Although I believe my 'counting squares' method was fairly accurate, I have no doubt that by using the figures given by the oscilloscope my results for the experiment would have been more accurate. However, this will have made little difference to the pattern of the results or the outcome of the experiment.

7. Conclusion



I conclude that the inductance and capacitance in an RLC circuit is directly related to the frequency input. At a specific frequency they cancel each other out causing the circuit to behave as a resistive circuit, where impedance is at its lowest.

From a comparison of the results of the experiment and the results of the simulation it can be concluded that a simulated circuit does not take into account resistive losses within the components which gives the circuit an appearance of having a high Q Factor (higher efficiency). Therefore, although simulating circuits is a good way to see how different components may affect a circuit and its behaviour, it is important to conduct a practical experiment to establish the effects on the circuit by component resistances, temperature etc.

8. Reference List

- [1] Unknown Author – Series Resonance Circuit - Available online: <https://www.electronics-tutorials.ws/accircuits/series-resonance.html> (Accessed January 19th 2019)
- [2] Unknown Author – RLC Circuit - Available online: <https://www.electrical4u.com/rlc-circuit/> (Accessed January 25th 2019)
- [3] Image taken from online: (<https://www.elprocus.com/guide-on-resonant-rlc-circuits-working-and-application/> Accessed January 25th 2019)
- [4] Unknown Author – RLC Series AC circuits – Available online: <https://opentextbc.ca/physicstestbook2/chapter/rlc-series-ac-circuits/#import-auto-id1169738164070> (Accessed January 19th 2019)
- [5] Andrew McHutchon – Resonant Circuits (April 20, 2013) – Available online: <http://mlg.eng.cam.ac.uk/mchutchon/ResonantCircuits.pdf> (Accessed January 18th 2019)
- [6] Unknown Author – Available online: <https://whatis.techtarget.com> (Accessed January 18th 2019)

FINAL GRADE

GENERAL COMMENTS

Instructor

61/100

PAGE 1



Comment 1

Nice abstract. It tells me what I need to know about the work you have done in few words.

PAGE 2



Comment 2

through.

Current flows through components, not across them.

PAGE 3

PAGE 4

PAGE 5



Comment 3

respectively

PAGE 6

PAGE 7



Comment 4

Nice graph but not sure why your frequency axis starts at 1Hz when the data starts at 100Hz.

PAGE 8

PAGE 9

**Comment 5**

I assume you are referring to inductive and capacitive reactance here.

GRADING FORM: SMU GENERIC_SMOSEY

STUART ATKINS**61.30****ENGAGEMENT WITH LITERATURE**

including reading, referencing, academic conventions and academic honesty



You have included a number of independently retrieved references, but you should be looking to use more credible sources such as peer reviewed journal papers, and text books etc. Referencing conventions consistently applied.

2.5**KNOWLEDGE & UNDERSTANDING**

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



Knowledge is extensive. Exhibits a thorough understanding of the concepts discussed.

19.2**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. You have shown an ability to devise and sustain persuasive arguments, and to review the reliability, validity & significance of evidence. Ability to communicate ideas and evidence accurately and convincingly. Sound, convincing conclusions.

18.3

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



A good and appropriate application of standard methods, tools and techniques. Good appreciation of the context of the application.

17.4

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.

3.9