

Resonance Report

by Luke Penny

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TIME SUBMITTED	15-FEB-2019 09:04AM (UTC+0000)	WORD COUNT	2784
SUBMISSION ID	100723503	CHARACTER COUNT	18505

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Author: Luke Penny

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Objective

The main objective of this report is to perform a laboratory experiment to record and analyse data from a series RLC circuit. Then perform the same circuit on a simulation software and compare the results and determine the resonant frequency and 'Q' factor.

Abstract

Resonance in an electrical circuit occurs when the reactance of an inductor balances the reactance of a capacitor at a given frequency value. In this report there will be comparative data on resonance within a series circuit. In order to gather data on resonance in a series circuit, two different types of experiment were conducted. The first experiment was taken place in a laboratory using relevant components and oscilloscopes. The second part of the experiment was to simulate the same RLC series circuit in a software program called proteus. The results show that in a resonant circuit when the capacitance and reactance are of equal measure, they cancel each other out. There is no phase shift present in an ac circuit at resonance so the only impedance on the circuit is resistance.



Introduction

In this report, the topic of resonance will be explained and relevant data will be introduced to compare results from a laboratory experiment and the same experiment run on a simulation software, the results will be produced and data will be analysed.

Firstly, Ohms law must be introduced to understand the relationship between Voltage, Current and Resistance. He stated that at a constant temperature, the electrical current flowing through a fixed resistance is directly proportional to the voltage applied across it, and this is also proportional to resistance. By knowing any two values of Voltage, Resistance or Current, we can use this law to find the third missing value. [1]

Resonance in an RLC circuit occurs when the reactance of an inductor balances the reactance of a capacitor at a given frequency value. This causes the electrical energy stored in the inductor and capacitor to oscillate between the magnetic field. When the resonant frequency is reached, the impedance of the circuit is at a minimum making a series RLC circuit a resonant circuit. Being a resonant circuit, the current will be maximum and offering minimum impedance. In a parallel resonant circuit, the opposite is valid. [2]



To understand how to find out impedance, reactance and inductance on a circuit there are some formulae to follow, as shown below; [2]

- Inductive reactance: $X_L = 2\pi fL = \omega L$
- Capacitive reactance: $X_C = \frac{1}{2\pi fC} = \frac{1}{\omega C}$
- When $X_L > X_C$ the circuit is Inductive
- When $X_C > X_L$ the circuit is Capacitive
- Total circuit reactance = $X_T = X_L - X_C$ or $X_C - X_L$
- Total circuit impedance = $Z = \sqrt{R^2 + X_T^2} = R + jX$



Figure 1 - Equations [1]

From the equations above we can see for inductive reactance, if either the frequency or the inductance is increased, the overall inductive reactance of the inductor would increase, thus being illustrated as a straight-line linear curve, showing that inductive reactance is proportional to frequency. The same can apply to capacitive reactance but in reverse, so if either the frequency of the capacitance is increased, the overall capacitive reactance would decrease.

The frequency point at which the capacitive reactance of the capacitor becomes equal to the inductive reactance of the inductor is called the resonant frequency. This can be worked out using the equation shown, $\frac{1}{2\pi\sqrt{LC}}$ [3].

The 'Q' (quality) factor can be used to assess the performance of a resonant circuit. The 'Q' factor is a number that describes the damping in the circuit, this also provides an indication of the resonator's bandwidth relative to the frequency. These values of 'Q' factor can be used to define the performance of an inductor and a capacitor. 'Q' is defined as the ratio of the energy stored in the resonator to the energy supplied, per signal, to keep the amplitude constant, at a frequency where the energy stored is constant with time. The 'Q' factor can be measured by looking at the sharpness of the peak, this relates to the peak (maximum) energy stored in the circuit.

Series RLC circuits are widely regarded as one of the most important circuits and have many applications such as in radio and television tuning circuits because they can be finely tuned to receive different frequency channels because they have a low impedance.

4

Materials and Method.

The laboratory experiment required several components and software to be able to record any data, the list below shows what components were used in the laboratory experiment;

- Breadboard
- Oscilloscope
- Oscilloscope probe/ground
- Jumper wires
- Resistor
- Inductor
- Capacitor
- Signal Generator
- Crocodile clips

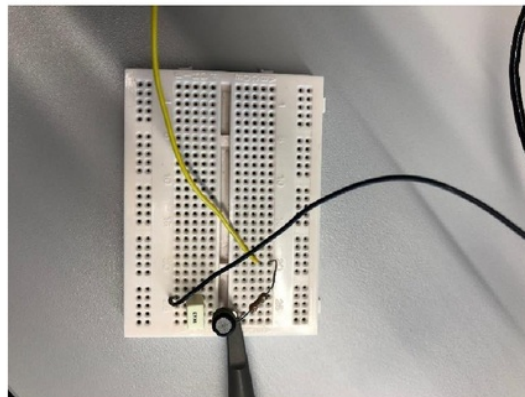


Figure 2 - Final Breadboard configuration

Figure 2, above shows the set-up of the breadboard, containing all the components in a series circuit and the oscilloscope probe connected to gather data across the inductor and capacitor.



Figure 3 - Oscilloscope and Signal Generator

Figure 3, shows the signal generator and oscilloscope used to record data collected from running the experiment.

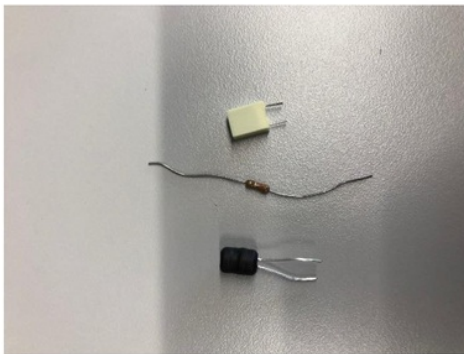


Figure 4 - Resistor, Capacitor and Inductor

Figure 4, shows the components used in the experiment, the top is an inductor, the middle component is a resistor and the bottom component is the capacitor.



Figure 5 - Oscilloscope Probe

Figure 5, shows the oscilloscope probe used in the experiment.

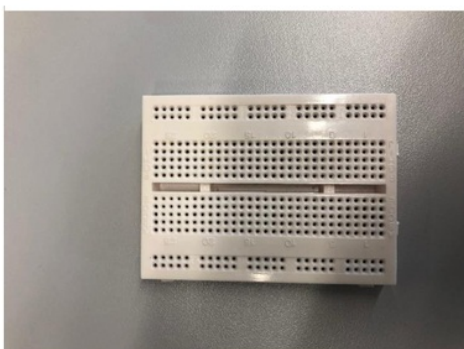


Figure 6 - Breadboard

Figure 6, shows the breadboard, where all the components were installed in a series circuit

Experiment Procedure

- 1) Build the circuit as shown in **figure 2**, using the correct components in a series configuration on the breadboard.
- 2) Connect the oscilloscope probe to the oscilloscope/signal generator.
- 3) Connect the oscilloscope probe to the base of the inductor.
- 4) Use the jumper wires either side of your components to connect to the jumper leads to the signal generator.
- 5) Set the signal generator output to 4 VRMS at 5kHz
- 6) Measure V_R , V_C and V_L at 5kHz.
- 7) Repeat the above procedure for a range of frequencies up to a maximum of 30kHz.
- 8) Plot the results onto Microsoft excel into a table, with the headings for frequency and V_C and V_L . 'f' will be along the 'x' axis and V_C and V_L along the 'y' axis.
- 9) Determine resonant frequency from the graph generated from the results and compare with that determined from basic theory.
- 10) Determine 'Q' from the graph and compare with basic theory.

In order to produce a detailed graph generated from the results, several close measurements from the oscilloscope will need to be taken when reaching the peak of the response in order to determine the peak accurately.

Simulation Procedure

- 1) Build the circuit as shown in **figure 7**, on the simulation software proteus. All the components are generic components found on the software database.

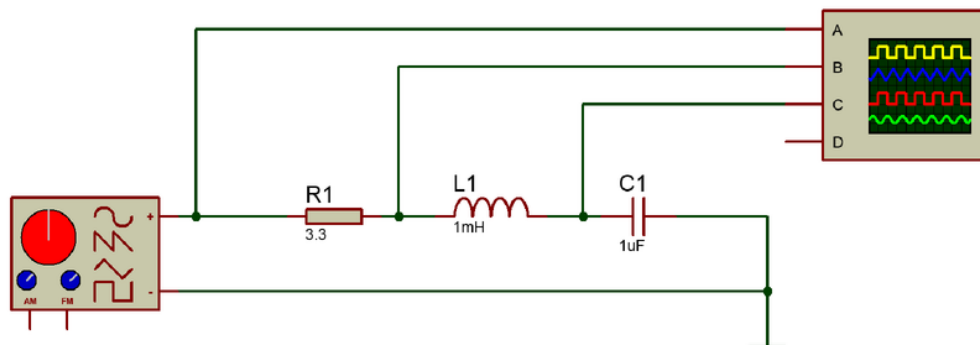


Figure 7 – Component layout on proteus.

- 2) Connect the components together in a series configuration as shown, connect to the oscilloscope and signal generator.
- 3) Set the given values for each component in the diagram, making sure to use the correct units.
- 4) Set the signal generator to an output of 4 VRMS at 5kHz and record the data shown on the oscilloscope. The 'sine' wave produced from the 'B' output on the signal generator is the measurement that needs to be taken.
- 5) Measure V_R , V_C and V_L at 5kHz.
- 6) Repeat the above procedure at a range of frequencies, up to a maximum of 30kHz.
- 7) Plot the results onto Microsoft excel into a table, with the headings for frequency and V_C and V_L . 'f' will be along the 'x' axis and V_C along the 'y' axis.
- 8) Determine resonant frequency from the graph produced from Microsoft excel and compare that to basic theory.
- 9) Determine 'Q' factor from the graph and compare with basic theory.

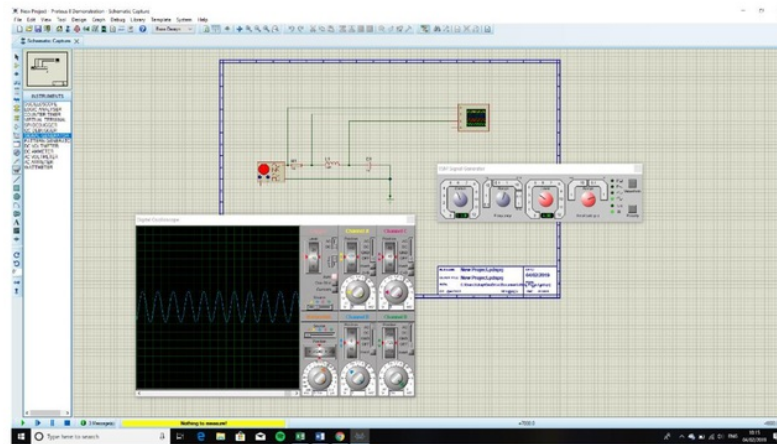


Figure 8 – Final set-up on Proteus

Figure 8, shows the final layout of components on Proteus including the signal generator and oscilloscope. The 'sine' wave produced onto the digital oscilloscope shows the reading from an input of 4 VRMS at a frequency of 5kHz. In order to record the data produced on the graph, the peak to peak response is needed to be measured. This is achieved by counting the number of squares on the oscilloscope when the peak reaches it maximum and minimum point on the table. The same applies to the software simulation as the laboratory experiment and several close measurements will need to be taken near the peak of the response in order to determine the resonant frequency accurately. Once all data has been inputted into the table and a graph produced, 'Q' factor can be determined.

Results

The results produced from both experiments have been plotted onto fully labelled graphs showing the voltage drop at certain frequencies and then resonant frequency for each experiment has been determined from the graph. Bandwidth has been measured and then

using the correct formula, the 'Q' factor has been established for both the simulation and the laboratory experiment.

Below are the results gathered from the laboratory experiment using the components in a series configuration on the breadboard.

Frequency	$V_L + V_C$	Inductance	Capacitance
100	4.3	0.628318531	1591.549431
200	4.2	1.256637061	795.7747155
300	4.2	1.884955592	530.516477
400	4.15	2.513274123	397.8873577
500	4.1	3.141592654	318.3098862
1000	4	6.283185307	159.1549431
2000	3.2	12.56637061	79.57747155
3000	1.8	18.84955592	53.0516477
4000	0.95	25.13274123	39.78873577
4100	0.8	25.76105976	38.8182788
4200	0.75	26.38937829	37.89403407
4300	0.65	27.01769682	37.01277746
4400	0.6	27.64601535	36.17157798
4500	0.45	28.27433388	35.36776513
4600	0.4	28.90265241	34.59890067
4700	0.33	29.53097094	33.86275385
4800	0.3	30.15928947	33.15727981
4900	0.25	30.78760801	32.48060063
5000	0.25	31.41592654	31.83098862
5100	0.275	32.04424507	31.20685159
5200	0.3	32.6725636	30.60671983
5300	0.35	33.30088213	30.02923455
5400	0.41	33.92920066	29.47313761
5500	0.5	34.55751919	28.93726238
5600	0.55	35.18583772	28.42052555
5700	0.6	35.81415625	27.92191984
5800	0.66	36.44247478	27.44050743
5900	0.7	37.07079331	26.97541408
6000	0.8	37.69911184	26.52582385
6500	1.1	40.8407045	24.48537586
7000	1.4	43.98229715	22.73642044
8000	1.8	50.26548246	19.89436789
9000	2.25	56.54866776	17.68388257
10000	2.6	62.83185307	15.91549431
15000	3.5	94.24777961	10.61032954
20000	3.8	125.6637061	7.957747155
30000	4	188.4955592	5.30516477

Figure 9 – Laboratory Experiment

Figure 9 – Shows the data gathered from running the experiment in the laboratory using the breadboard and various components shown in **figure 4**.

We can see that with an increase in Frequency (f), the voltage across the inductor and capacitor starts to drop.

At around 5kHz, we can see the voltage drop start slowly raising back to the original input voltage of 4 VRMS.

From using the formula for working out the capacitance and the reactance we can see that they work in opposite effect and the point at which the figures reach a similar value shows the resonant frequency.

From these results we can determine the resonant frequency is around the 5000Hz to 5200Hz range.

I ran the experiment up to 30kHz, to show the voltage gain back to the original value, in order to produce a more detailed graph.

The results were recorded by counting the squares produced on the oscilloscope from the signal generator so there could be slight human error when determining the true value of the input frequency using the sine wave.

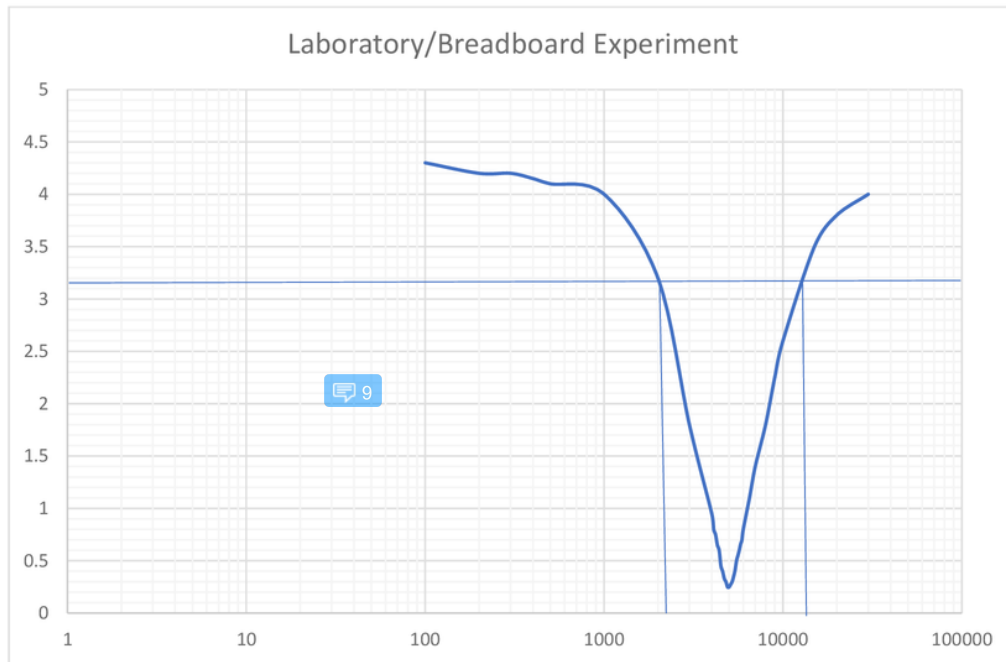


Figure 10 – Graph produced from Microsoft excel, showing the results from the breadboard experiment.

The graph (figure 10), shows the data placed in a graph format, with Frequency (f) along the 'x' axis $V_L + V_C$ and along the 'y' axis.

Looking closely at the data on the graph, we can insert minor gridlines to gather an accurate figure for the peak of the curve, thus determining the resonant frequency. The laboratory experiment shows the resonant frequency of this circuit to be 5000Hz.

To determine the Bandwidth of the graph, the frequency is measured between the 70.7% amplitude points of the series resonant circuit. Therefore, in the above graph, the 100% point is 4.4 V, so 70.7% of this figure shows at 3.1 V. The horizontal blue line on the graph represents this 70.7% range in order to figure out the bandwidth. Where the curve of the graph meets the blue horizontal line, this is the start of our bandwidth region for this given circuit.

The graph above shows the bandwidth region to be between 2100Hz and 14000Hz, subtracting these figures from one another we can determine a bandwidth range of 11900Hz. We can then use this data along with the resonant frequency to figure out the 'Q' factor of this circuit.

The 'Q' factor is determined by dividing the resonant frequency with the bandwidth.

$$Q = F_R / BW$$

$$Q = 5000\text{Hz} / 11900\text{Hz} = 0.42$$

From the 'Q' factor figure we can determine that the circuit has a low 'Q' factor, showing it isn't a very sharp curve and has a very wide bandwidth region. This could be due to higher resistance in the circuit from the components used. The low 'Q' factor figure shows this circuit is not that tune-able and is not an ideal resonant circuit.

Frequency	$V_L + V_C$	Inductance	Capacitance
100	4	0.628318531	1591.549431
200	4	1.256637061	795.7747155
300	4	1.884955592	530.516477
400	4	2.513274123	397.8873577
500	4	3.141592654	318.3098862
1000	4	6.283185307	159.1549431
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4100	3.9	25.76105976	38.8182788
4200	3.9	26.38937829	37.89403407
4300	3.7	27.01769682	37.01277746
4400	3.6	27.64601535	36.17157798
4500	3.5	28.27433388	35.36776513
4600	3.35	28.90265241	34.59890067
4700	2.85	29.53097094	33.86275385
4800	2.1	30.15928947	33.15727981
4900	0.9	30.78760801	32.48060063
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5200	2.6	32.6725636	30.60671983
5300	3.1	33.30088213	30.02923455
5400	3.4	33.92920066	29.47313761
5500	3.55	34.55751919	28.93726238
5600	3.68	35.18583772	28.42052555
5700	3.75	35.81415625	27.92191984
5800	3.8	36.44247478	27.44050743
5900	3.86	37.07079331	26.97541408
6000	3.88	37.69911184	26.52582385
6500	3.95	40.8407045	24.48537586
7000	4	43.98229715	22.73642044
8000	4	50.26548246	19.89436789
9000	4	56.54866776	17.68388257
10000	4	62.83185307	15.91549431
15000	4	94.24777961	10.61032954
20000	4	125.6637061	7.957747155
30000	4	188.4955592	5.30516477

Figure 11 – Results from running the experiment on Proteus

Figure 11 – Shows the data gathered from running the experiment on the simulation software proteus using the circuit shown in **figure 8**.

We can see that with an increase in Frequency (f), the voltage across the inductor and capacitor starts to drop.

At around 5kHz, we can see the voltage drop start slowly raising back to the original input voltage of 4 VRMS.

Using the formula in **figure 1** for working out the capacitance and the reactance we can see that they work in opposite effect and the point at which the figures reach a similar value shows the resonant frequency.

From these results we can determine the resonant frequency is around the 5000Hz to 5100Hz range.

I ran the experiment up to 30kHz, to show the voltage gain back to the original value, in order to produce a more detailed graph.

The results were recorded in the same way as the breadboard experiment using the sine wave produced on the oscilloscope and counting the number of squares between the peaks to determine the value.

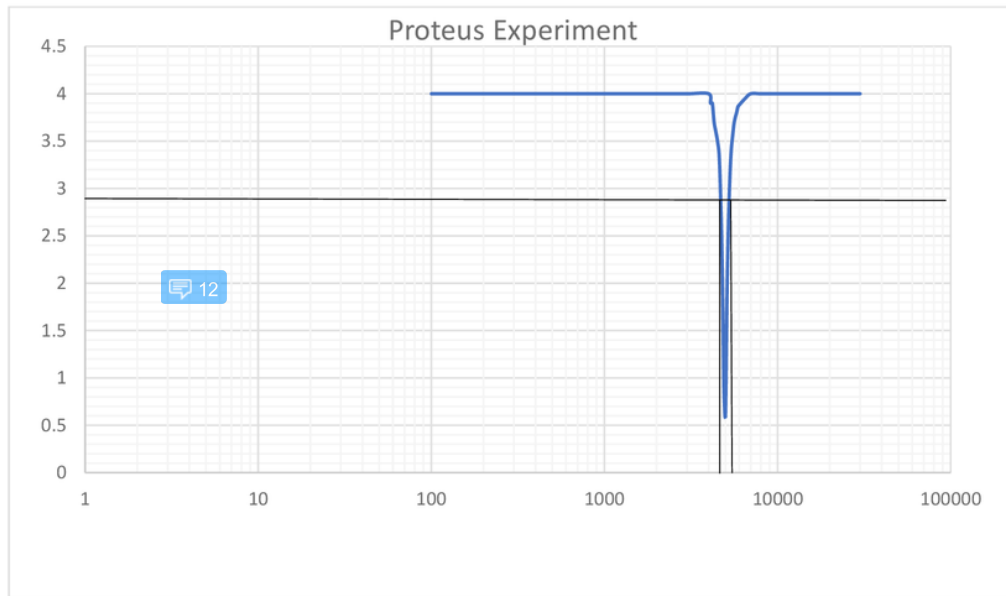


Figure 12, graph produced from the data for the Proteus experiment

The graph (figure 12), shows the data placed in graph format, with Frequency (f) along the 'x' axis $V_L + V_C$ and along the 'y' axis.

Looking closely at the data on the graph, we can insert minor gridlines to gather an accurate figure for the peak of the curve, thus determining the resonant frequency. The simulation experiment shows the resonant frequency of this circuit to be 5000Hz.

To determine the Bandwidth of the graph, the frequency is measured between the 70.7% amplitude points of the series resonant circuit. Therefore, in the above graph, the 100% point is 4 V, so 70.7% of this figure shows at 2.8 V. The horizontal black line on the graph represents this 70.7% range in order to figure out the bandwidth. Where the curve of the graph meets the black horizontal line, this is the start of our bandwidth region for this given circuit.

The graph above shows the bandwidth region to be between 4800Hz and 5350Hz, subtracting these figures from one another we can determine a bandwidth range of 550Hz. We can then use this data along with the resonant frequency to figure out the 'Q' factor of this circuit.

The 'Q' factor is determined by dividing the resonant frequency with the bandwidth.

$$Q = F_R / BW$$

$$Q = 5000\text{Hz} / 550\text{Hz} = 9.09$$

From the 'Q' factor figure we can determine that the circuit has a high 'Q' factor, thus showing with the sharp peak on the graph.

The table below (**figure 13**) shows the stated/measured values for each component used in both the experimental laboratory experiment and the proteus simulation.

	Resistor	Inductor	Capacitor
Stated Value	3.3 Ω	1 mH	1 μF
Measured Resistance	2.89 Ω	2.89 Ω	
Measured Inductance	13.7 μH	0.977 mH	
Measured Capacitance			1.013 μF
ESR @ 1kHz			5.09189 x 10⁻⁵
ESR @ 10kHz			7.63784 x 10⁻⁴

Figure 13, component figures

From the figures above we can calculate the resonant frequency and 'Q' factor for both sets of components.

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

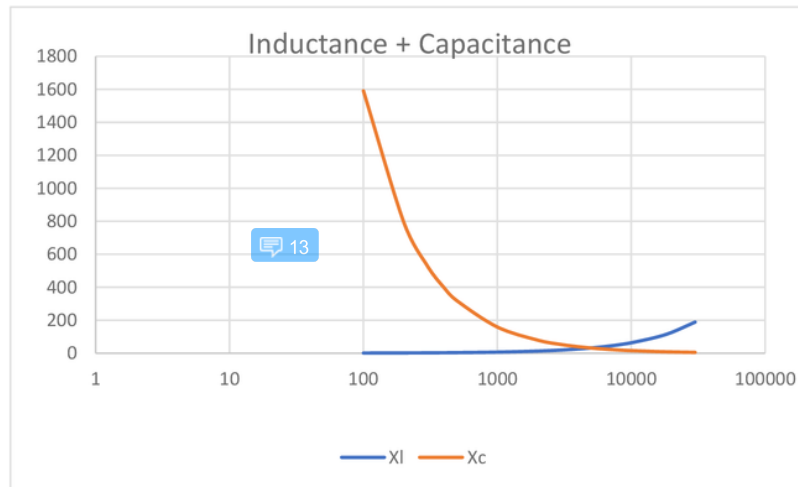
$$f_r = \frac{1}{2\pi\sqrt{1*10^{-3}*1*10^{-6}}} = 5032.921 \text{ } f_r \text{ Simulation}$$

$$f_r = \frac{1}{2\pi\sqrt{1*0.977*10^{-3}*1*1.013*10^{-6}}} = 5059.042 \text{ } f_r \text{ -- Real World}$$

$$Q = \frac{1}{R} * \sqrt{\frac{L}{C}}$$

$$Q = \frac{1}{3.3\Omega} * \sqrt{\frac{1*10^{-3}}{1*10^{-6}}} = 10.942 \text{ 'Q' Simulation}$$

$$Q = \frac{1}{2.89\Omega} * \sqrt{\frac{0.977*10^{-3}}{1.013*10^{-6}}} = 10.746 \text{ 'Q' Real World}$$



The graph shows the inductance and capacitance of the circuit on the proteus experiment. When the inductance and capacitance are of equal measure there is no reactance, X_L and X_C cancel out in a resonant circuit, so the only impedance in place is resistance.

Conclusion

As we can see from the results, we can see the different values produced from both the simulation and the breadboard experiment for resonance and 'Q' factor. The resonant frequency is achieved at around 5000Hz – 5200Hz for both experiments and the 'Q' factor is markedly different.

The difference in 'Q' factor can be shown by the bandwidth region of both experiments. The higher the bandwidth, the more impedance is present. From the breadboard experiment, the bandwidth of the circuit is 11900Hz, giving the circuit a low 'Q' factor. The bandwidth region for the proteus experiment is 550Hz, giving the circuit a higher 'Q' factor. This could be due to the simulation software not taking into account internal tolerances of the inductor and other components. When using the equations to work out 'Q' factor for both the simulation and the laboratory experiment using the given figures for each components the 'Q' factor was very similar. The low 'Q' factor for the breadboard experiment could be due human error when making the circuit on the breadboard or the interpretation of the data analyzed on the oscilloscope. The jumper wires used to connect the circuit were of slightly different length so this could be a cause for error.

From what we have discussed through this report we can establish that resonance has its application in various forms of circuitry, all transmission and receiver business's depend on resonance. Televisions, radios and other communication systems all use resonance. They are used because they serve as a stable frequency source. Series resonance circuits are also useful for constructing high frequency selective filters. However due to the high current and voltage, they can cause damage to the circuit.

For resonance to occur in any circuit it must have at least one inductor and one capacitor. The results show that when $X_L = X_C$ resonance occurs. When the circuit is at resonance the impedance of the circuit is equal to the resistance, therefore $Z = R$.

At the low frequencies the series RLC circuit is capacitive, this gives the circuit a leading power factor and at high frequencies, the circuit is inductive, meaning it has a lagging power factor. The high value of current at resonance produces high values of voltage across both the inductor and capacitor. In series resonance the impedance is minimum and the current maximum, these types of circuits can also be called acceptor circuits.

References

- [1]. Retrieved from Electronics Tutorials: <https://www.electronicstutorials.com/basics/resonance.htm>)
- [2]. Retrieved from Electronics Tutorials: https://www.electronicstutorials.ws/dccircuits/dcp_2.html
- [3]. Retrieved from <https://formulas.tutorvista.com/physics/resonant-frequency-formula.html>:
<https://formulas.tutorvista.com/physics/resonant-frequency-formula.html>

Resonance Report

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

62/100

PAGE 1

PAGE 2



Comment 1

Your abstract has everything it needs apart from a short statement about your results.



Comment 2

oscillate between the magnetic field and where else?



Comment 3

You should consider using the equation editor in word to enter your equations rather than inserting them as pictures. You should also separate them out and have one equation per caption.

PAGE 3



Comment 4

...because they can be selective to a small range of frequencies. Nothing to do with low impedance.

PAGE 4



Comment 5

inductor and capacitor are the wrong way around.

PAGE 5

PAGE 6



Comment 6

This could have been summarised in a couple of sentences rather than giving me an instruction manual. You should assume the reader has knowledge of the details of how something like this would be done.

PAGE 7



Comment 7

Do you mean "capacitive and inductive reactance"?



Comment 8

You need not include a table of results. You have included a graph which makes it far easier to see trends in the data.

PAGE 8



Comment 9

Nice graph, but where are your axis labels, and why does the X axis start at 1 when the data starts at 100?

PAGE 9



Comment 10

Well spotted



Comment 11

capacitive and inductive reactance?

PAGE 10



Comment 12

See comments for previous graph

PAGE 11

PAGE 12



Comment 13

See comments for first graph

**Comment 14**

Please use the referencing guidance document when building reference lists. You should include more information about the website used and when you accessed it. Most websites are not generally considered to be highly credible, you should be looking to use more peer reviewed research and text books etc..

GRADING FORM: SMU GENERIC_SMOSEY

LUKE PENNY

62

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



Inclusion of a range of literature, including sources retrieved independently. Referencing conventions mostly consistently applied. You should look to use higher quality sources.

2.5

KNOWLEDGE & UNDERSTANDING

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



Knowledge is extensive. Exhibits understanding of the breadth and depth of established views.

18.6

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 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

20.4

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



A very good application of a range of methods, tools and techniques. Very good consideration of the context of the application.

18

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 effectively in a suitable format, but may have minor errors. Mostly coherent work and is in a suitable structure.

2.5