

Resonance Assignment

by Max Smith

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Electrical and Electronic Principles
Assignment
Resonance

By Max Smith - 1810364

Abstract

A detailed comparison of a simulated series RLC circuit and a physically built series RLC circuit to determine resonant frequency and the Q factor effect. Similarly valued components were used for this experiment, the simulated components were 'Perfect World' as opposed to real world components which have deficiencies. The resonant frequency for both circuits was found to be close to that which was predicted. The Q factor for both circuits was found to be low. The simulated circuit was not affected by real world issues so the finding was a perfect world scenario, whereas the lab built circuit was affected by resistance, noise and such. It was found that because the Q factor was low the bandwidth was too broad thus making it unsuitable for real life applications such as communications and power supplies.



Introduction

The aim of this report is to analyse the results of a series circuit compiled of a resistor, inductor and capacitor also known as an RLC circuit. RLC circuits can function in both direct current and alternating current circuits. They act as filters, oscillators, voltage multipliers and pulse discharge circuits [1]. RLC circuits are widely used in radio's, power supplies and television's, the circuits are set up to run at a variety of frequencies allowing for transmission. The purpose of the experiment was to measure the voltage of the circuit across the components at various frequencies ranging between 100Hz and 18kHz to determine the point of resonance and evaluate the effect of the 'Q' factor. The RLC circuit has been built both physically in a laboratory setting and on a suitable simulation software. As this was a series circuit, resonance occurs when the supply frequency to the circuit causes the voltages across the inductor and capacitor to be both equal and opposite in phase. Resonance is an issue when measuring voltage across a circuit because resonance is purely resistive and can impede on the voltage flow. This is where the q factor comes in. By determining the level of the q factor, it is possible to determine the dampening effect caused when the circuit gets to the point of resonance. In this type of circuit damping is caused by loss of energy in resistive components. [2] [3]

Aim

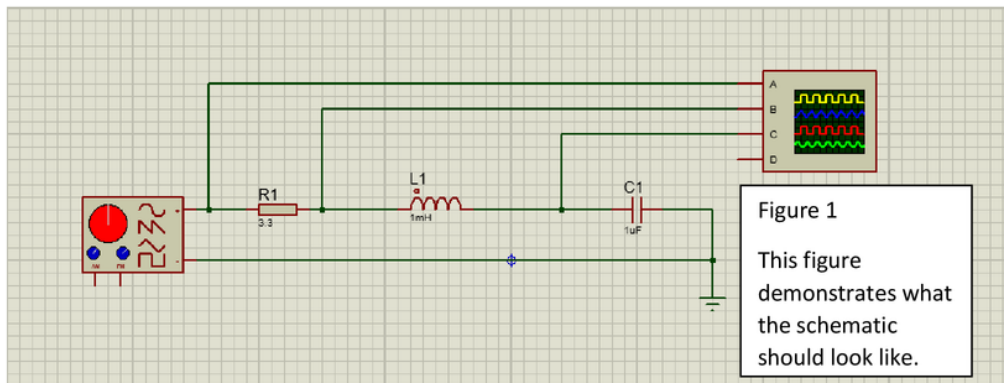
To carry out an experiment comparing the results from a laboratory based built series RLC circuit and a software simulated series RLC circuit. To build the series RLC circuit comprised of a 3.3Ω resistor, a 1mH inductor and a $1\mu\text{F}$ capacitor. Use a sinusoidal signal generator to set the input voltage to 12V and whilst using an oscilloscope take measurements across the components at various frequencies ranging between 100Hz to 18kHz . Tabulate the results and show them in graphical form. Determine the resonant frequency and the Q factor comparing against basic theoretical principles.

Method

The simulation software used for this experiment was Proteus 8. Proteus 8 is an electronics circuit software used for designing simple and complex circuits, running simulations and collecting information [4]. Proteus 8 for this experiment was used to build the series RLC circuit and run a simulation enabling the measurement of the voltage across the components at multiple frequencies.

The simulation was carried out as follows:

- 1) Open Proteus 8 and set up a schematic 5
- 2) Build the circuit using components found in the library. Making sure to connect in to ground.
- 3) Once the circuit is drawn, insert the digital oscilloscope and frequency generator. The frequency generator acts as the power supply and frequency input. Connect this to the resistor and the ground. The oscilloscope is used to record the voltages at the supply and across the inductor and capacitor.
- 4) Run the simulation making sure to set the supply voltage to 12V and adjust the frequency between 100Hz and 20kHz.
- 5) Record and tabulate the results.



The laboratory based experiment was within a lab setting. For the purpose of the experiment the supply voltage was 2V pk2pk rather than 12V pk2pk due to safety concerns about potential exposure to the current flowing through the circuit when taking measurements, as a current of $\sim 0.8\mu\text{A}$ across the heart could kill someone. The frequency generator or sinusoidal oscillator was used as a means of precise control of amplitude. The equipment used for this experiment was, a protoboard, a 3.3Ω resistor, a 1mH inductor, a $1\mu\text{F}$ capacitor, wires, wire cutters, wire strippers, a frequency generator, an oscilloscope, oscilloscope cables and an oscilloscope probe. 6

The components were measured to find the actual values as opposed to what each component was meant to be. The resistor value was stated to be 3.3Ω but when measured, the resistance was found to be 2.89Ω with a component inductance of $13.7\mu\text{H}$. The inductor value was stated to be 1mH but when measured, the inductance was found to be 0.977mH with a series resistance of 2.89Ω . The capacitor was stated to be $1\mu\text{F}$ but when measured, the capacitance was found to be $1.013\mu\text{F}$ with the dissipation factor (ESR) at $1\text{kHz} - 5.09189 \times 10^{-5}$ and the dissipation factor at $10\text{kHz} - 7.63784 \times 10^{-4}$ [5]. The experiment was carried out as follows:

- 1) Before connecting anything, set the frequency to 100Hz and the generator output to 2V pk2pk.

- 2) Using the protoboard and wires connect the 3.3Ω resistor, 1mH inductor and $1\mu\text{F}$ capacitor in series circuit. Use the appropriately cut wires to the ground rail on the protoboard and the live rail on the protoboard to enable connection to the frequency generator and the oscilloscope. Here the pk2pk voltage was measured using the oscilloscope. The 3 components were connected in series with the frequency generator acting as the power supply.
- 3) The oscilloscope probe was connected to the leg of the resistor nearest to the inductor to enable readings on the oscilloscope at the different frequencies.
- 4) The equation for calculating the expected resonant frequency was done and recorded.
- 5) The results for a range between 100Hz and 20kHz were recorded.
- 6) Once completed, the equipment was powered down and disconnected.

Results

The findings from the simulated experiment of the RLC circuit can be seen in the table below. The frequency ranges between 100Hz and 18kHz. There is an extra column for decibels which was calculated whilst recording the results. The reasoning for this is that in electronics, decibels is the ratio of two signals, in this case VL and VC are the two signal amplitudes. The following equation was used

$$20 \log_{10} \frac{A_2}{A_1} [5]$$

They are sometimes used to get an absolute measure of amplitude as it takes into account possible noise generated by the resistor.

Table 1

Frequency (Hz)	Supply Voltage (V)	VL + VC (V)	Decibels (dB)
100	12	12	0
200	12	12	0
500	12	12	0
1000	12	12	0
2000	12	12	0
4500	12	10.5	-1.15984
4600	12	9.7	-1.84819
4700	12	8.4	-3.09804
4800	12	6.2	-5.73579
4900	12	2.7	-12.9563
5000	12	1.75	-16.7229
5100	12	5.46	-6.83977
5200	12	7.8	-3.74173
5300	12	9.2	-2.30787
5400	12	10.2	-1.41162
5500	12	10.6	-1.07751
10000	12	12	0
18000	12	12	0

The graphical representation below shows the findings from the simulated experiment on Proteus 8 showing the frequency in respect to voltage. It shows the point of resonance as occurring between 4.5kHz and 5.5kHz.

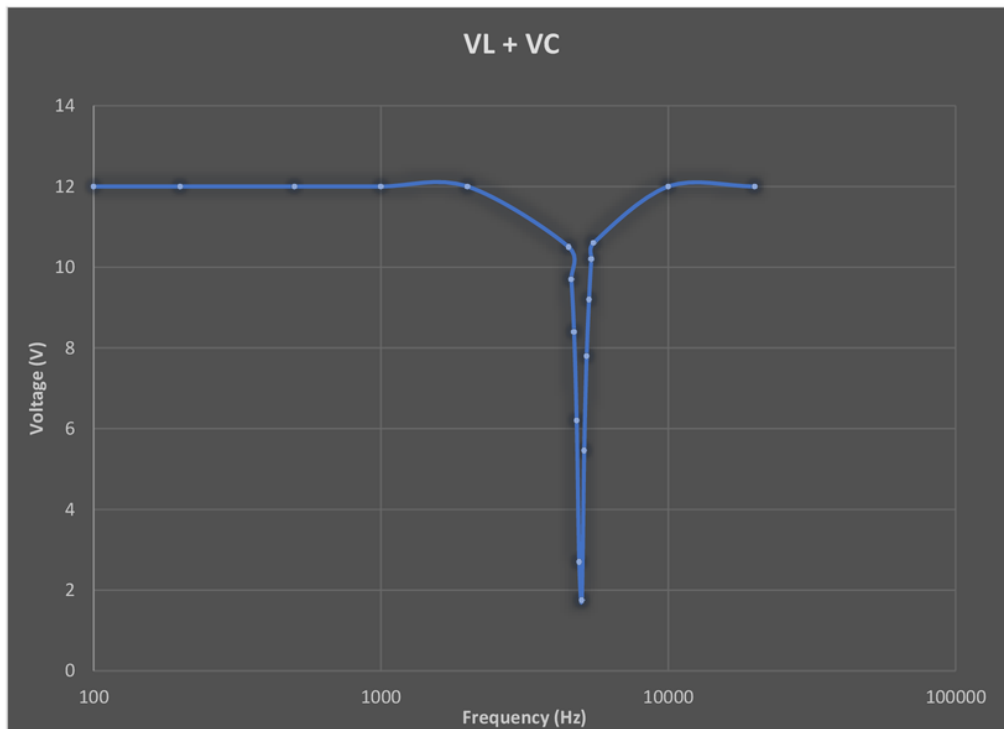


Figure 2

If we had been looking at the current at point of resonance you could expect to see a similar result but inverted, as at resonance there is the least resistance which would allow for better flow of current.

The findings from the laboratory experiment of the RLC circuit can be seen in the table below. The frequency ranges between 100Hz and 18kHz.

Table 2

Frequency (Hz)	Supply Voltage (V)	VL + VC (V)	Decibels (dBs)
100	2	2	0
200	2	1.7	-1.41162
500	2	1	-6.0206
1000	2	0.58	-10.752
2000	2	0.32	-15.9176
4500	2	0.12	-24.437
4600	2	0.12	-24.437
4700	2	0.12	-24.437
4800	2	0.1	-26.0206
4900	2	0.09	-26.9357
5000	2	0.09	-26.9357
5100	2	0.09	-26.9357
5200	2	0.12	-24.437
5300	2	0.13	-23.7417
5400	2	0.13	-23.7417
5500	2	0.13	-23.7417
10000	2	0.29	-16.7726
18000	2	0.48	-12.3958

The graphical representation below shows the findings from the lab experiment showing frequency in respect to voltage. It shows the point of resonance as occurring between 4.5kHz and 5.5kHz.

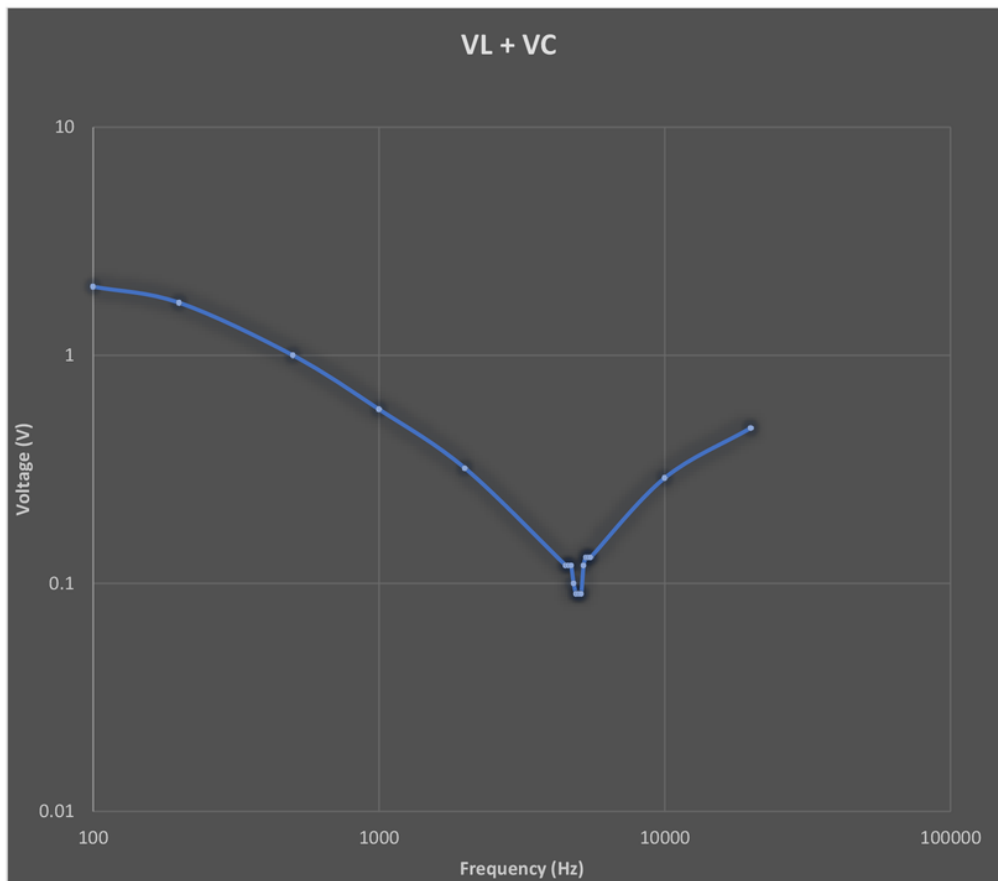
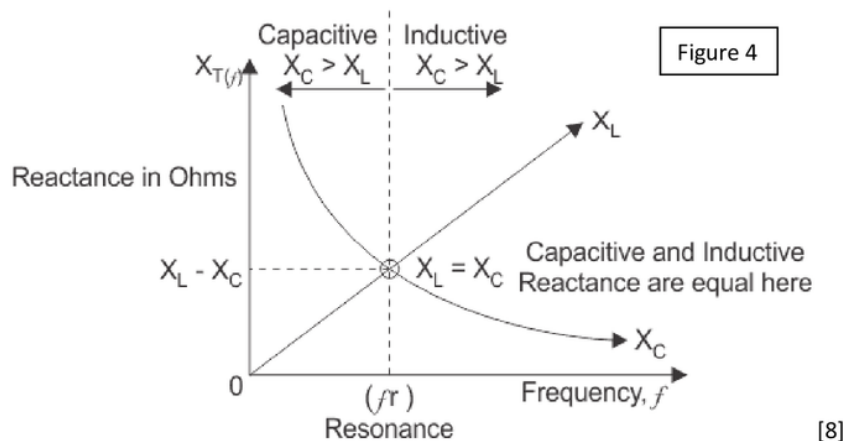


Figure 3

Discussion

An RLC circuit is comprised of three unique components, a resistor which is used to reduce the flow of current through a system, this is also known as impedance/resistance. A capacitor is “an electrical component consisting of two or more conductive plates separated by insulation and used to store energy in an electrostatic field” [6]. An inductor stores the electrical energy within an electromagnetic field that occurs when current flows through it. An inductor opposes the changes in current flow. An RLC circuit creates a harmonic oscillator and resonates accordingly, this is the desired effect of an RLC circuit, as the resonance creates an AC signal which enables signal filtration or signal tuning which is why these types of circuits are used mainly in radios and power supplies etc. [1] [7]. Resonance occurs when the inductive reactance is equal to the capacitive reactance of a circuit, see figure 4.



The practical application of an RLC circuit is the phenomenon when resonance occurs and is used as a filter. RLC circuit have a range of frequencies at which they are effective, this range is known as the bandwidth. It is on the bandwidth capacity that the Q factor is seen. The Q factor is defined “as the quality of the second-order filter stages” [9]. RLC circuits with a wide bandwidth will have a low Q factor effect and will dampen the circuit, whereas RLC circuits with a narrow bandwidth will have a high Q factor effect and will be under damped. The desired outcome would be to have a circuit which produces a narrow bandwidth and has a high Q factor, due to nature in which RLC circuits are applied [10]. With gain and phase shift regarding level of frequency, it is inevitable that the operational amplifier will decrease at some frequency due to formation of a low pass filter as a result of signals of impedance which drive the capacitive loads. The output impedance will generally fall in a circuit between a frequency range of 100Hz and 10kHz [11].

Using the following equation, the predicted resonant frequency for the RLC circuit in the experiment was 5032.92121Hz.

$$\frac{1}{2\pi\sqrt{LC}} [5]$$

Looking at the results from the simulated experiment, at a frequency of 4.5kHz to 5kHz the capacitive reactance starts to decrease, and the inductive reactance increases, this is due to the time before each phase shift decreasing and the electromagnetic field of the inductor and the electrostatic field of the capacitor were starting to harmonize. The clear point of resonance in the

RLC circuit occurs at approximately 5kHz where the level of reactance from both the capacitor and inductor are in phase allowing for the most current to pass through. When the frequency was increased from 5kHz to 5.5kHz the reactance from both the capacitor and inductor begin to go out of phase restricting the flow and returning to the original state. In comparison to the calculated resonant frequency using the earlier equation, the level of frequency in which resonance occurred in the simulated experiment was in line with that of the calculated result. The results acquired from the simulation experiment are demonstrative of a circuit that functions exactly as it should with no external or internal inferences. This would be nigh impossible to create in an actual lab environment and get the same results, due the fact that the components in the simulation are perfect world/ideal components, and the connections in the simulation circuit have no resistance affecting the results.

The Q factor for the simulated experiment was calculated using the following equation, using the measured values of the components. There are many ways to calculate the Q factor, this was just one of the ways. The Q factor was calculated using the measured values of the components.

$$Q = \frac{1}{R} \sqrt{\frac{L}{C}} [5]$$

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

$$Q = 9.582659576$$

"The quality factor, Q , of a resonant system is considered to be high if the system loses little energy over time compared to the energy in the system" [12]. "Circuits having a high Q -factor (say, in the order of 100 to 300) are therefore more useful in communications" [13]. The Q factor calculated for the circuit is low, indicating that at point of resonance the circuit loses a lot energy over the time it was in the system.

The equation used for calculating the bandwidth was as follows, where 'Fr' is resonant frequency and BW is bandwidth.

$$BW = \frac{Fr}{Q} [5]$$

$$BW = \frac{5032.92121}{9.582659576}$$

$$BW = 525.2113122 \text{ Hz}$$

The equations used for finding the upper and lower limits of the bandwidth were as follows, where Fl is lower frequency and Fh is the higher frequency.

$$Fl = Fr - \frac{1}{2} BW \text{ and } Fh = Fr + \frac{1}{2} BW [5]$$

$$Fl = 5032.92121 - \frac{1}{2} 525.2113122 \text{ and } Fh = 5032.92121 + \frac{1}{2} 525.2113122$$

$$Fl = 4770.315554 \text{ Hz and } Fh = 5295.526866 \text{ Hz}$$

The circuit had a low Q factor, meaning the bandwidth for the circuit was broad. As in the simulated experiment, the conditions when running the test are faultless with regards to interference, it can be stated that the RLC circuit is not ideal for comms when using components of the stated values.

Looking at the results from the lab experiment, the results were not what was expected. The actual measurements for the components were taken into account and the new expected level of frequency was calculated using the following equation, which gave the new resonant frequency value of 5059.040162Hz.

$$\frac{1}{2\pi\sqrt{LC}} [5]$$

The point of resonance occurred across 4.9kHz to 5.1kHz as opposed to the more concise result taken from the simulated experiment. After the point of resonance, the capacitive reactance and inductive reactance did not behave as expected. The effects of the point of resonance appear not to fully dissipate hindering the voltage return. When the lab experiment was carried out it was noticed that the leg of the resistor had come out of the protoboard. The result of the resistor having been not fully connected could have caused potential damage to the component or the circuit. The resistor was refitted and the experiment re-run to gather the results.

The Q factor for the lab experiment was calculated using the following equation, using the measured values of the components. There are many ways to calculate the Q factor, this was just one of the ways. The Q factor was calculated using the measured values of the components.

$$Q = \frac{1}{R} \sqrt{\frac{L}{C}} [5]$$

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

$$Q = 10.74594755$$

The Q factor calculated for the circuit is low, indicating that at point of resonance the circuit loses a lot energy over the time it was in the system.

Using the value of the Q factor it was possible to calculate the bandwidth. The bandwidth is vital to any RLC circuit due them being used for comms etc. Comms such as radios are tuned to specific frequency's, so if the Q factor is too high then the bandwidth will be very narrow and potentially miss out bits, and if the Q factor is too low then the bandwidth will be broad and potentially pick up external signals.

The equation used for calculating the bandwidth was as follows, where Fr is resonant frequency and BW is bandwidth.

$$BW = \frac{Fr}{Q} [5]$$

$$BW = \frac{5059.040162}{10.74594755}$$

$$BW = 470.7858603 \text{ Hz}$$

$$Fl = Fr - \frac{1}{2}BW \text{ and } Fh = Fr + \frac{1}{2}BW [5]$$

$$Fl = 5059.040162 - \frac{1}{2}470.7858603 \text{ and } Fh = 5059.040162 + \frac{1}{2}470.7858603$$

$$Fl = 4823.647232 \text{ Hz and } Fh = 5294.433092 \text{ Hz}$$

The circuit had a low Q factor, meaning the bandwidth for the circuit was broad. It could be deduced that the anomalies seen in the results were caused by external signals.

14

The use of a signal generator or sinusoidal oscilloscope, whilst it provides better control over the amplitude, it would have been better to use a frequency synthesizer as these generate sine waves which can be precisely set.

The decibel levels recorded for the lab experiment depict not only the internal noise from the components but also external noise. There are many ways in which readings from a circuit can be affected, with one of the most common ones being noise. All circuits are susceptible to intrinsic noise which is noise that comes from within the circuit and affects the response given to external inputs. All components contain noise sources, and because this was a series circuit, noise can be shown as zero-impedance voltage generators. [14] [15].

Another common type of noise is Gaussian Noise otherwise known as Johnson Noise, this type of noise is generated by the resistors in a circuit which will affect sensitive measurements. Due to the issue which occurred in the lab experiment it is plausible to put some of the issues down to this. Interference from external sources/signals can cause fluctuations in the results. These can come from lighting, electrical equipment and other impulsive interfaces due to be broad in the spectrum and spiky in the amplitude [13].

Many circuits and cables are sensitive to vibration and sound due to being microphonic. Loss in results can be down to the cables and instruments used, whether it is capacitive loading, interference pick up or transmission line effects. Whilst noise and equipment can be factors that affect any given results when measuring a circuit, this issue in the lab experiment was human error.

As a result, the lab experiment was recreated and carried out and new results were taken. The experiment was not an exact second, the protoboard used was different to the first and the components were not the same. The measurements of the components used were not taken but should have been. The findings from the laboratory experiment of the RLC circuit can be seen in the table below.

Table 3

Readings were taken at more points of frequency in this run of the experiment to show more fluidity in the values given.

Frequency (Hz)	Supply Voltage (V)	VL + VC (V)	Decibels (dBs)
100	2	2	0
200	2	1.95	-0.21990769
500	2	1.85	-0.67716535
1000	2	1.6	-1.93820026
2000	2	1.45	-2.79323987
3000	2	1	-6.02059991
4000	2	0.5	-12.0411998
4500	2	0.28	-17.0774393
4600	2	0.25	-18.0617997
4700	2	0.225	-18.9769496
4800	2	0.16	-21.9382003
4900	2	0.14	-23.0980392
5000	2	0.12	-24.436975
5100	2	0.14	-23.0980392
5200	2	0.16	-21.9382003
5300	2	0.17	-21.4116215

5400	2	0.18	-20.9151498
5500	2	0.22	-19.1721463
6000	2	0.36	-14.8945499
7000	2	0.64	-9.89700043
8000	2	0.85	-7.4322214
9000	2	1.1	-5.19274621
10000	2	1.2	-4.43697499
14000	2	1.5	-2.49877473
18000	2	1.7	-1.41162149

The graphical representation below shows the findings from the laboratory experiment re-run showing the frequency in respect to voltage.

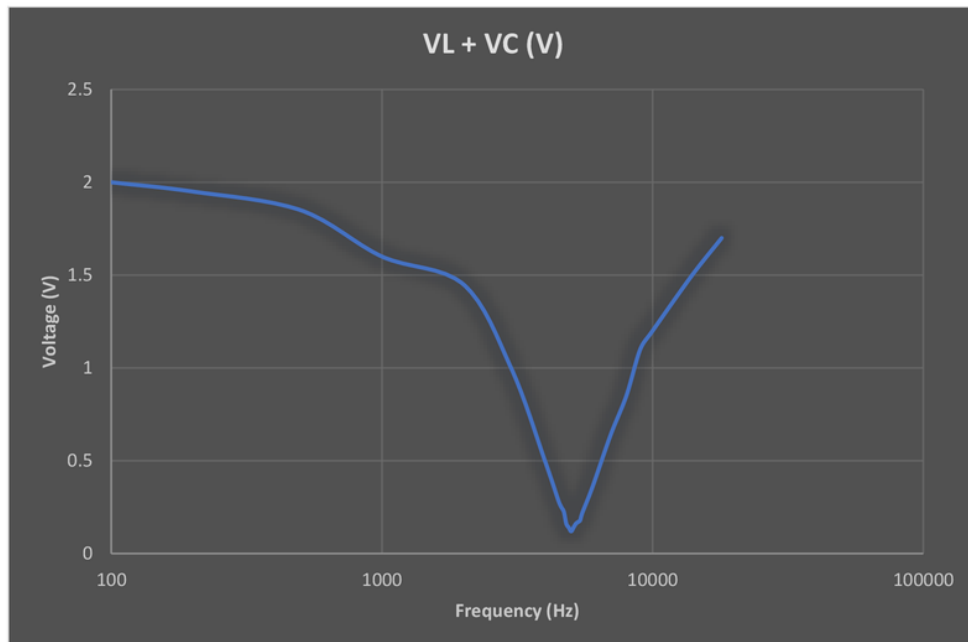


Figure 5

The results attained in the lab re-run were more favorable regarding what would be expected in an RLC circuit when approaching point of resonance. It shows the point of resonance as occurring between 4.5kHz and 5.5kHz.

Below are some images that were taken at the time of the re-run.

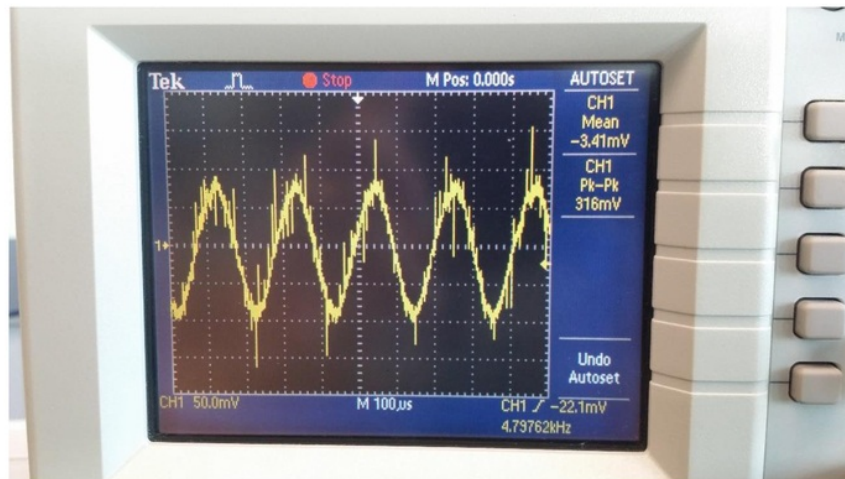


Figure 6

The wavelength in this figure, the level of interference in the signal. It could be that more disruption was seen at this point as the circuit was nearing resonant frequency or that there was still a lot of noise present in and around the circuit.

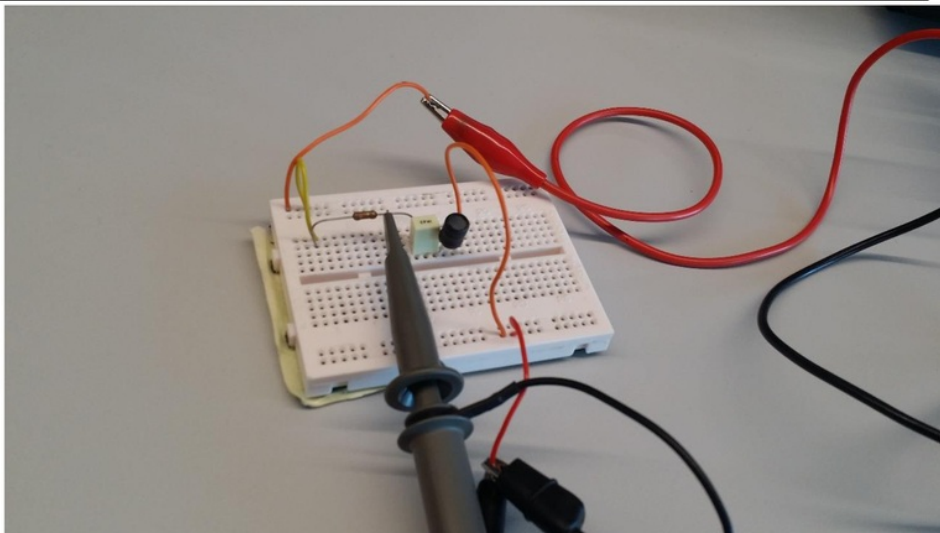


Figure 7

This figure shows how the circuit was set up on the protoboard. This time around on the experiment the protoboard was a different size to the one used in the first experiment. The circuit could have been connected/set up more efficiently to reduce the length of cabling thus reducing the amount of resistance on the circuit.

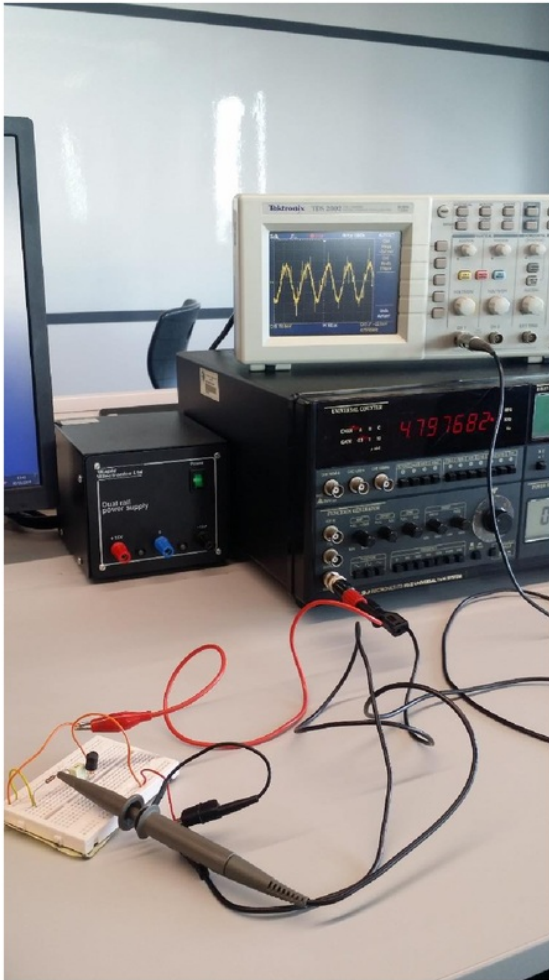


Figure 8

This figure shows the lab set up for the experiment. The tuner for the frequency level was not the most accurate and made it near impossible to get the exact desired frequency. This was the same workbench used as in the first experiment, in attempt to recreate the scenario.



The results attained for all experiments show the point of resonance occurring at near on identical frequencies. The lab results were multiplied by 6 to make them representative in figure 9 and 10. However the actual bandwidth compared to the calculated bandwidths are vastly different for the lab experiments. The readings were only taken up to 18kHz so for the first lab experiment the actual bandwidth was unobtainable but vast. The second lab experiment the actual bandwidth was approximately 11kHz. With this approximate result the recalculated Q factor was as follows.

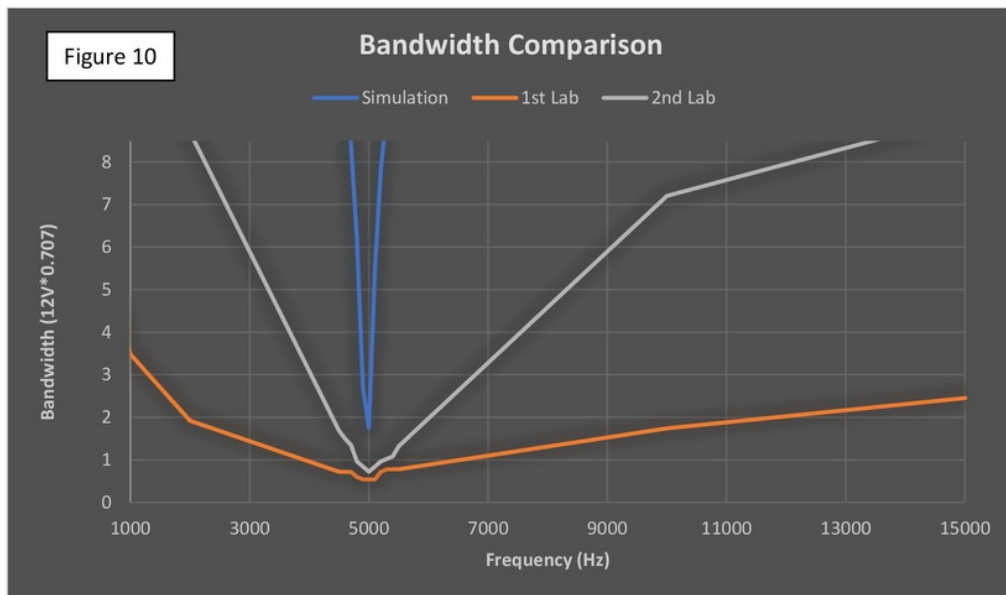
$$Q = \frac{Fr}{BW} [5]$$

$$Q = \frac{5059.040162}{11000}$$

$$Q = 0.459912742$$

The Q factor calculated for the circuit was very low, indicating that around point of resonance the circuit loses a lot energy.

The graph below is not to the correct scale but simply to demonstrate more clearly the actual bandwidths.



Conclusion

The circuit used for this experiment both simulated and lab based would not be ideal for use in comms or power supplies. A simulated RLC experiment was carried out and the results taken. The graphical results taken were what was expected, for the resonant frequency to occur at the calculated frequency. The simulation does not consider any slight differences in the components as they are not always what is stated. The circuit was not exposed to any interference from external sources so cannot be fully reliable to what would occur in a live circuit. A lab-based experiment was carried out and that results taken. The results were not what you would expect to see for an RLC circuit. Point of resonance occurred where expected but as seen in the graphical result there was an anomaly. There was human error when taking the readings, which potentially damaged one of the components. The components used in the circuit were measured and found not to be the values as stated. The circuit was exposed to a lot of background and/or internal interference which caused issues when reading the results. The Q factor for both the simulated and lab-based experiments was found to be low which meant the bandwidth exposure of the circuit was broad, thus making it susceptible to external interference. The lab-based experiment was re-run at a later date and the results taken were more like what would be expected. If the experiment was to run again, the components would be measured prior to use and the closest to stated value used. It would be carried out in relative isolation, meaning the work space would be clearer of other technology and people. The use of a frequency synthesizer would be preferable to clearly set the frequency and amplitude.

References

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Resonance Assignment

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

63/100

PAGE 1

PAGE 2



Comment 1

Nice abstract, but it would have been nice to see some numerical results to backup your statements.

PAGE 3



Comment 2

Misplaced apostrophe. Apostrophes are used to show ownership or to contract and concatenate words.

e.g.

The radio's buttons. - The buttons belong to the radio.

Or:

You've submitted a report. - You have submitted a report.



Comment 3

do you mean "component voltages"



Comment 4

around the point of resonance

PAGE 4

PAGE 5



Comment 5

You didn't need to provide an instruction manual. This could have been summarised in a couple of sentences. You should assume the reader has some knowledge on the subject and understands how the experiment could be done.



Comment 6

The concerns were about potential damage to the signal generator due to excessive current draw. The current you have quoted required to stop a heart is only valid for direct electrical connections to the heart i.e. with a person's rib cage opened and wires applied directly to the heart. This event was not a major risk in the lab and as such is generally not considered a likely occurrence.

PAGE 6



Comment 7

You do not need to write instruction manuals. See previous comments

PAGE 7



Comment 8

You do not need to include tables of results when you show a graph. Graphs are far better for showing trends in data.

PAGE 8

PAGE 9

PAGE 10

PAGE 11



Comment 9

This is applicable to 2nd order filter circuits, not to RLC circuits.

Q factor is defined as the ratio of resonant frequency to bandwidth.

PAGE 12



Comment 10

I assume you mean influences and not inferences.



Comment 11

You should probably have read the bandwidth from your graph, then calculated Q again. This

you should probably have read the bandwidth from your graph, then calculated Q again. This would allow you to compare the expected Q factor and actual Q factor.



Comment 12

This assumes a linear symmetric frequency response.

PAGE 13



Comment 13

It would have just invalidated your data, not causing any damage to the equipment or other components, only increasing your annoyance.

PAGE 14



Comment 14

How could you prove this?



Comment 15

Not an issue when taking measurements at these voltage levels. This would become more apparent in the nanovolt range.

PAGE 15

PAGE 16

PAGE 17

PAGE 18

PAGE 19

PAGE 20

PAGE 21

GRADING FORM: SMU GENERIC_SMOSEY

MAX SMITH

62.60

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 referencing skills, consistently applied.

3.75

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.

19.5

COGNITIVE & INTELLECTUAL

Evaluate underlying concepts and principles of a subject and interpret qualitative and quantitative data in order to develop lines of argument and make sound judgements.

 Sound, logical, analytical thinking; synthesis and evaluation. Ability to 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. It would have been nice for you to explain the differences in results from experiments 1 and 2

18.6

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, with perceptive use of examples, where relevant. Evidence of some innovation and creativity.

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.

2.75