

EP assignment year 1

by Steven James

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Electronic Principles for OME

RESONANCE

Year 1 assignment

Steven James (1810370)
2-5-2019

ABSTRACT

This experiment was designed to build an LCR circuit in a simulation package and then build the same circuit in an electronics lab. Measurements were taken to show how the two circuits compared to one another and where the resonant frequency was. The resonant frequency was ~5 kHz and all circuits compared very well. The bandwidth and 'Q' factor did not compare well. The lab built circuit was not aligned with that of the simulated circuit. The simulation gave a bandwidth was 525 Hz and 'Q' factor of 9. Whereas the measured circuit had a 'Q' factor of 0.5 and a bandwidth of 9.5 kHz. Possible reasons behind this are discussed later in this report.  1  2

Objective

The objective of this of this report was to build and test an RLC (resister, inductor, capacitor) circuit in a suitable simulation package. Following this the same circuit was built in a lab condition. Measurements were taken at various frequencies looking for where the circuit is at resonance. A comparison of the two circuits is then made to establish the relationship between 'real world' circuits and those created using a simulation package.

Introduction

"A resonant circuit can be used to 'block' (i.e. present high impedance toward) a frequency or range of frequencies, thus acting as a sort of frequency 'filter' to strain certain frequencies out of a mix of others" [1]

"In essence, this is how analogue radio receiver tuner circuits work to filter, or select, one station frequency out of a mix of different radio station frequency signals intercepted by the antenna" [1]

In the defence industry this is used for communication signals using radio frequency such as troops in the field using analogue radio. Complex weapon systems can also use the same type of circuit to block signals as to ensure that they are not 'functioned' accidentally by use of radio communications. A much more complicated use of a resonant circuit can be used to focus a RADAR signal that guides a guided missile system towards a target that is being tracked. For this application a frequency with a very high 'Q' factor and a very low bandwidth would be used. This type of circuit is out of the remit of this report; however, the design can be traced back to the basic circuit being looked considered.  3

Resonant circuits can even be found in the most complex of theoretical ideas such as those put forward by Antonov in his journal report on Multiverse time travel [2].  4

The purpose of this report is to show the relationship between frequency and voltage on a resistor, inductor, and capacitor (RLC) circuit. A comparison is made using basic theory, computer simulation and real time laboratory measurements of the built circuit.

The information gathered from these made circuits allows the resonant frequency and 'Q' factor to be worked out and measured, then compared through each of the circuits and calculated responses. The 'Q' factor of the RLC means the quality of the circuit. It determines how well the circuit can respond or discriminate between signals at different frequencies. A circuit with a low 'Q' cannot discriminate very well between signals, thus has a high bandwidth where signal is not selective and can pick up interference from many other signals. A circuit with a high 'Q' factor means the circuit can be very selective, the higher the 'Q' the better the quality and the more selective the circuit with a very low bandwidth. [1]  5

Apparatus

The list below shows the equipment that was used to conduct the experiment

- Proteus 8, electronics lab simulation package
- Function generator
- Digital oscilloscope
- Resistor (3.3 Ω)
- Inductor (1mH)
- Capacitor (1 μ F)
- Connecting wires
- Oscilloscope probe

Method

The experiment began by using the electronic simulation package 'Proteus 8' to build the circuit. The simulation was run through a range of frequencies to establish the how the voltage across the capacitor and inductor would change at the different frequencies and thus establish the resonant frequency of the circuit

The requirement was to set up the RLC circuit using a 3.3 Ω resistor, a 1 mH inductor and a 1 μ F capacitor. A function generator was used to create a 12 V peak to peak ac signal input and an oscilloscope is used to measure the signal across the inductor + capacitor and across the capacitor. [Fig 1 and 2]

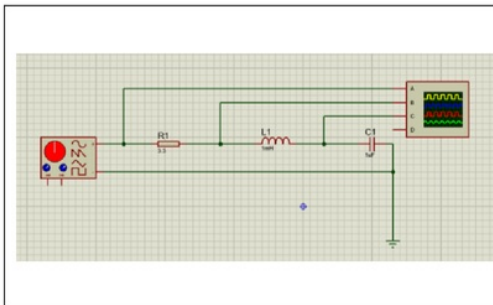


Fig. 1, circuit layout in Proteus

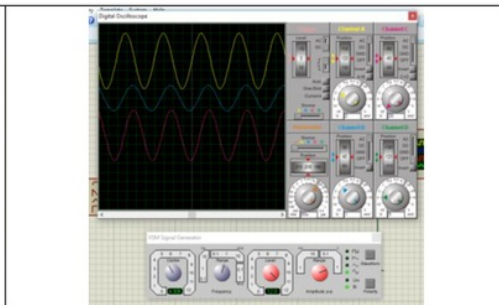


Fig. 2, Hardware simulation in Proteus

A wide range of frequencies were measured from 100 Hz to 20 kHz with a narrower selection of frequencies around the calculated area where resonance was expected to occur. The results that were measured through the range of frequencies have been tabulated in the results section along with graphical representation.

Following the simulation package results. Time was spent in the electronics lab to recreate the circuit using real components. The purpose of this was to establish whether the predictions made using the simulation package would be recreated in a real laboratory situation. In order to recreate the circuit, 'breadboard' was used. Breadboard is a simple deck made up of copper rails inside a plastic housing. The rails copper rails run in one direction with a break through the centre. They have sprung openings which allow components to be attached and removed easily without the use of solder or any permanent connection. Two further rails run along the side of the board at 90° to the component rails to allow a power source and earth to be connected.

Electronic Principals Assignment

To connect the components to the breadboard the legs of the resistor were bent at a suitable distance so that they would fit into the board. All the components (resistor, inductor and capacitor) were then inserted into the board ensuring that they were in far enough so that a good connection would be made (Fig 3). In this circuit the capacitor was not electrolytic, therefore it could be inserted either way around. Extra wires were cut to size so that the circuit could be connected to the function generator to complete the circuit. A probe was connected to the resistor leg between the resistor and the inductor allowing the voltage $V_c + V_l$ to be measured. The probe was connected to the oscilloscope with the negative of the probe to Earth (Fig 4).

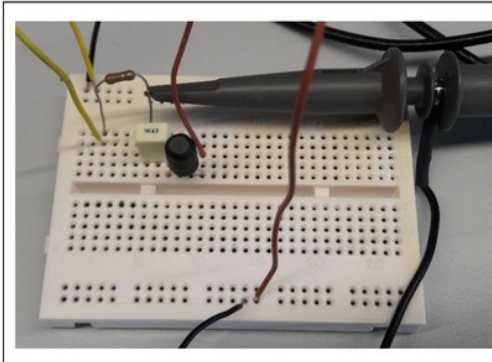


Fig 3, circuit attached to breadboard



Fig 4, lab set up

Due to the way high current can be drawn through an RLC circuit it was recommended that in the lab experiment 4 V peak to peak should be used. As the components were ideally the same as those used in the simulation package, when the measurements were taken point of resonance would not change.

Measurements were taken with the same frequencies used for the simulation and the results long



Results

The results set out in table 1 show the the measurement of $V_L + V_C$ taken using the simulation package using a 12 V peak to peak input.

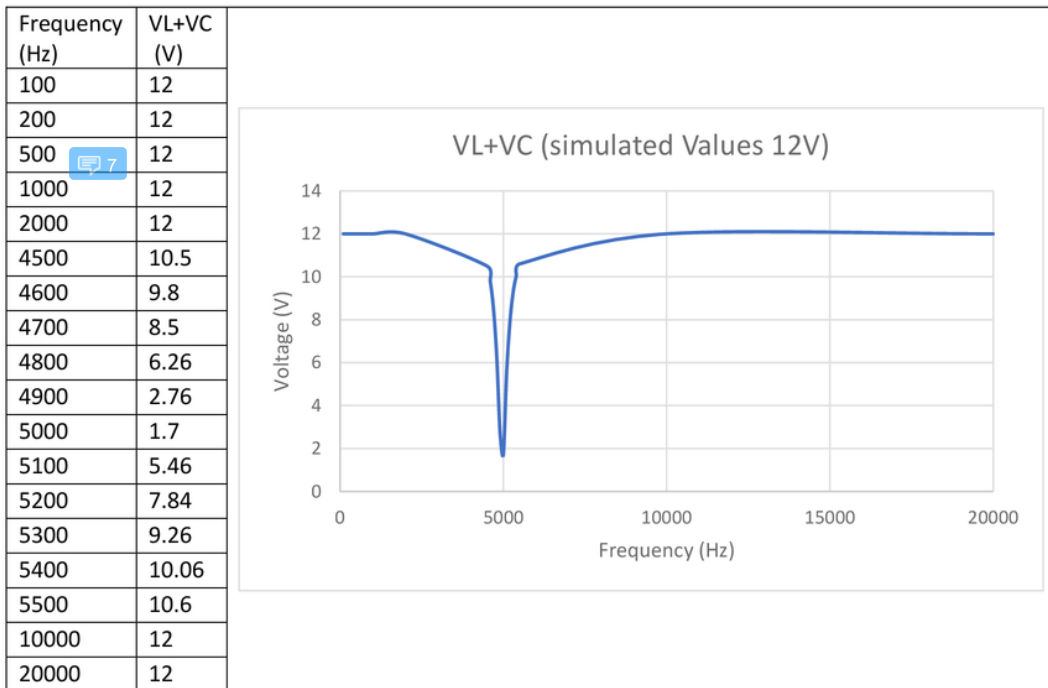


Table 1

Looking at the graph it can be seen that the resonant frequency is ~5 kHz

Electronic Principals Assignment

The results set out in table 2 show the measurements taken in the lab using breadboard and real components with the input set at 4V peak to peak

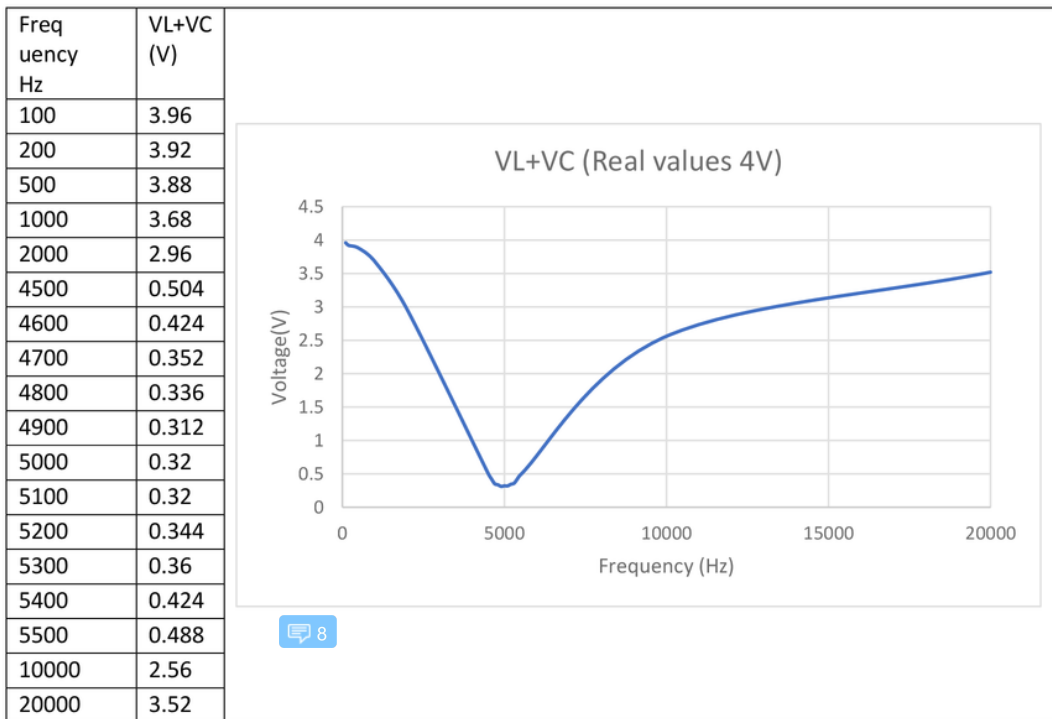


Table 2

The graph in table 2 shows a different shape, however it can be seen that the resonant frequency is around 5 kHz

Electronic Principals Assignment

As the initial requirement was to run the simulation package at 12 V peak to peak, comparing it to the real circuit at 4 V peak to peak. It was decided that for a fair comparison the simulation should be analysed again at 4 V so that the two circuits would be a direct representation of one another.

Table 3 shows the measurements taken when the simulation was run a second time, using 4 V peak to peak

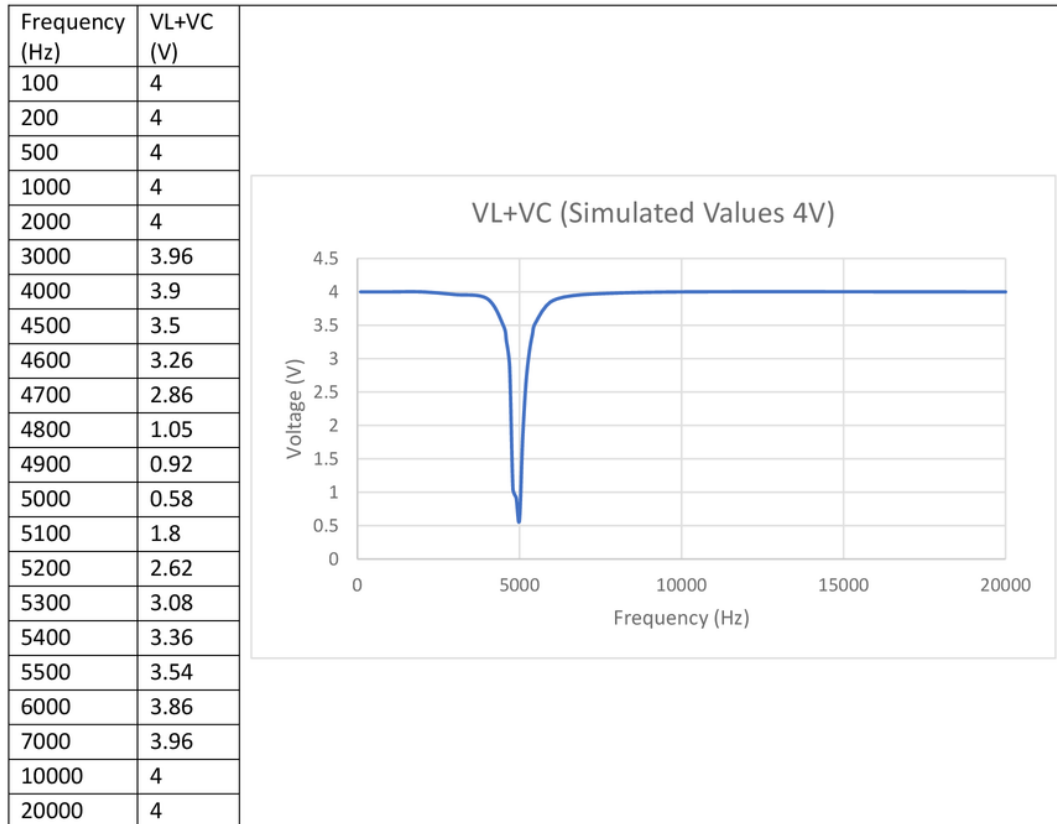


Table 3

Looking at the graph in table 3 it can be seen that the resonant frequency is around 5 kHz

The measurements taken during the lab experiment did not give a response that was expected (barring that of the resonant frequency). The bandwidth was seen to be much higher than simulated. Therefore it was decided that the circuit would be built and run a second time in the electrical workshop at the authors workplace. Components to the values required for the circuit were not available therefore a series of decade boxes were used. A decade box allows many different values of a component to be switched without the need to change the component.

On this occasion a larger selection of frequencies were used so that a more concise frequency graph could be drawn

Electronic Principals Assignment

Table 4 shows the voltage measured across V_L and V_C using decade boxes to the value of the components required for the circuit.

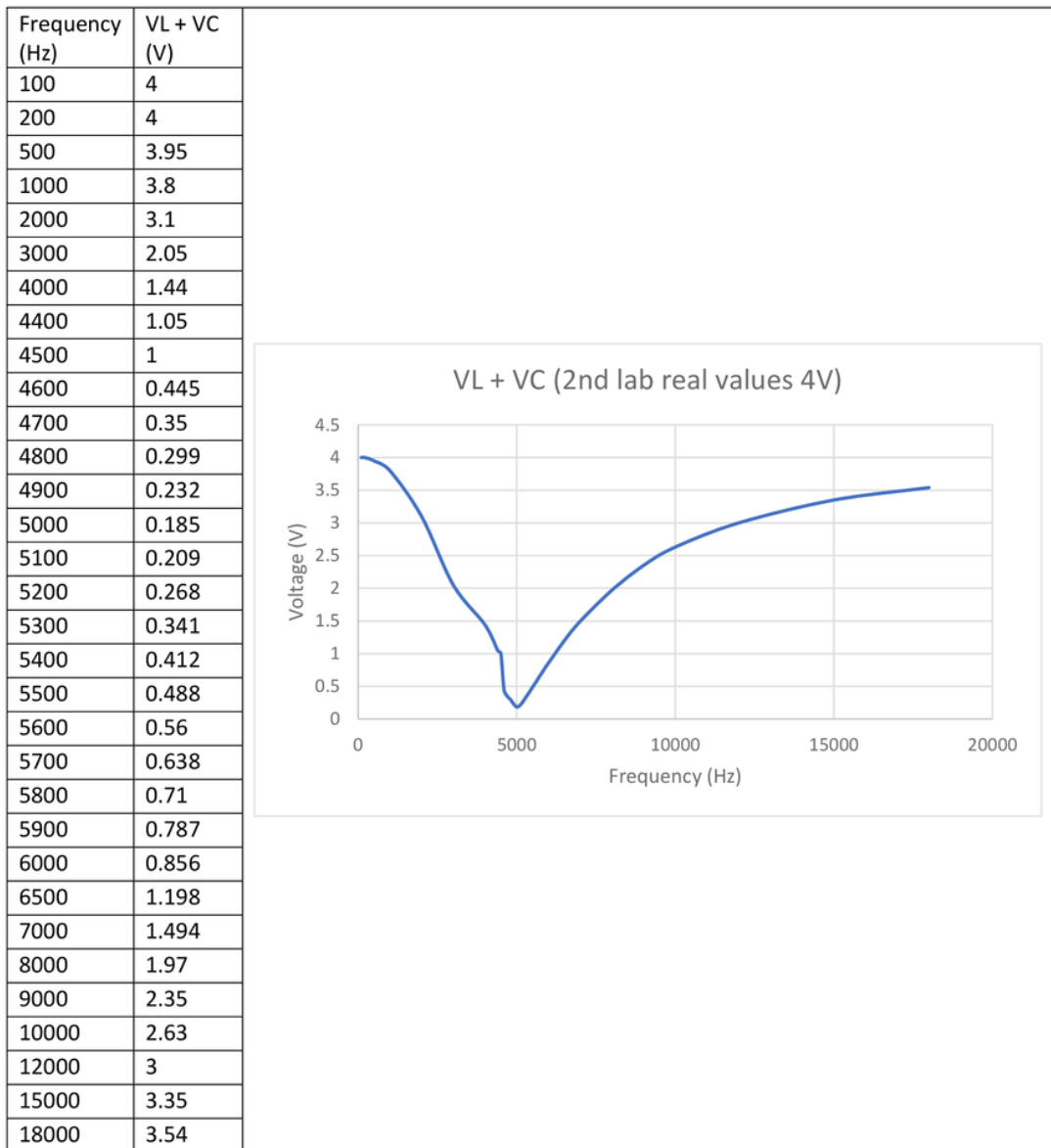


Table 4

Looking at the graph in table 4 it can be seen that the resonant frequency is around 5 kHz and the frequency response matches that of the measurements taken in the first lab experiment.

Four different sets of results have been compiled so that an accurate comparison of the circuit can be made.

Electronic Principals Assignment

In table 5 all of the results have been overlaid onto a graph.

Frequeneeny (Hz)	2 nd lab based measurement VL + VC (4V)	1 st lab based measurment VL+VC (4V)	Simuated VL+VC (4V)	Simuated VL+VC (4V) 9
100	4	3.96	4	12
200	4	3.92	4	12
500	3.95	3.88	4	12
1000	3.8	3.68	4	12
2000	3.1	2.96	4	12
4500	1	0.504	3.5	10.5
4600	0.445	0.424	3.26	9.8
4700	0.35	0.352	2.86	8.5
4800	0.299	0.336	1.05	6.26
4900	0.232	0.312	0.92	2.76
5000	0.185	0.32	0.58	1.7
5100	0.209	0.32	1.8	5.46
5200	0.268	0.344	2.62	7.84
5300	0.341	0.36	3.08	9.26
5400	0.412	0.424	3.36	10.06
5500	0.488	0.488	3.54	10.6
10000	2.63	2.56	4	12
20000	3.54	3.52	4	12

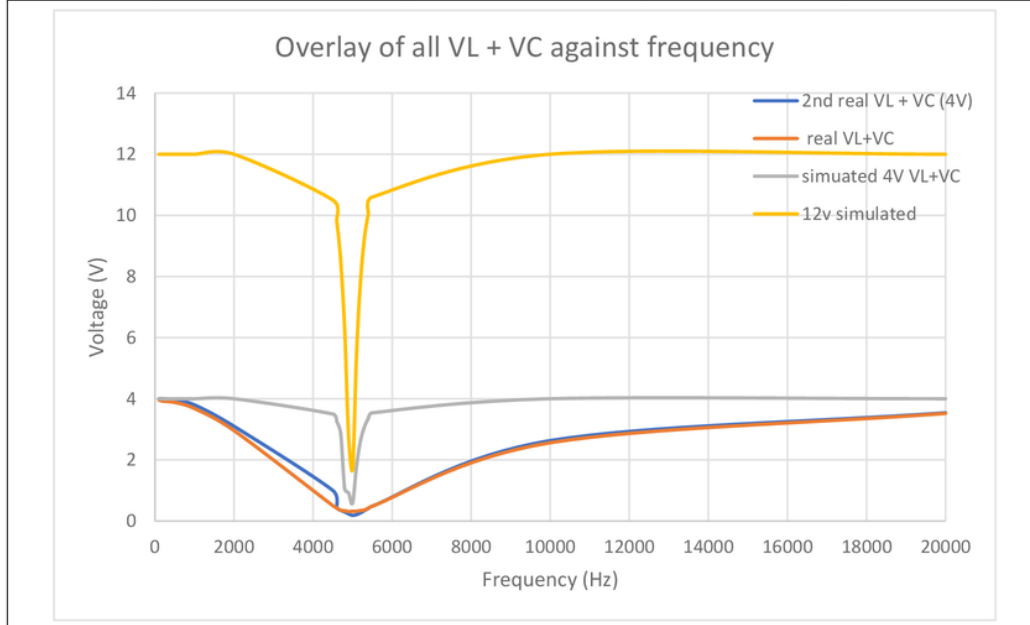


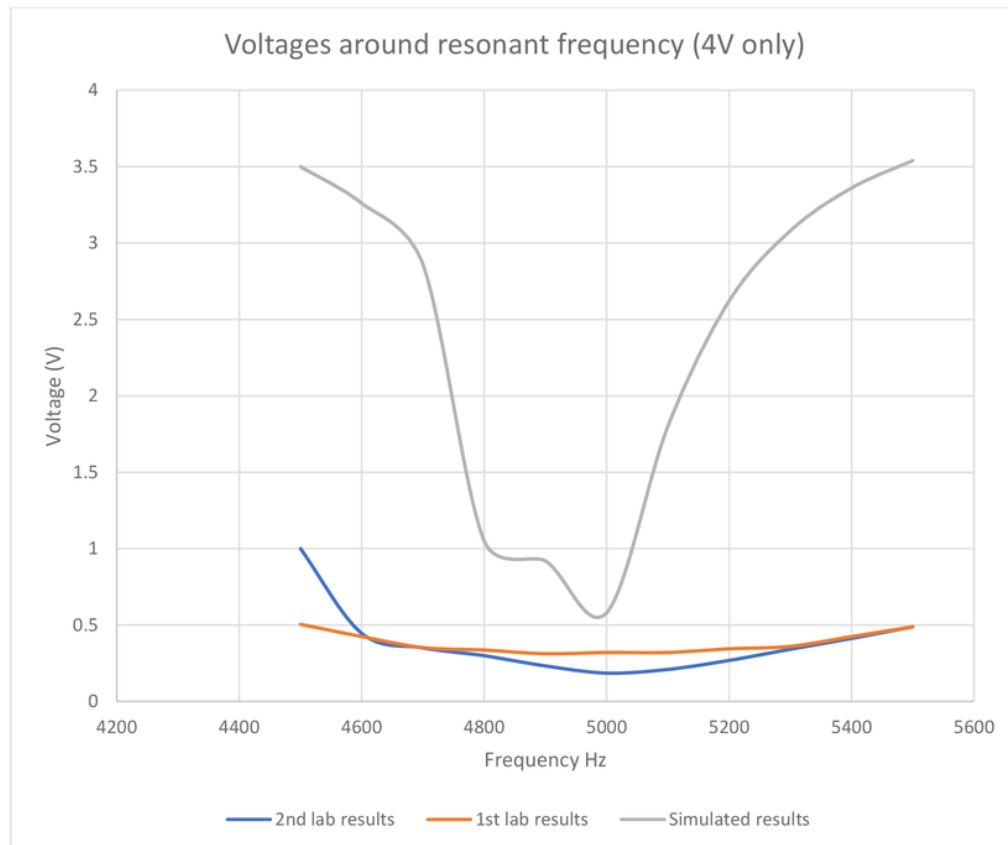
Table 5

Electronic Principals Assignment

Quick interpretation shows that the resonant frequency, when $V_c + V_l$ is at the lowest value, is ~5 kHz. It should be noted that some of the measured values have had to be removed in order to allow the spreadsheet program to overlay the graphs on top of one another.

If all of the results obtained are relayed over one another, it shows that the lowest voltage measured is at the same frequency.

Zooming into the graph [Graph 1] makes it possible to look closer at where the resonant frequency has been measured. As the 12 V simulation enlarges the graph, it has not been drawn on the 'zoomed' representation.



Graph 1.

Looking at the results obtained from both simulation and measurement we can say that the resonant frequencies are as follows. (the graph drawn by Excel doesn't necessarily represent the figures inputted to obtain the graph)

4V simulation	1 st lab measurment	2 nd lab measurement
5 kHz	4.9 kHz	5 Hz

Table 6.

From the results measured in both simulation and electronics lab it can be suggested that the resonant frequency is approximately 5 kHz.

Analysis and Discussion

Two circuits were required for the purpose of the experiment, simulated 12 V and a real 4 V circuit. Following the measurements taken it was decided to create a second simulation at 4 V to better contrast the real circuit against the simulation circuit. A further real circuit at 4 V was built and tested to in order to check/clarify the measurements taken during the lab exercise.

The analysis and discussion here is based around the simulated 4V circuit and the first lab builds 4 V circuit.

The From basic electronic theory it is known that in a simple resistive circuit Ohms law states [1]

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

This can be transposed as

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

In such a resistive circuit the current and the voltage are known as 'in phase'.

Due to an AC circuit having the ability to have phase shift (current leading/lagging the voltage) depending on the type of the circuit. The resistance may include the angel of phase shift, therefore resistance in the AC circuit is known as impedance, (Z)

In a purely capacitive circuit the current will lead the voltage by 90°

In a purely inductive circuit the voltage leads the current by 90°

Capacitors and inductors have an opposition to current flow, this what is known as reactance (X). Reactance in a capacitor is known as X_c and reaction in the inductor is known as X_L . The total reactance of a circuit is known as X_T . An all cases reactance is measured in Ohms, however the use of (X) shows that the circuit is not purely resistive. [3]

The reactance is calculated based on the frequency of the circuit at the time. Therefore through varying the frequency, the reactance from the components will change. At resonance the reactance (X_{fr}) is 0 Ω and the circuit is purely resistive. The reason reactance is 0 Ω is that as X_L and X_c oppose each other, when they are of equal value the cancel out, leaving only resistance in the circuit. [1] [5]

The calculation for Capacitive reactance $X_C = \frac{1}{2\pi fC} = \frac{1}{\omega C}$

The calculation for Inductive reactance $X_L = 2\pi fL = \omega L$

When $X_L > X_C$, the circuit is inductive

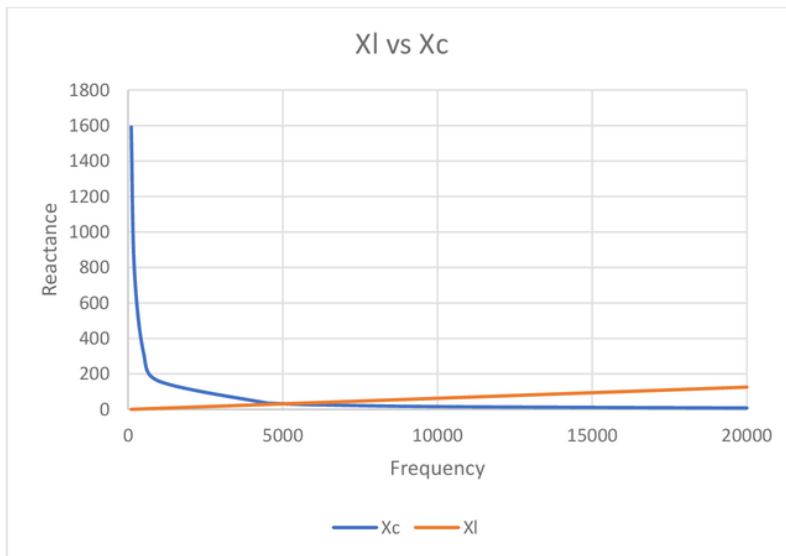
When $X_C > X_L$, the circuit is capacitive

The point at which $X_L = X_c$ the current and the voltage of the RLC circuit are in phase, this is known as the resonant frequency

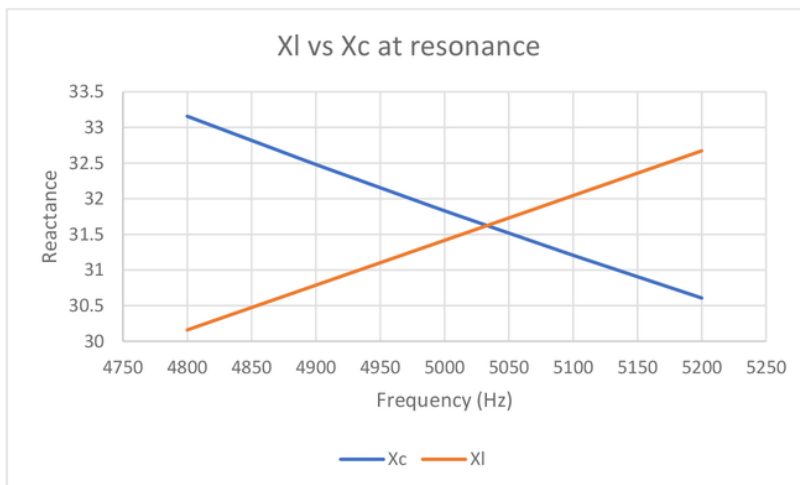
Total circuit reactance = $X_T = X_L - X_C$ or $X_C - X_L$

Electronic Principals Assignment

This information was used to create the following graph of Capacitive and Inductive reactance.



When this graph was zoomed in it was easier to see where the resonant frequency is



From the graph it could be seen that using the results from the simulation package to find where $X_c = X_l$ the resonant frequency was around 5030 Hz.

This matches with the results from the simulation package.

The 'Q' factor of the simulated circuit can be calculated using the formula: [4]

$$Q \text{ factor} = \frac{1}{r} \sqrt{\frac{l}{c}} = \frac{1}{3.3} \sqrt{\frac{1m}{1u}} = 9.58266$$

The resonant frequency can be calculated using the formula [3]

$$\text{Resonant frequency} = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{1m \times 1u}} = 5032.921\text{Hz}$$

Using basic theory it can be determined that the circuit will be at resonance when the frequency of the input voltage is 5032.921 Hz (5.032921 kHz). The 'Q' factor has been calculated as 9.58266.

With these calculations the bandwidth of the circuit can be calculated using the formula [3]

$$Q = \frac{\text{resonant frequency}}{\text{bandwidth}}$$

Therefore

$$\text{bandwidth} = \frac{\text{resonant frequency}}{Q} = \frac{5032.921}{9.58266} = 525.233 \text{ Hz}$$

The components used in the lab practical had values stated to match those used in the simulation. However, these were not the actual values.

The actual values were measured as: resistor = 2.89 Ω , inductor = 0.977 mH and capacitor 1.013 μF

Using this information the Q factor can be calculate as

$$Q \text{ factor} = \frac{1}{r} \sqrt{\frac{l}{c}} = \frac{1}{2.89} \sqrt{\frac{0.977m}{1.013u}} = 10.7459$$

The resonant frequency can be calculated as

$$\text{Resonant frequency} = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{0.977m \times 1.013u}} = 5059.04 \text{ Hz}$$

The bandwidth can then be calculated as

$$\text{bandwidth} = \frac{\text{resonant frequency}}{Q} = \frac{5059.04}{10.7459} = 470.79 \text{ Hz}$$

From the calculations made. It is not clear how they correspond to the results that were measured. The calculated 'Q' factor of the simulated circuit is 9.58, the calculated 'Q' factor of the lab built circuit is 10.75. This means that the lab built circuit should have been a 'better' or 'more selective' circuit with a narrower bandwidth. However when the results were analysed it was quite clear on the graph that the bandwidth was much larger.

Electronic Principals Assignment

A further consideration for the difference on an electronic basis is the internal resistance of the inductor itself. When measuring the real system the internal resistance of the inductor should be added to the series resistance of the circuit.

In LCR circuits both internal (inductor) resistance, and external resistance are present in the complete circuit. Therefore, it will be easier to consider that the voltage V_R is the voltage across the TOTAL circuit resistance, which comprises the internal resistance of L, added to any separate fixed resistor. Where V_S is mentioned, this is the applied supply voltage. [4]

The resistor used in the real circuit was measured at $2.89\ \Omega$, however, the internal resistance of the inductor was also measured at $2.89\ \Omega$. Using the above statement this is very important to consider as the total resistance of the circuit was effectively doubled,

$$R_{total} = R + R_{inductor}$$

Now the total resistance of the circuit is $5.78\ \Omega$.

The Q factor will now be

$$Q \text{ factor} = \frac{1}{r} \sqrt{\frac{L}{C}} = \frac{1}{5.78} \sqrt{\frac{0.977m}{1.013u}} = 5.37$$

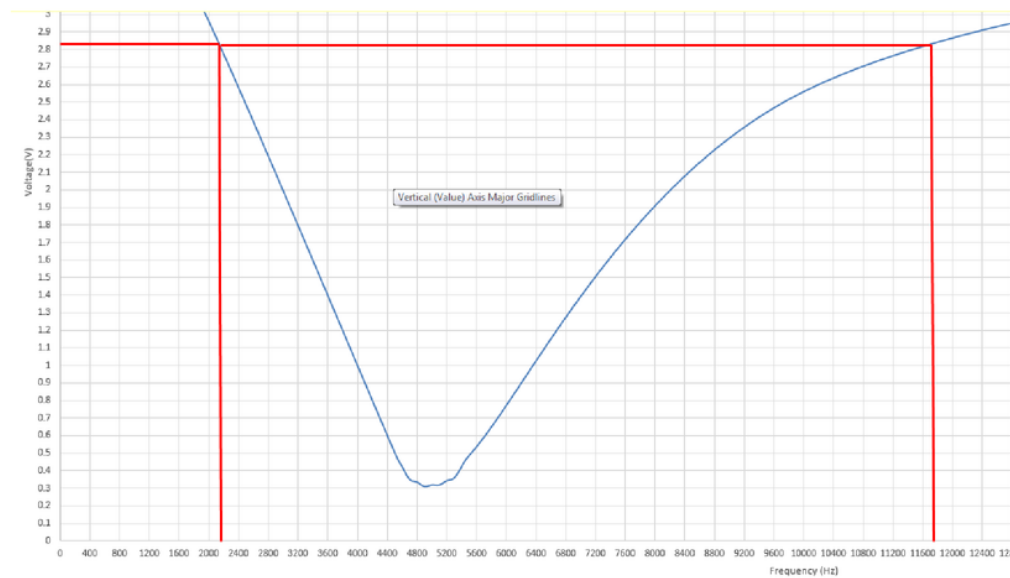
This shows that the Q factor of the real circuit was actually half the calculated Q where no consideration was given to the internal resistance of the inductor.

The much lower Q factor will have a major effect on the bandwidth of the circuit

$$bandwidth = \frac{resonant \ frequency}{Q} = \frac{5059.04}{5.37} = 942.09 \text{ Hz}$$

This was only the calculation though. The bandwidth was measured from the graph below [graph 2] by finding 70.7% (half power) of the total voltage, 4V. This was worked out as 2.82V. By measuring where the 2.82 V line intersects with frequency the bandwidth can be worked. The bandwidth from the graph created is approximately 9500 Hz.

Electronic Principals Assignment



Using the bandwidth measured from the graph, the Q factor can then be worked out to be

$$Q = \frac{\text{resonant frequency}}{\text{Bandwidth}} = \frac{5059.04}{9500} = 0.53$$

This is a very low Q, meaning that the circuit is a very 'bad' circuit and is susceptible to interference from all the frequencies within the bandwidth

Transposing the formula for working out the Q the possible full resistance in the circuit can be predicted.

$$Q = \frac{1}{r} \sqrt{\frac{L}{C}}$$

Therefore

$$\frac{Q}{\sqrt{\frac{L}{C}}} = \frac{1}{R} \quad \frac{0.53}{\sqrt{\frac{0.977m}{1.013u}}} = \frac{1}{R} \quad R = 58.6 \Omega$$

The capacitor may also have resistances similar to that of the inductor, this is known as ESR

The ESR is the ohmic part of an equivalent series circuit. Its value assumes all losses to be represented by a single resistance in series with the idealized capacitor. The ESR is the ohmic part of an equivalent series circuit. Its value assumes all losses to be represented by a single resistance in series with the idealized capacitor. [6]

This basically takes into account all the resistances internal to the capacitor through the dielectric, lead terminations and any other minor resistance pathways.

For the components values given in the lab experiment the ESR values for the capacitor were quoted as

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Electronic Principals Assignment

ESR @ 1 kHz - 5.09189×10^{-5}

And

ESR @ 10 kHz - 7.63784×10^{-4}

When put into the equation to work out the impedance (Z) of the circuit the results are [6]

$$z = \sqrt{\left(ESR^2 + \left(2\pi fl - \left(\frac{1}{2\pi fc}\right)\right)^2\right)}$$

Therefore, at 1 kHz

$$z = \sqrt{\left(5.09189 \times 10^{-5}^2 + \left(2\pi 1k0.977m - \left(\frac{1}{2\pi 1k1.013u}\right)\right)^2\right)}$$
$$= 150.9738088 \, \Omega$$

Also at, at 10 kHz

$$z = \sqrt{\left(7.63784 \times 10^{-4}^2 + \left(2\pi 10k0.977m - \left(\frac{1}{2\pi 10k1.013u}\right)\right)^2\right)}$$
$$= 45.67547237 \, \Omega$$

Unaffected impedance of the circuit is calculated as [3]

$$z = \sqrt{r^2 + X_T^2}$$

At 1 kHz

$$z = \sqrt{2.89^2 + 150.9738088^2}$$
$$Z = 151.001467 \, \Omega$$

At 10 kHz

$$z = \sqrt{2.89^2 + 45.67547237^2}$$
$$Z = 45.76680977$$

These calculations show the impedance solely and inclusive of ESR have very little difference. Although there is a difference, in the circuit we have tested, the ESR plays a negligible effect.

There could be several reasons why the results obtained during this exercise did not follow the predictions from the simulation package. The simulation package works on a “perfect world” system with accurate component values and no losses across the circuit. In reality this would not be possible.

Resonant circuit components can be easily effected by external factors introducing noise onto the system. This could include the frequencies created by fluorescent lighting systems. Other circuits of the same type being tested nearby. Mobile phones can cause interference with a circuit if it is not shielded, although due to the tuning of the system the call could not be ‘intercepted’.

There are internal reasons why the results were different. The simulation does not take into account the extra resistance and circuit disturbances caused by using breadboard. Although breadboard is a useful tool to have in the lab, the more connections are made to it using wires the larger the chance of introducing breaks and poor connections. Small interferences in the circuit could add up to make a noticeable difference.



The function generator has an output impedance of $50\ \Omega$, if this is taken into consideration along with the series resistance of the circuit and any other small resistances, this would make a big difference to the voltages measured and why the frequency bandwidth is so wide. Using the ‘Q’ factor worked out from the bandwidth, the calculated series resistance of the circuit is $58.6\ \Omega$ which is very close to the impedance of the function generator + the circuit resistance of $5.78\ \Omega$ totalling $55.78\ \Omega$

Conclusion

If the idea of the experiment was just to measure and compare the resonant frequency of a simulated circuit and a real circuit. It could be quite well suggested that, although the resonant frequencies are slightly different, the inaccuracies of the real components show that the two circuits represent each other well.

The objective was not just to compare the resonant frequencies, it was to consider the differences of the LCR circuit and the resonance. In a perfect world situation the results taken and graphs drawn would have matched perfectly with that of the simulation. This was not the case. The resonant frequency matched, however the bandwidth and thus, the ‘Q’ factor did not match the simulation package at all.

After considering all the options as to why they may not have matched, such as internal resistances, inaccuracy of the components, the use of breadboard and the impedance of the function generator (non-extensive list). It could be reasonable to say that if you know all these component intricacies then they could be planned into the simulation. If they are all considered in the simulation then the result should be as expected.

What the experiment does show however, is that when using a simulation package to predict the output of an experiment. It is a much faster and easier way to set up the circuit then to build it properly. If the simulation successfully gives the output that is planned, then confidence can be taken that the prototype real circuit will be accurate which can aide the movement forward toward full implementation of the circuit.

References

- [1] Electrical and Electronic Principles and Technology (3rd edi). John Bird. 2007. Page 251.
- [2] Multiverse Time Travels, Antonov, Alexander A. International Journal of Pure and Applied Sciences and Technology; Kokrajhar Vol. 12, Iss. 2, (Oct 2012): 43-56. Para 2.1
- [3] <https://www.electronics-tutorials.ws/accircuits/series-resonance.html>. Last accessed 4/2/19
- [4] http://www.learnabout-electronics.org/ac_theory/lcr_series_91.php . Last accessed 4/2/19
- [5] AC theory. Mosey S. UWTSD class notes. 2018
- [6] <https://www.vishay.com/docs/26033/gentechinfofilm.pdf>. Last accessed 4/2/19

EP assignment year 1

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

70/100

Instructor

PAGE 1

PAGE 2



Comment 1

what



Comment 2

Nice abstract. Contained all the information needed.



Comment 3

misplaced word



Comment 4

Interesting, but I'm not sure this is relevant to this investigation.



Comment 5

Good description of Q factor

PAGE 3

PAGE 4



Comment 6

along

PAGE 5



Comment 7

You have included a graph of the data. You do not need to include a table as it is far easier to identify trends using a graph.

PAGE 6



Comment 8

No need for table, graph is better.

PAGE 7

PAGE 8

PAGE 9



Comment 9

(12V)

PAGE 10

PAGE 11



Comment 10

misplaced 'The'



Comment 11

Not sure what you are trying to say here.

Also I think you mean 'angle' instead of 'angel'



Comment 12

opposition to change of current flow

PAGE 12

PAGE 13

PAGE 14

PAGE 15



Comment 13

ESR



Comment 14

Good point, well spotted.

GRADING FORM: SMU GENERIC_SMOSEY

STEVEN JAMES

70.25

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



Inclusion of a wide range of research-informed literature, including sources retrieved independently. Selection of relevant and credible sources. Very good use of referencing conventions, consistently applied.

3.25

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 or through effective collaboration. 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.



A very good application of a range of methods, materials, tools and/or techniques. Evidence of some innovation and creativity.

19.5

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 well, confidently and consistently



in a suitable format. Work is coherent and fluent and is well structured and organised.

3.4