

Resonance Frequency of a RLC circuit

by George Goddard

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Resonance Frequency of a RLC circuit

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Abstract

The purpose of this report is to compare resonance on two different circuits. The first circuit will be a computer simulation, the second being a lab practical. From these two circuits a number of different calculations will be made including bandwidth and Q factor. From these calculations comparisons and discussions can be made on different aspects of the circuits.



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Introduction

This report explores resonance in an RLC circuit. An RLC circuit contains a resistor, capacitor and an inductor, in this report these components are connected in series. The name of the circuit comes from the three components used, however the order in which they are placed may change and these circuits are also commonly known as LCR circuits.

Resonance occurs when the inductive reactance and capacitive reactance are equal and cancel each other out. Because of this RLC circuits are used in radio systems and used as filters to block frequencies.

A practical and a computer simulation were used to gather data. For the practical aspect a circuit was built using a breadboard a signal generator and an oscilloscope.

Besides resonance this report will also cover Q factor, impedance, reactance and effective series resistance. This will include graphs and calculations.

Apparatus list

A number of components were identical between the practical lab exercise and the theoretical simulation of the circuit, these are:

- 3.3 Ohm resistor
- 1 Milli Henry inductor
- 1 Micro Farad capacitor
- Signal generator
- Oscilloscope
- Wires

Theoretical

To complete the theoretical aspect of the exercise Proteus 8 professional computer software was used in addition to the specified generic components to simulate the RLC circuit.

Practical

In addition to the generic components a breadboard was used to enable all the components to be connected as a circuit.

Method

Theoretical

Proteus was used to simulate the circuit; the resistor, capacitor and inductor were selected from the component menu and placed onto the circuit board, appropriate values given to each component. The components are then connected using wires and a ground, signal generator and oscilloscope are added as shown in figure 1.

Wires are taken from the oscilloscope and placed between the signal generator and the resistor and between the resistor and the inductor.

Once the circuit is set up, the signal generator was started. The signal generator was then set to 12 volts constant and different frequencies as shown in table 1. $V_L + V_C$ was then read from the graph and tabulated in excel.

Lab practical

To complete the lab practical all the components were collected ready to begin the assembly of the circuit. The resistor, capacitor and inductor were placed into the breadboard and short wires were used to connect the components in series. Figure 2 shows how the components and wires were connected to the breadboard.

The probe was connected between the resistor and the inductor ready for readings to be taken. Disconnecting the wire between the resistor and the inductor broke the circuit to enable the voltage to be set on the signal generator; this was set to 1.2 volts. The point at which the probe was placed can be seen in figure 3, along with the wires connecting the signal generator to the circuit and earth wires.

Once the signal generator was set the wire was reconnected to complete the circuit, ready for readings to be taken. The intervals at which readings were taken are shown in table 1. To take the readings the signal generator was set to the stated frequency and the voltage was read off the oscilloscope. The voltage was collected in two ways, firstly by counting the squares peak to peak of the waveform, and secondly and more accurately taking the peak to peak value given on the oscilloscope.

Once both sets of results were collected they were put into graphs on excel with a logarithmic scale.

Table 1

frequency Hz
100
200
500
1000
2000
4500
4600
4700
4800
4900
5000
5100
5200
5300
5400
5500
10000
20000

Figure 1

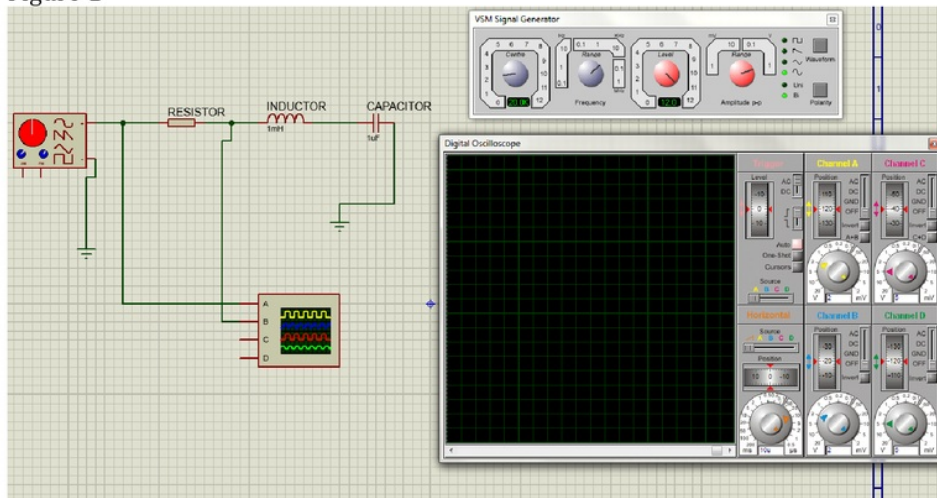


Figure 1 shows the setup of the circuit in Proteus.

Figure 2

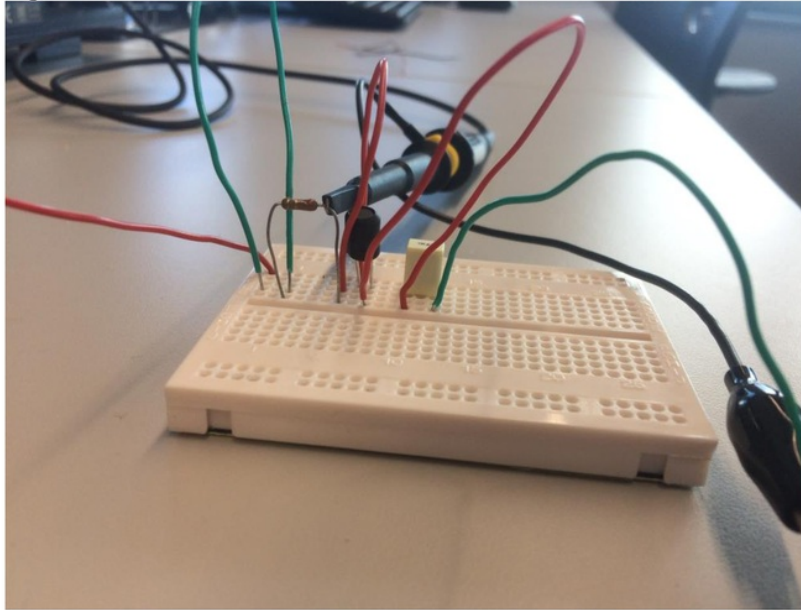


Figure 2 shows how the components were placed in the breadboard

Figure 3

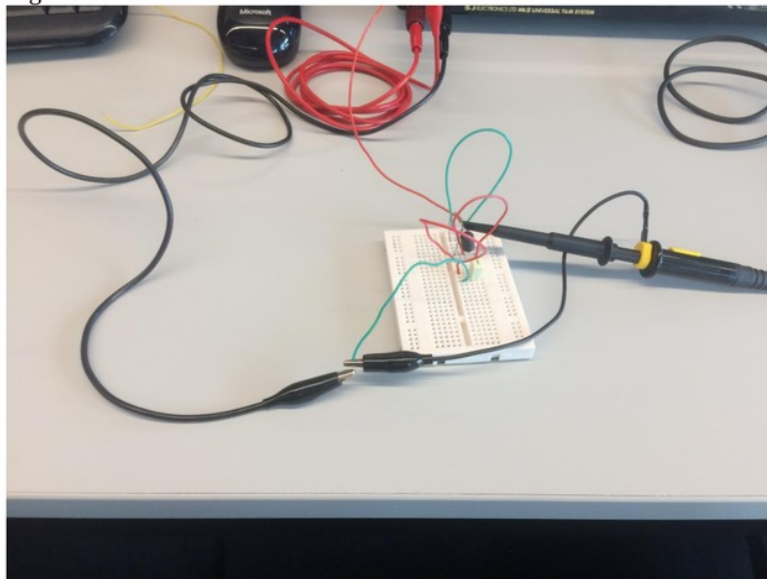


Figure 3 shows an overall view of the lab set up with the signal generator coming into the circuit and ground leaving the circuit.

Figure 4

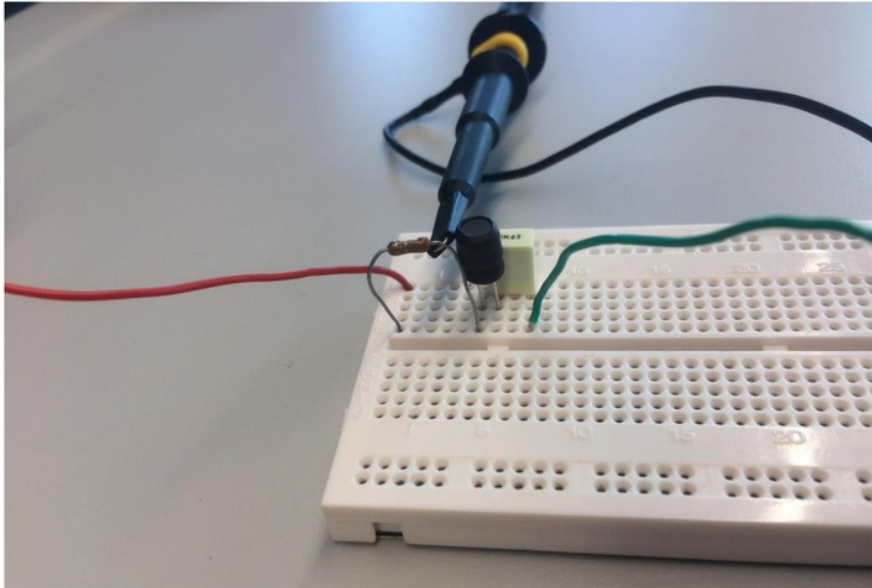


Figure 4 shows how the circuit could have been connected in a more efficient way without using wires between the components.

Results

Table 2

Frequency (Hz)	VL+VC Volts
100	12
200	12
500	12
1000	12
2000	12
4500	10.2
4600	10
4700	8.1
4800	6.1
4900	2.4
5000	2
5100	5.8
5200	8
5300	9.4
5400	10.1
5500	10.8
10000	12
20000	12

Table 3

Frequency (Hz)	VL+VC Actual value (Volts)	VL+VC Counting squares (Volts)
100	1.24	1.2
200	1.24	1.2
500	1.24	1.2
1000	1.16	1.2
2000	0.928	0.88
4500	0.17	0.14
4600	0.16	0.145
4700	0.12	0.11
4800	0.1	0.095
4900	0.094	0.08
5000	0.089	0.088
5100	0.092	0.09
5200	0.094	0.092
5300	0.102	0.098
5400	0.122	0.116
5500	0.137	0.132
10000	0.776	0.76
20000	1.1	1.1

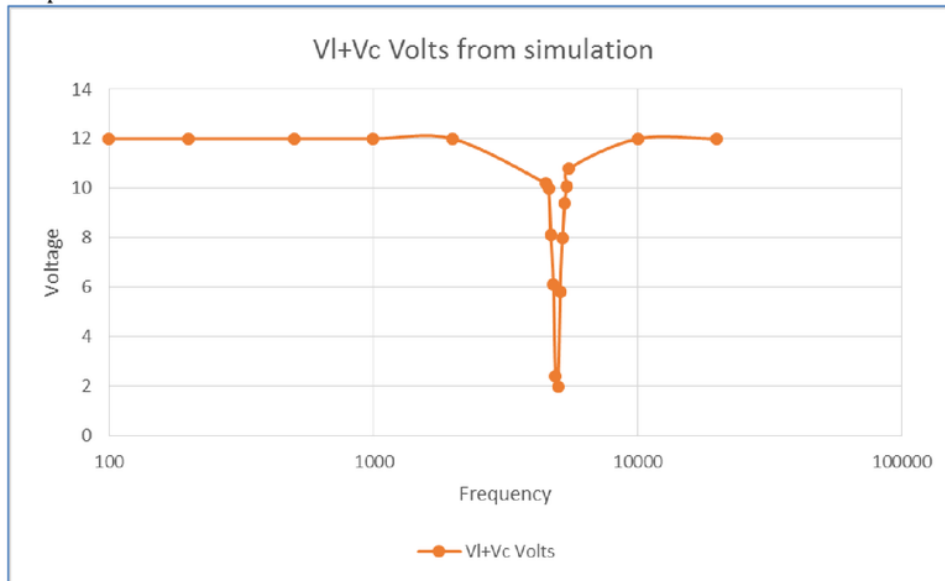
Table 2 shows the raw data from the proteus simulation.

Table 3 shows the raw data from the lab exercise, it shows the actual voltage taken by reading the value from the oscilloscope and the value by counting squares.

Table 4		
Component	Stated value	Measured value
Inductor	1 μ F	1.013 μ F
Capacitor	1 mH	0.977 mH
Resistor	3.3 Ω	3.27 Ω

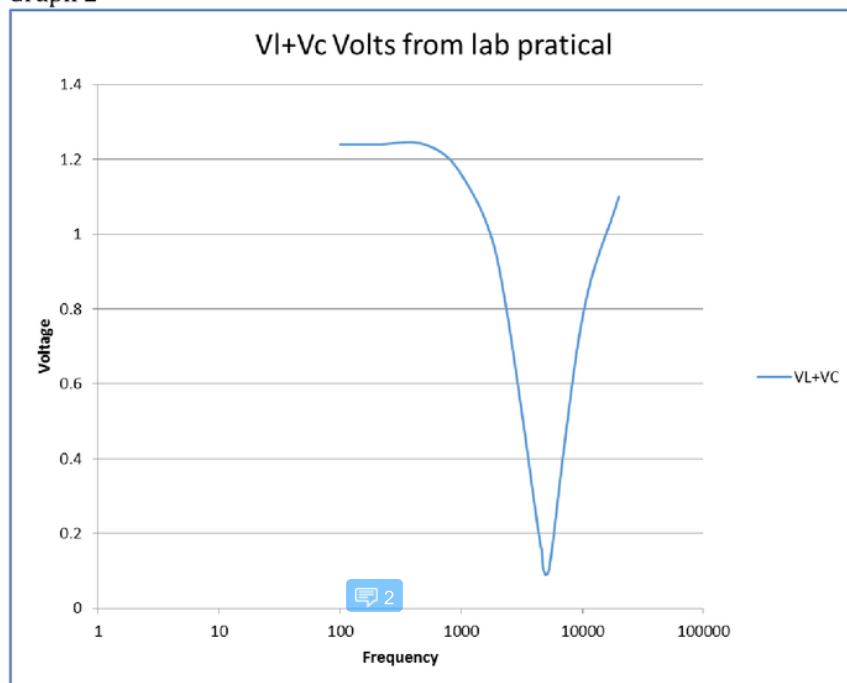
Table 4 shows the stated and measured values of the components used in the lab practical.

Graph 1



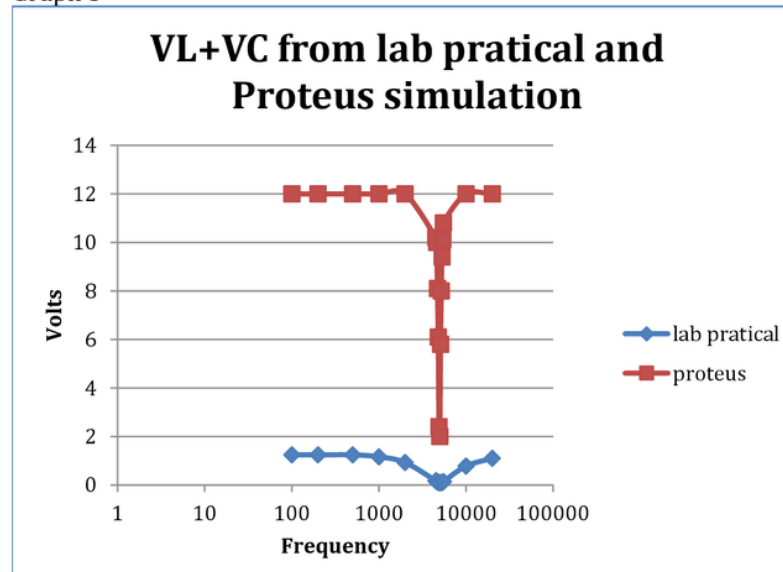
Graph 1 shows the data from the Proteus simulation plotted on a line graph.

Graph 2



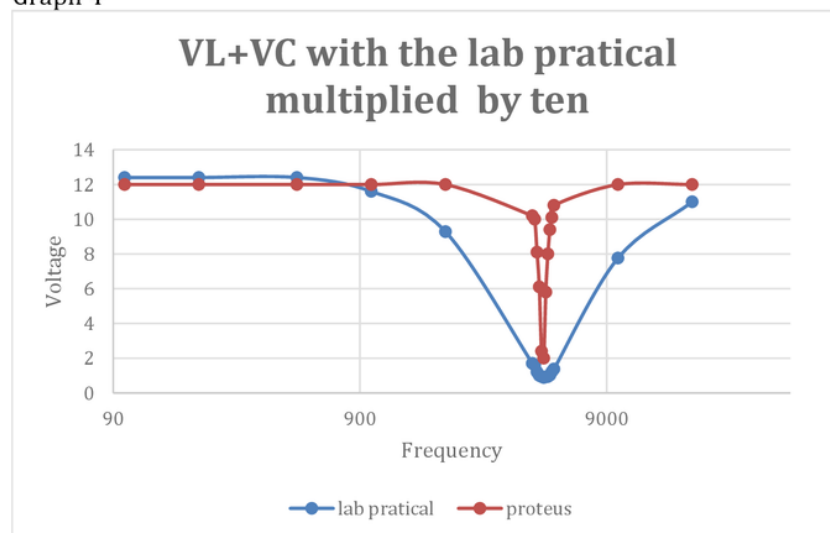
Graph 2 shows the data from the lab practical plotted on a line graph.

Graph 3



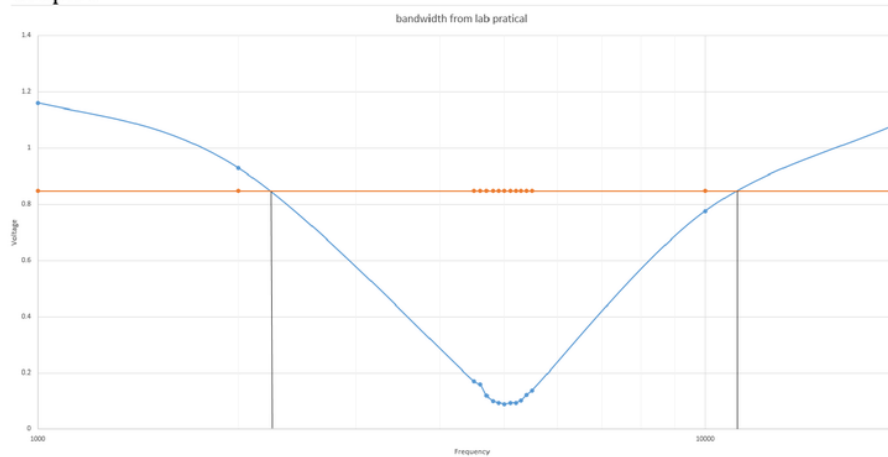
Graph 3 shows the simulation results and the lab practical results.

Graph 4



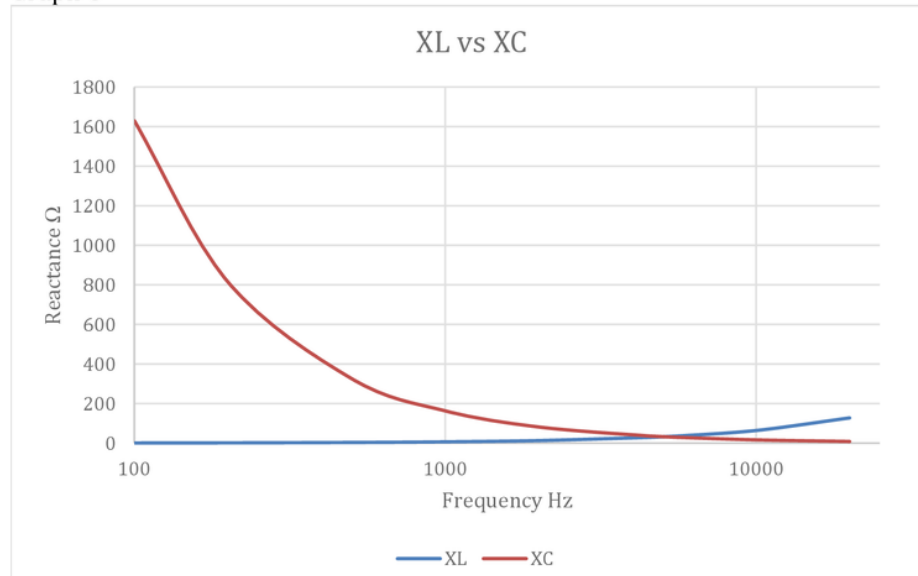
Graph 4 gives a better view of the two curves on the same plot with the lab results being multiplied by ten.

Graph 5



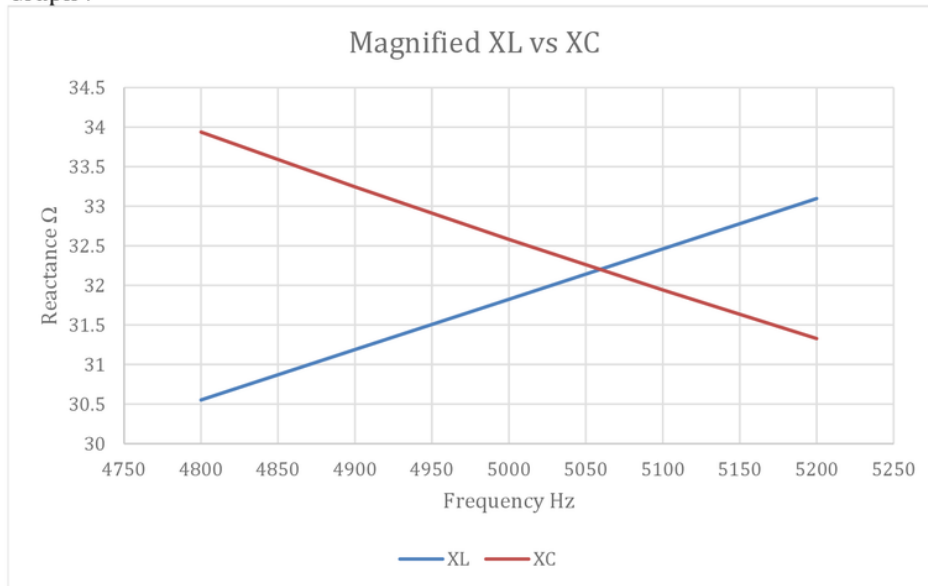
Graph 5 shows how the bandwidth is calculated using the 70.7% line.

Graph 6



Graph 6 shows series resonance frequency for the lab practical where the inductive and capacitive reactances are equal.

Graph 7



Graph 7 is a magnified portion of graph 6 showing the point at which the inductive and capacitive reactances are equal.

Equations

The following equations are based on the Proteus simulation.

Equation 1 [1]

$$XL = 2\pi fl$$

$$XL = 2 \times \pi \times 5032.92121 \times 1 \times 10^{-3}$$

$$XL = 31.622 \Omega$$

Equation 2 [1]

$$XC = \frac{1}{2\pi fc}$$

$$XC = \frac{1}{2 \times \pi \times 5032.92121 \times 1 \times 10^{-3}}$$

$$XC = 31.622 \Omega$$

Equation 3 [1]

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

$$F_{res} = \frac{1}{2 \times \pi \times \sqrt{1 \times 10^{-3} \times 1 \times 10^{-6}}}$$

$$F_{res} = 5032.9212$$

Equation 4 [1]

$$Q = \frac{XL}{R}$$

Equation 5 [1]

$$Q = \frac{XC}{R}$$

Equation 6 [1]

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

$$Q = \frac{31.622}{3.3}$$

$$Q = 9.58$$

Equation 7 [1]

$$Q = \frac{Fr}{BW}$$

Equation 8 [1]

$$BW = Fh - Fl$$

Equation 9 [2]

$$ESR = \frac{DF}{XC}$$

Theory

Resonance

When an RLC circuit is at resonance the two reactance's X_L and X_C are equal and cancel out, thus giving resonance. This occurs when the circuit current and applied voltage are in phase. Resonance is used to establish a stable frequency in AC circuits. Resonant circuits are also used as filters to block a frequency or range of frequencies. [3]

'Inductive reactance X_L is equal to capacitive reactance X_C .

Total impedance of circuit becomes minimum which is equal to R i.e. $Z = R$.

Circuit current becomes maximum as impedance reduces, $I = V / R$.

Voltage across inductor and capacitor cancels each other, so voltage across resistor $V_r = V$, supply voltage.

Since net reactance is zero, circuit becomes purely resistive circuit and hence the voltage and the current are in same phase, so the phase angle between them is zero.' [4]

Q factor

'The quality factor or 'Q' of an inductor or tuned circuit is often used to give an indication of its performance in a resonator circuit. The Q or quality factor is a dimensionless number and it describes the damping in the circuit. It also provides an indication of the resonator's bandwidth relative to its center frequency.' [5]

Impedance

Impedance, measured on ohms (Ω) is the opposition of current within a circuit. It is similar to resistance but takes into account inductance and capacitance.

Frequency varies impedance unlike resistance which is constant regardless of frequency. [6]

Reactance

'Reactance is a measure of the opposition of capacitance and inductance to current. Reactance varies with the frequency of the electrical signal. Reactance is measured in ohms (Ω).

There are two types of reactance: capacitive reactance (X_C) and inductive reactance (X_L).' [6]

Effective series resistance

When a capacitor is in series it displays an internal resistance that appears with capacitance of the device. The resistance can vary from milliohms to several ohms; these losses can result in reduced efficiency, power losses and instability of power supply. The resistance that shows depends on a number of factors, these can be:

- The quality of the device
- How it was constructed
- Its dielectric material
- Its reliability

Discussion

Resonance

Resonance occurs when the inductance reactance is equal to the capacitive reactance, or $X_L = X_C$. This is shown by the sharp drop on the graphs of the two sets of results. X_C and X_L can also be calculated mathematically, and from this, resonance can be calculated.

Proteus

From the data acquired from the computer simulation you can see that there is a very steep curve down to the resonant frequency. As can be seen in the results table 2 readings were taken at closely spaced intervals around the resonant frequency. From this we can see that the resonant frequency is approximately 5 KHZ.

Basic theory allows the calculation of the resonant frequency. This is achieved by using calculation 3. As can be seen this gives a resonant frequency of 5032.9212 Hz.

These two figures of 5000 Hz and 5032.9212 show that the simulation has performed as expected. These figures compare well, had smaller intervals been taken around the 5 KHz Peak a more accurate result could be achieved. However

due to the signal generator that Proteus uses smaller intervals cannot be taken and 100 Hz is that smallest interval available at 5 KHz.

Lab exercise

Graph 2 shows resonance at 5 KHz with a shallower curve down to resonance. As with the simulation readings were taken at closely spaced intervals around the resonant frequency.

Again, basic theory allows the calculation of the resonant frequency. This is achieved by using calculation 3. This time the measured values of the components were used rather than the stated values to give an accurate resonant frequency of 5059.04 Hz

Both figures are similar as with the simulation. This is again due to the intervals at which the readings were taken.

Comparison

The results from the simulation and lab practical compare very well as can be seen in graph 3. Although taken at different voltages, you can still see that resonance occurs at ≈ 5 KHz. While the simulated graph has a steep curve down to resonance the practical has a gentler curve. Due to the extra resistance from the wires and the breadboard this will show the shallower curve.

Graph 5 shows the two curves side by side but the lab exercise values have been multiplied by ten to give the same voltage as the simulation. Having both curves on the same plot gives a better view of the two sets of results. This really shows the difference in the two sets of data showing the much larger bandwidth of the lab results.

Real components and simulated ideal components

All components used in the lab practical will have a tolerance, although close to the specified values there will be some difference and the measured values are shown in table 4. Proteus doesn't take into account these tolerances or other real world factors like extra resistance due to the wires used in the circuit. Temperature can also have an effect on the way a circuit operates, again not taken into consideration in the simulation.

From the ideal components used in simulation you get accurate results, in a simulated environment. From the lab practical you get measurements from live components. Differences are expected, however the real world results give a true reflection on what the circuit is doing. Simulation is great for design and verification of a circuit but only when it is manufactured and tested can you get physical data.

Simulation is used early on in circuit design to keep costs down. At this stage components can easily be changed or edited to give the desired application of the circuit. One of the limitations of simulation is it does not take into account that these are physical components and if you pass too much voltage through them they will burn out and not function.

To complete the lab practical a breadboard was used for the base of the circuit. Breadboards are a very practical way of prototyping a circuit and have their advantages and disadvantages. For teaching they are a useful aid as they are plug and play. No soldering is required and you just place the components into the terminals. Little experience is needed to use a breadboard and components can easily be changed for different component values or additional components and all components can be reused unlike in a PCB. However they have their disadvantages, as there is no solder to hold components in place there is the possibility for poor connections or components to come out of the terminal. This type of prototyping also is not suitable for high voltages or high current applications. In these cases a PCB would be more suited for the circuit. Due to the way breadboards are set up they have a very high resistance due to the strips that connect the terminals.

Figure 4 shows how the practical could have been set up in a better way. The components are connected across the breadboard without any wires. Doing this will reduce the circuit resistance and make the circuit more efficient.

Q Factor

There are a number of different calculations that can be used to calculate Q factor. To use calculations 4 or 5 you must first use calculations 1 and 2 to calculate X_L or X_C . Once X_L or X_C has been worked out the Q factor can be calculated.

As can be seen from the calculations the Q factor for the proteus simulation is 9.58.

Using the same calculations we can calculate Q for the lab practical X_L and X_C are calculated at 31.055 and the Q factor is calculated at 9.497.

The slight variation between the two Q factors is due to using the measured values rather than the stated values from the components. Although this gives us a Q factor for the lab practical this is only a calculation and still in a perfect situation. To get a true Q factor for the lab practical you must use equation 8 and calculate the bandwidth.

To calculate the bandwidth it must be calculated from the graph. This is done by calculating the 70.7% or -3dB amplitude points. 70.7% is the frequency at which the power of the signal is half, this point is also known as half power. Once calculated a line is drawn on the graph and the upper and lower values are read

off and subtracted giving you the bandwidth. This can then be used in equation 7 to calculate the true Q factor.

Q factor calculation for the lab practical

$$70.7\% = 1.2 \times 0.707$$

$$70.7\% = 0.8484$$

$$BW = 1060 - 2900$$

$$BW = 7260$$

$$Q = \frac{5059.04}{7260}$$

$$Q = 0.6$$

Using the same equations the Q factor for proteus was calculated at 10.066. The difference between the two proteus calculations will be down to the inaccuracy of reading off a graph. These two values are still close, giving us a good idea of the Quality factor.

With the calculations for the practical it can be deduced that the Q factor calculated using the bandwidth is the correct Q factor. As can be seen the bandwidth is much wider than the simulated bandwidth, thus giving a much lower Q factor.

A higher Q factor will give a narrow bandwidth and a low Q factor will give a wide bandwidth. This can be seen in graphs 1 and 2 as the simulation has a Q factor of 9.58 and a narrow bandwidth. The lab practical has a much wider bandwidth and has a much lower Q factor than the simulation. This can be explained by, "As losses decrease so the tuned circuit becomes sharper as energy is stored better in the circuit". [5] Therefore increasing the Q factor.

The low Q factor for the lab practical can be attributed to a number of factors. One factor will be the breadboard and wires that were used to assemble the circuit. The breadboard and wires will give the circuit extra resistance lowering the Q factor. To rectify this a PCB would be the best solution and to solder in the components, but just removing the wires and setting the components up as shown in figure 4 will have an effect and increase the Q factor.

XL vs. XC

Graphs 6 and 7 show XL plotted with respect to XC against frequency and reactance. These graphs once again confirm that previous calculations are correct. As can be seen from graph 7 the two curves cross at approximately 5060 which is what the calculated resonance frequency is. These graphs show a good representation of where XL and XC are equal and cancel each other out giving you the resonance frequency.

Effective series resistance

Equation 9 was used to calculate the ESR (Effective series resistance) at 1 KHz, 5 KHz and 10 KHz.

$$1 \text{ KHz} = 5.09189 \times 10^{-5}$$

$$5 \text{ KHz} = 2.54595 \times 10^{-4}$$

$$10 \text{ KHz} = 7.63784 \times 10^{-4}$$

These calculations were calculated using the manufactures dissipation factor of 0.08%.

As can be seen from the calculations the resistances are milli ohms and are within a few milli ohms of each other. These values are negligible and wouldn't affect the main results gathered in this report.

This energy is lost as heat through the capacitor. As the temperature of a capacitor rises so does the ESR however the rises are non-linear. In power supply circuits that have high current this temperature rise could be significant. However the current in the tested circuit is very low and wouldn't have been affected by the ESR values.

Conclusion

There are a number of conclusions that can be drawn from this report. The first is the difference between a physical lab practical and a simulation. As shown by the curves from the two data graphs one showing a shallow and one showing a steep curve. The Q factor from the two exercises also shows differences, the simulated circuit had a Q factor of 9.58 while the lab practical circuit had a Q factor of 0.6, showing that the real circuit has much higher energy loss. Both circuits gave very similar resonance frequency's which proves that both exercises and calculations were carried out correctly, but continues to show the difference between simulation and a practical.

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- [5] E. Notes, "Quality Factor / Q Factor; formulas and equations," [Online]. Available: https://www.electronics-notes.com/articles/basic_concepts/q-quality-factor/basics-tutorial-formula.php.
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Resonance Frequency of a RLC circuit

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

59/100

PAGE 1



Comment 1

You need to state your results, or your main conclusions.

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

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PAGE 9



Comment 2

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

Also what units are the axis in?

PAGE 10

PAGE 11

PAGE 12

PAGE 13



Comment 3

units?

GRADING FORM: SMU GENERIC_SMOSEY

GEORGE GODDARD

58.60

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



Inclusion of a wide range of literature, including sources retrieved independently. Selection of relevant and some 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.



Knowledge is accurate with a good understanding of the field of study.

17.7

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.



Evidence of some logical, analytical thinking and synthesis. Can analyse new and/or abstract data and situations without guidance. An emerging awareness of different stances and ability to use evidence to support the argument. Valid conclusions.

17.4

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, with some use of examples.

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

2.85