

Resonance Assignment

by Peter Zoltan Down

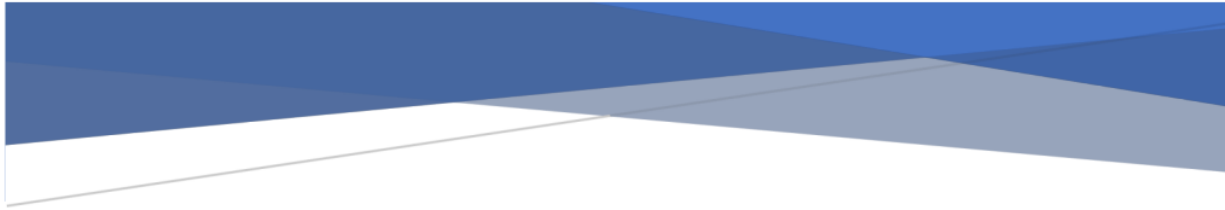
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RESONANCE ASSIGNMENT

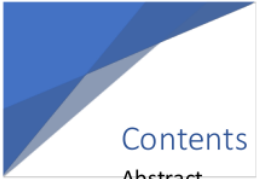
Electrical and Electronic Principles

Abstract

This report details measuring the output voltage in an LC circuit dependent on frequency in order to investigate the resonant frequency. This was done as a laboratory exercise and also a simulation and this report will compare the results from each. It was found that the simulation had a higher Q-factor and higher peak value than the laboratory exercise. A second simulation including additional component and circuit attributes was found to more accurately reflect the measured values of the physical components.

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[Email address]



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Introduction

In this experiment, an LC circuit, also known as a tank or a tuned circuit, is used. The circuit consists of a capacitor and inductor.

As an isolated ideal circuit consisting just of the capacitor and inductor, continuous oscillations would be observed. As the capacitor discharges it causes current to flow. As the current goes through the inductor it generates a magnetic field. When the limited amount of charge stops flowing, the inductor's magnetic field collapses. This causes a current to flow in the opposite direction to before. This, in turn charges the capacitor again, but this time in the opposite polarity.

In an ideal LC circuit, no energy is consumed due to there being no circuit resistance [1]. In reality there would be resistances present in the source, the wires and the components that would cause the oscillations to be damped each time the current flows. In an ideal circuit, the above process of charging and discharging components would continue forever, however the effect of resistance would dissipate the energy as electromagnetic radiation leading to a damping effect on the circuit.

The frequency at which the isolated circuit oscillates is known as the resonant or natural frequency. This is determined by the value of the capacitor and inductor and occurs at the point where the reactance of the capacitor and inductor are equal.

The reactance of a capacitor is inversely proportional to frequency whereas the reactance of an inductor is directly proportional to the frequency, as can be ascertained from the equations in figure 1. This leads to an LC circuit exhibiting interesting behaviour at resonance.

$$X_C = - \frac{1}{2\pi fC}$$

$$X_L = 2\pi fL$$

$$Z = R + X_C + X_L$$

Figure 1: Equations for capacitive reactance, inductive reactance and impedance. In a parallel circuit the impedance equation above only applies to one branch of the circuit. [2]

This behaviour is different and opposite depending on the circuit configuration used. In a series circuit, impedance is determined by adding the values of resistance, capacitive reactance and inductive reactance. In an ideal LC circuit there is no resistance and at the resonant frequency the reactances of the inductor and capacitor are equal and opposite. As such, impedance is at a minimum meaning that the value of the current approaches infinity.

This lends itself to band pass filters as the current is very large in a range of frequencies surrounding the resonant frequency. An application of this is for tuning radio transmitters and receivers [1]. This is how a radio can be tuned to one particular frequency – or in reality a small range of frequencies around the desired frequency, and ignore all others. Another application of series LC circuits is for voltage magnification. As can be derived from ohm's law, the magnification is the source voltage multiplied by the Q factor [3].





$$\begin{aligned}Z_{\text{parallel}} &= \frac{1}{\frac{1}{Z_L} + \frac{1}{Z_C}} \\Z_{\text{parallel}} &= \frac{1}{\frac{1}{100 \Omega \angle 90^\circ} + \frac{1}{100 \Omega \angle -90^\circ}} \\Z_{\text{parallel}} &= \frac{1}{0.01 \angle -90^\circ + 0.01 \angle 90^\circ} \\Z_{\text{parallel}} &= \frac{1}{0} \quad \textbf{Undefined!}\end{aligned}$$

Figure 2: Combination of parallel reactances [4]

The behaviour of an LC circuit is the opposite when the capacitor and inductor are in parallel. This is due to the fact that impedances of individual branches add up using the equation in figure 1 but the total impedance across both branches uses the equation in figure 2. Yet again, at the resonant frequency where the reactances of the capacitor and inductor are equal but opposite, they cancel out. In parallel however that results in the impedance being $1/0$, or in other words infinite. As a result, the current is at its minimum value.

This lends itself to band-stop filters as the current is minimum at a small range of frequencies [5]. These can be used for stopping noise passing through in a given frequency range. It can also be used for current magnification the value of which is attained by multiplying the source current by the Q factor [6].

This report will be to detail the results from both a laboratory exercise and a simulation of a parallel LC circuit. The aim is to compare the results and analyse any differences that might be observed. The circuit itself will be discussed in the simulation setup section. The results will then be presented from both the simulation and laboratory exercise. The results will then be analysed and whether any improvements to the circuit can be made will be discussed. Finally, the report will lead to a set of conclusions based on the outcome of the discussion.



Simulation Setups

The circuit used in both the laboratory exercise and the simulation was a parallel LC circuit consisting of a signal generator, a 1000 Ω resistor in series, and a 1 μF capacitor and 1mH inductor in parallel to each other. The input voltage used was 2 V peak to peak. An oscilloscope has been used to take measurements in both the simulation and the laboratory exercise. The circuit can be seen in figure 3.

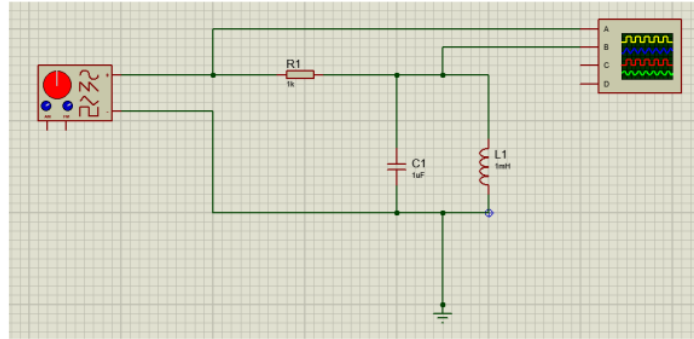


Figure 3: Circuit used in laboratory exercise and simulation

The independent variable in this exercise is the frequency whereas the dependent variable is the output voltage. The frequency values selected ranged from 100 Hz and 20000 Hz on a logarithmic scale. 19 data points were selected for the laboratory exercise whereas 18 of the same data points were used for the simulation. This is because the laboratory exercise also had a data point almost exactly on the calculated resonant frequency. On both laboratory exercise and simulation there was a concentration of data points around the resonant frequency which was calculated to be 5032.92121 Hz using the equation in figure 4.

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

When $X_L = X_C$ resonance occurs

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

Figure 4: Resonant frequency equation [7]

The output voltage was used as the dependent variable as when power remains constant, the value of output voltage is inversely proportional to the current, the current is inversely proportional to the impedance, which itself is affected by changing the frequency.

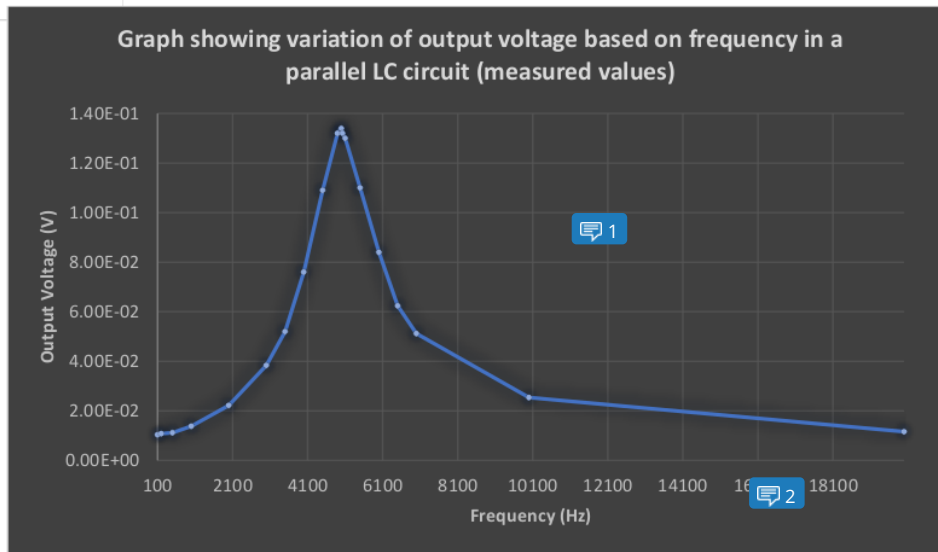


Figure 5: Measured values of V_{out}

Figure 5 is a graph showing the measured values attained during the laboratory exercise. As can be seen, the output voltage peaks at around 5000 Hz as predicted, and does not have a very sharp peak. The maximum value is around 0.135 V.

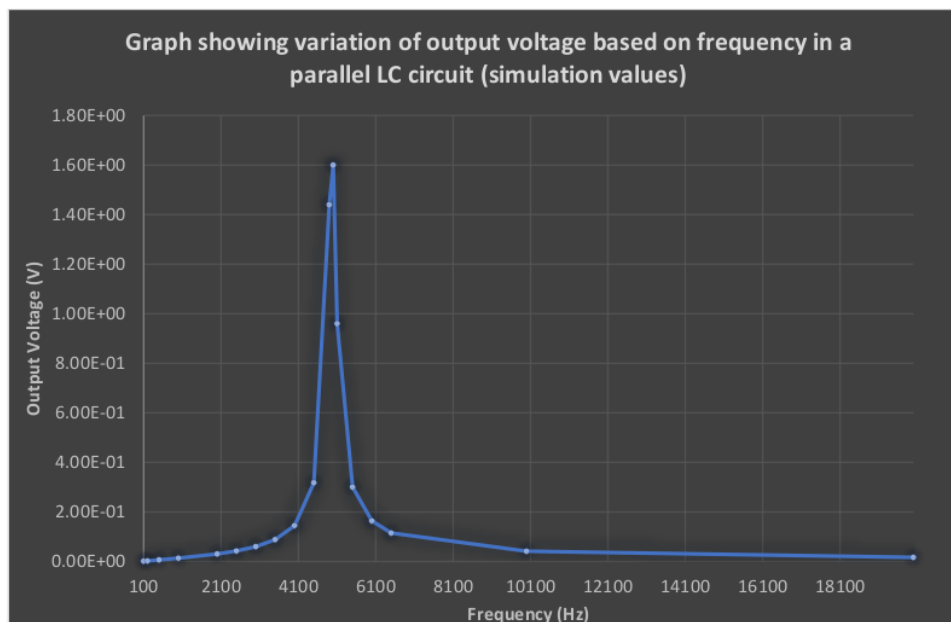


Figure 6: Simulated values of V_{out}

Figure 6 is a graph showing the values produced by the simulation. The peak of this graph is sharp and the maximum value is 1.6 V.

Discussion

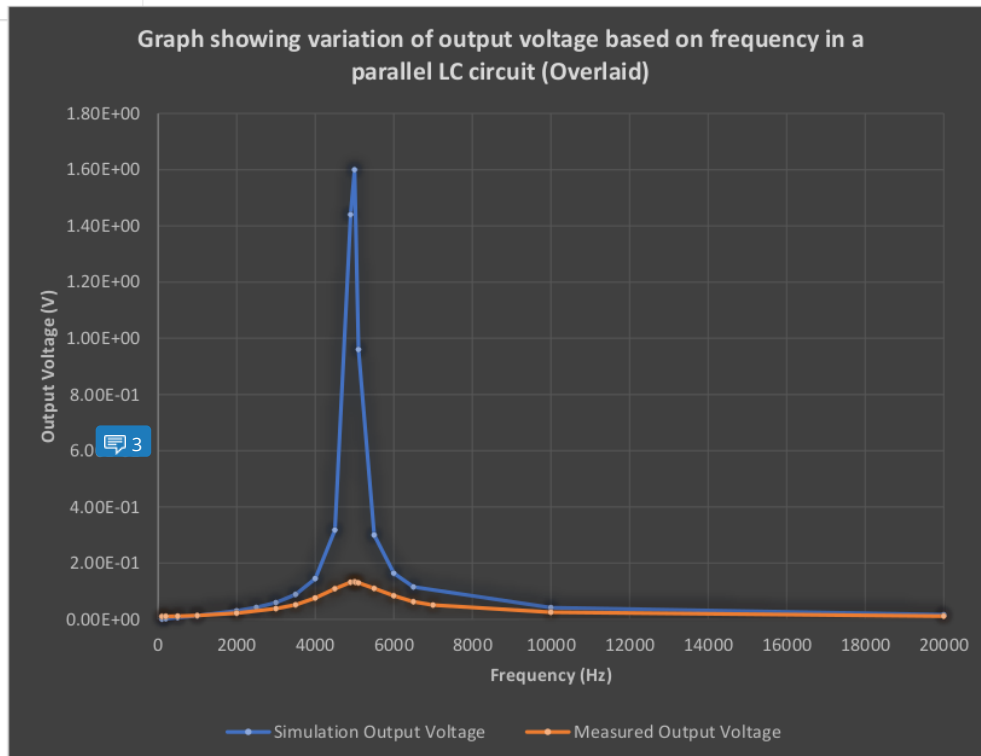


Figure 7: Overlaid graphs showing simulated values of output voltage against measured values

Both data sets represented in figure 7 peak at the 5000 Hz data point. This is expected for the simulation as that is the closest point to the calculated resonant frequency of 5032.92121 Hz. The practical values, which included a measurement at 5032 Hz also peak at 5000 Hz. Therefore, the resonant frequency is slightly lower than the ideal value. The reasons why the resonant frequency is lower lie in the fact that the components are not ideal.

Rather than settle for these ideal values, the simulation can be improved by modelling the components more accurately and considering other attributes of the components.

The inductor used in the simulation had a value of 1mH and the physical inductor used also had a stated value of 1mH. When measured however the inductor only had a value of 0.994mH. This would have the effect of reducing the component reactance as reactance is directly proportional to inductance. This means that the resonant frequency would be slightly higher in order for the capacitor and inductor reactance's to be equal.

Misplaced apos.

On the other hand, the inductor is made using a lot of wire meaning that the resistance of that wire within the component is significant. The measured value of this resistance is 7.32 Ω . The resistance can be considered to be in series and is considered in the branch impedance calculation. This has the effect of lowering the resonant frequency [8].

Similarly, the capacitor in reality is slightly different to that used in the simulation. The value of the capacitor in the simulation and the stated value of the physical component is 1 μF . In actuality, the

measured value is 1.064 μF . This has the effect of decreasing the component reactance as reactance is inversely proportional to capacitance. As a result, the resonant frequency would be slightly lower in order for the reactance to equal the reactance of the inductor.

However, this is offset by the equivalent series resistance (ESR) of the capacitor. The value of ESR is dependent on frequency and so two values of ESR were measured: 5.09189E-05 Ω at 1 kHz and 7.63784E-04 Ω at 7 kHz. This is considered to be in series with the capacitor and as such, it has the effect of increasing the resonant frequency [8].

The resistor used in the circuit had a 1000 Ω stated value. When measured this was in fact only 979 Ω . This decrease in resistance is however offset by the internal resistance of the source and the internal resistance of the wires that is considered in the original simulation. As these resistances are connected in series to the LC part of the circuit, they do not impact the resonant frequency point. The effect they do have is to reduce the Q factor. This can be seen in figure 8 which shows that the resistance is inversely proportional to the Q factor.

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

Where, $X_L = 2\pi fL$

$$Q = \frac{2\pi fL}{R}$$

Where,

X_L = Reactance

f = Frequency

L = Inductance

R = Resistance

Figure 8: Equation for Q factor in terms of resistance and inductance [9]. The equation for capacitive reactance also has the same inversely proportional relationship between Q factor and resistance

$$Q = \frac{f_r}{B} \quad \text{or} \quad B = \frac{f_r}{Q}$$

Figure 9: Equation for Q factor in terms of bandwidth and resonant frequency [10]

As can be seen in the equation in figure 9, when the Q factor decreases without the value of resonant frequency changing, the bandwidth increases. This has the effect of lowering the peak output voltage at the resonant frequency. The Q factor of the measured values is 3.30033 as opposed a Q factor of 17.85714 for the simulated values.

The 1000 Ω resistor also has a very small inductance, as do all conductors. In this instance, the inductance is 84.5 μH which is in series with the LC oscillator. As it must also be taken into account when working out circuit impedance, the resonant frequency will be slightly lower in order to keep the total inductive reactance equal to the total capacitive reactance.

After adding many of these factors to the simulation, the results should reflect the laboratory exercise values of output voltage far more closely. This is because the components in the first simulation were not considered to be lossy like the real components are and therefore the sharpness of the peak should be far more limited in the second simulation where the loss in the components is also modelled [11].



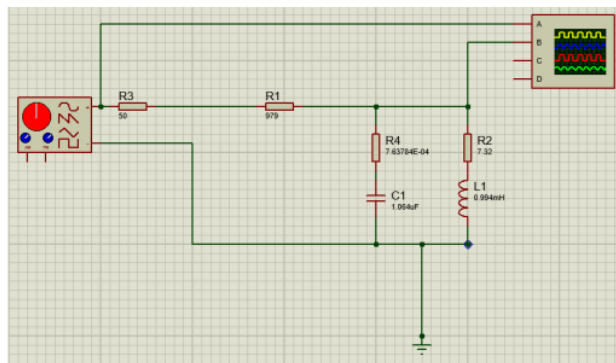


Figure 10: Circuit for second simulation and more accurate version of the circuit used in the laboratory exercise

Figure 10 shows the second simulation circuit that aims to emulate the physical circuit more accurately. The first circuit element added is an additional 50 Ω resistor in series which represents the internal resistance of the source and the wires throughout the circuit. The resistance of the inductor has also been added in series with the inductor. The equivalent circuit resistance of the capacitor has also been added when operating at 10 kHz. Finally, the values of the components were changed to be their measured values as opposed to their stated values.

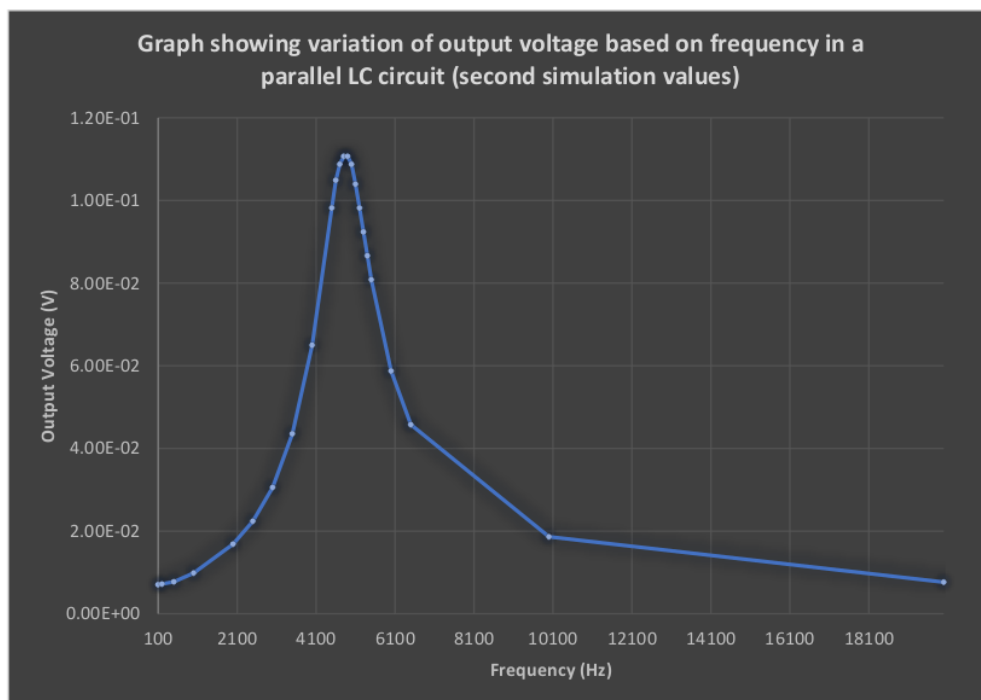


Figure 11: Simulated values of V_{out} from the second simulation

Figure 11 shows the simulated values of output voltage from the second simulation. This graph shows that the resonant frequency of the circuit is between 4800 Hz and 4900 Hz. This graph used 8 more data points than the first simulation centred around 5000 Hz in order to investigate any change in resonant frequency more accurately.

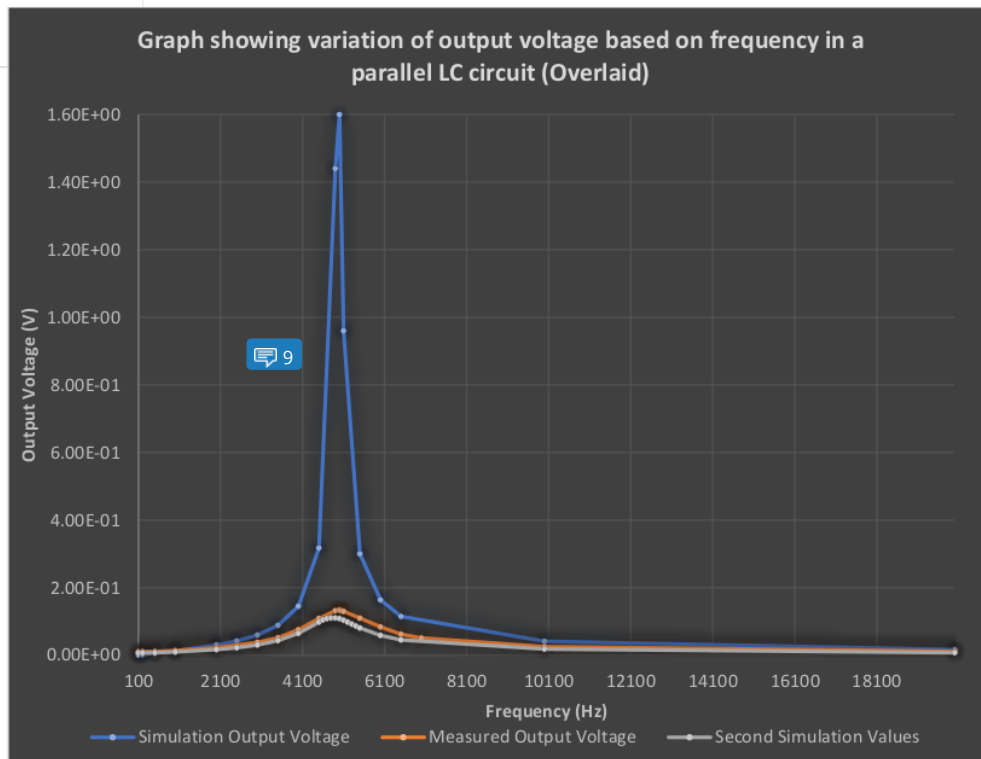
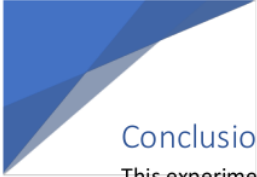


Figure 12: Overlaid graphs showing simulated values of output voltage against measured values and values from the second simulation

As can be seen in figure 12, the values of output voltage attained from the second simulation are far closer to those from the laboratory exercise than the initial simulation. This suggests that the simulation is now accurate to the physical circuit. A notable change is that the resonant frequency of the second simulation is lower measuring somewhere between 4800 Hz and 4900 Hz. This is because of the resistance added in series with the inductor being more significant than the equivalent series resistance of the capacitor resulting in the resonant frequency needing to be lower in order to reduce the reactance of the inductor to be equal to the reactance of the capacitor. Another change is that the Q factor is much lower in the second simulation than in the first, but is similar – albeit slightly higher – than the experimental values. The value of the Q factor from the second simulation is 3.656716.



Conclusion

This experiment has determined that the circuit provided, when simulated was an effective means of illustrating the function of an LC circuit, however was very unlike the physical circuit due to the ideal nature of the components in the first simulation. This resulted in ideal results including a far higher Q factor and aligned with the calculated values for resonant frequency. When modelled more accurately, including secondary component effects (such as resistance in the inductor) a far more realistic spread of results was achieved (see figure 11).

When designing a circuit that includes components such as inductors, capacitors and resistors, the secondary effects of these components must be accounted for in order to allow the circuit simulation and calculations to be accurate to the physical circuit. If these additional factors are excluded the simulation will yield results that do not closely reflect experimental values.

The effect of component resistances and other secondary component attributes is significant in affecting the Q factor and consequently the efficiency of the circuit. As such, these should also be addressed and optimised to design more efficient circuits that dissipate less energy. One way to do this is minimise series resistance.

In summary, modelling ideal components only leads to theoretical results that are dissimilar to practical values and this disparity is resolved only by considering all component attributes. Therefore, useful and functional circuit design must take the limitations, tolerances and physical characteristics of components into account.



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Resonance Assignment

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

67 / 100

PAGE 1

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Comment 1

The colour scheme chosen for your graphs does not fit with the formal writing style. Graphs should be clear, well labelled and simple.



Comment 2

should be $\log(f)$

PAGE 7



Comment 3

If the vertical axis were presented in dB rather than volts, both would peak at the same value and the difference in Q factor would be highlighted.



Comment 4

In what way are they not ideal?



Comment 5

You could calculate the difference in resonant frequency to support your argument.

A -6 μ H change in inductor value would actually increase the resonant frequency to 5048 Hz

QM

Misplaced apos.

Misplaced apostrophe:

An apostrophe can function to indicate a possessive when accompanied by an -s ("the book that belongs to Roy" = "Roy's book"). For words that already have an -s at the end, just adding the apostrophe will do ("the team belonging to the boys" = "the boys' team"). Certain exceptions to this rule apply, and possessive personal pronouns ("like ours," "yours," "hers," "his," "its") are possessive already and therefore do not take an apostrophe. It is always wrong to use a possessive apostrophe to simply make a word plural.



Comment 6

This would also affect Q factor

PAGE 8



Comment 7

These values were taken from the datasheet for the capacitor



Comment 8

You should not use contractions in formal writing. Instead of weren't, use were not

PAGE 9

PAGE 10



Comment 9

This graph does not take account of different input voltages. You should use dB on the vertical axis to allow a direct comparison between the three sets of results.

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PAGE 12

GRADING FORM: SMU GENERIC_SMOSEY

PETER ZOLTAN DOWN

67.35

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.



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.



Thoroughly logical work, supported by evaluated evidence. High quality analysis, developed independently. Ability to investigate contradictory

22.5

information and identify reasons for contradictions. Strong, persuasive, conclusions.

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. Very good consideration of the context of the application, with perceptive use of examples, where relevant. 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 professionally and, confidently in a suitable format. Work is coherent, very fluent and is presented professionally.

3.5