

RLC Q factor and Resonance Report

by George Tucker

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An Investigation into Resonance and Q Factor in an RLC Parallel Circuit

By George Tucker

Abstract

This report details the method, analysis and results of experiments carried out to determine the Q factor and resonant frequency of a parallel RLC resonance circuit. The experiments were conducted using a computer simulation of an RLC circuit, followed by the use of a breadboard to physically create and test the same circuit layout, providing a contrast of simulation vs reality.

Readings were taken for several values of frequency, and the data captured for analysis. The results from the simulation and the physical circuit showed that the simulated circuit had a higher Q factor (corresponding to an indicated better quality of circuit). This is consistent with the fact that the breadboard circuit contains real-world components that are not mathematical ideals, as can be found in the simulation software. In addition, comparisons with circuit theory indicated that the results from both the simulation and the breadboard experiment were both not entirely accurate when compared to the expected values for Q. On the other hand, it was possible to accurately infer a value for resonant frequency using the graphs plotted from the data that was collected.

Conclusions drawn show that simulations, whilst having their place, still have their limitations when compared to real-world situations, unless you are willing to consider all possible variables in great detail. As well as the fact that the quality and quantity of the initial data can greatly affect inferred results depending on the level of precision used when making readings.



Introduction



For this assignment piece we were given an RLC circuit layout which we would be testing in order to determine the resonant frequency and the Q factor. To test the circuit in order to obtain this information one physical experiment using a breadboard, and one computer simulation of the circuit would be carried out in order to gather two sets of data that could then be analysed and compared with each other, as well as basic theory.

The equipment used for this assignment was as follows:

- Circuit simulation software – this experiment used the Proteus software licenced to the university.
- For the second experiment the following apparatus was used: A breadboard, a picoscope, a 1 kΩ resistor, a 1 mH inductor and a 1 μF capacitor a multimeter probe attachment.

In order to provide more detailed information to assist in understanding this report, and provide better background and context, a list of definitions has been provided below. These will outline some of the key terms that are pertinent to understanding the work carried out during this assignment:

Capacitor – A device that is able to store charge on two metal plates opposing one another when a potential difference is applied to the plates. Symbol C, measured in Farads. [1]

Resistor – A circuit component that limits current. Symbol R, measured in Ohms. [1]

Inductor – A component that stores electrical energy as a magnetic field, it induces a back emf when this field collapses. Symbol L, measured in Henrys. [1]

RLC Circuit – A RLC circuit consists of a resistor (R), inductor (L), and a capacitor (C) connected together in some arrangement, either in series or parallel. [2] They can exhibit the properties of resonance and have practical applications in communications systems, filter circuits, radio transmitters, amplifiers and many more. [3]

Resonance – A condition of an RLC circuit where the Capacitive Reactance (X_C), and the Inductive Reactance (X_L), equal each other and cancel each other out. [2]

Resonant Frequency – This is the frequency at which resonance occurs it is also known as the “centre frequency” as it is the frequency indicated by the centre line on a bandwidth curve. It is denoted as f_0 and is given by the equation $f_0 = 1/2\pi\sqrt{LC}$. [4]

Bandwidth – Bandwidth is the difference between the upper and lower frequency bands ($f_u - f_l$) corresponding to the intersection of the line at -3dB from the peak value and the curve of results, on a Voltage (or Current)/Frequency graph, (where the Voltage/Current has been converted to decibels). [2]

Q-Factor – This is a value corresponding to the “quality of a resonant circuit”. Where “higher values represent narrower bandwidths”, and “Q is the ratio of power stored to power dissipated in the circuit”. [5]. It is given by the equation “ $Q = \frac{f_0}{BW}$ ” or $Q = R\sqrt{\frac{C}{L}}$ for parallel RLC circuits. [2]

Proteus – Proteus is a circuit simulation software that allows you to build and test artificial circuit layouts in order to gain a better understanding of how they work. It is used widely in industry to prototype plastics circuit boards before prototyping them physically, as well as being used widely in education. [6]

Picoscope – A PC oscilloscope that contains a signal generator allowing you to test a circuit using an AC wave form by setting frequency and collecting values using the paired software on a PC. It serves the function of traditional oscilloscopes/signal generators. [7]

Breadboard – A breadboard is a tool that can be used to prototype new circuit layouts in order to test them without having to solder them down and eliminating the need to print a PCB to test a design. [8]

Methodology

Initially the circuit was constructed in Proteus according to the assessment brief: an rlc parallel circuit with 1 k Ω resistor, 1 mH inductor and 1 μ F capacitor (see figure 1 below). Using the in-software tools, an RLC circuit was drawn and a virtual signal generator was used for the input power supply. The software also has a virtual oscilloscope that was attached to the circuit in order to measure the input Voltage values (V_{in}) as well as the voltage dropped across the inductor and capacitor (VLC). Next, using the virtual signal generator, a range of input frequencies were selected all at the same voltage, and the resulting peak to peak voltages on the oscilloscope were measured. This data was input straight into an excel spreadsheet.

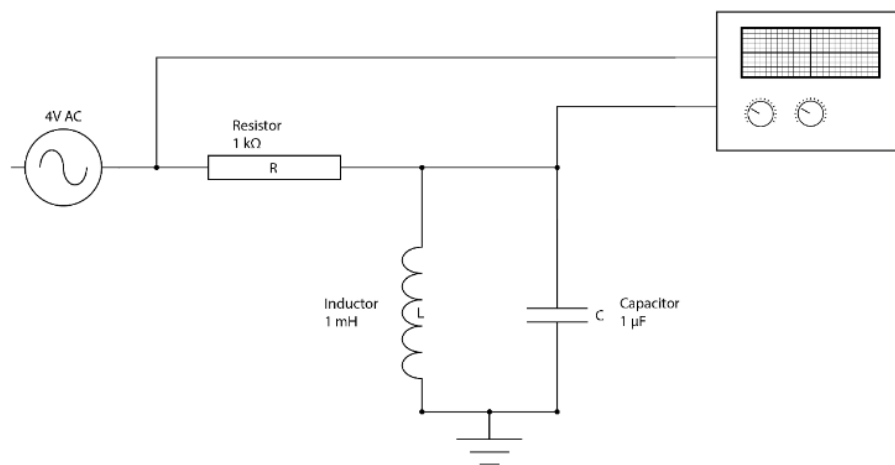


Figure 1- RLC circuit diagram that we were tasked with creating for the assignment.

After all the simulation data was captured, the second part of the experiment was commenced. This entailed using a breadboard in order to make the same circuit layout, only now with real physical components. The breadboard circuit was used in conjunction with a picoscope signal generator and digital oscilloscope software that came with the picoscope. Readings for voltage were made using a probe in order to measure the input voltage and the inductor-capacitor voltages. Again, the results were captured in an excel spreadsheet.

The next part of the process would be to plot the raw data that had been captured onto a graph. VLC for both sets of data would be plotted against frequency (f). This would show how the voltage changes with frequency and indicate the resonant frequency from the peak of the graph.

After this graph had been plotted, a second graph for each set of data could be plotted showing the attenuation against frequency for each set of data. To calculate values for attenuation the equation: $20 \cdot \log(V_{LC}/V_{in})$ would be performed on both sets of data. This generated values in decibels (dB) that could be plotted against frequency.

These attenuation curves would then allow for bandwidth to be calculated from the data. By drawing a line 3dB lower than the peak value, you can find the upper frequency (f_u) and the lower frequency (f_l) bounds by looking at the intercept points between this line and the plotted curve.

After this final process of obtaining the upper and lower frequency bounds, the analysis of the data could then be undertaken in order to obtain values for resonant frequency and Q factor.

Results

Here you can see the results of the investigation. Shown are the tables of the raw data, graphs for V_{LC}/f , graphs for Attenuation/ f and graphs showing the -3dB intercept points. Figures 2-5 display the Proteus simulation data, whilst figures 6-9 display the Breadboard experiment data.

Proteus			
Frequency	Vin	VLC	dB
100	4	0.002600	-63.742
200	4	0.005200	-57.721
500	4	0.012800	-49.897
1000	4	0.026680	-43.517
1500	4	0.044000	-39.172
2000	4	0.060500	-36.406
2500	4	0.085000	-33.453
3000	4	0.120000	-30.458
3500	4	0.177500	-27.057
4000	4	0.290000	-22.793
4500	4	0.633620	-16.005
5000	4	3.220000	-1.8841
5500	4	0.600000	-16.478
6000	4	0.330000	-21.671
6500	4	0.230000	-24.807
7000	4	0.180000	-26.936
7500	4	0.146000	-28.754
8000	4	0.128000	-29.897
8500	4	0.112000	-31.057
9000	4	0.100000	-32.041
9500	4	0.091000	-32.86
10000	4	0.083000	-33.66
20000	4	0.003354	-61.53

Figure 2- Raw data showing results of the proteus simulation.

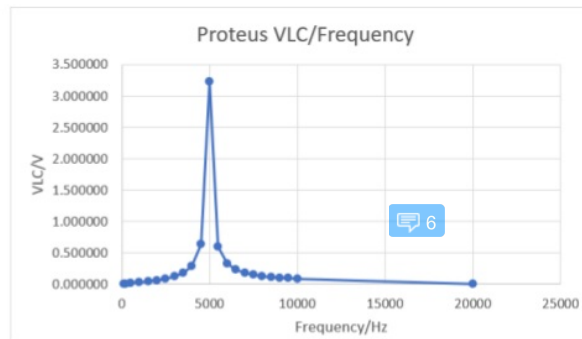


Figure 3- Graph showing the Raw data of VLC plotted against the corresponding frequencies for the proteus simulation. Note the peak at 5000 Hz.

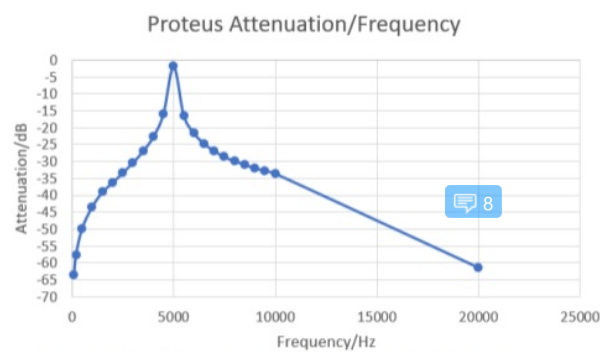


Figure 4- Graph showing the attenuation in decibels plotted against the corresponding frequencies for the proteus simulation.

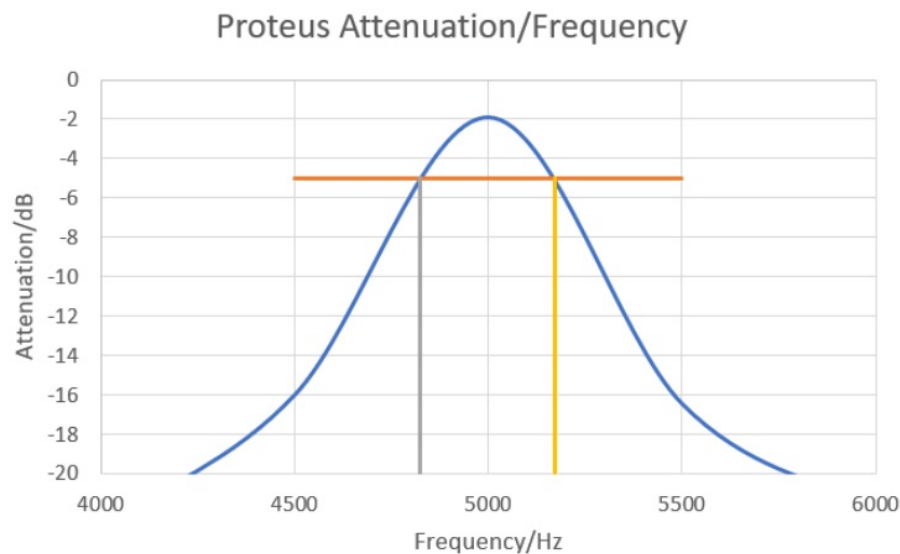


Figure 5- Enhanced view of figure 4, with lines added showing the -3dB level from the peak value and the corresponding intercept points with the curve. The intercept values are: fl (4825, -5) and fu (5170, -5).

Breadboard			
Frequency	V _{in}	V _L	dB
100	2.501	0.01281	-45.811
200	2.5	0.01295	-45.713
500	2.495	0.01473	-44.577
1000	2.495	0.02135	-41.353
1500	2.495	0.02989	-38.431
2000	2.493	0.04032	-35.824
2500	2.497	0.05503	-33.136
3000	2.499	0.07586	-30.355
3500	2.501	0.109	-27.214
4000	2.52	0.1661	-23.621
4500	2.558	0.2807	-19.193
5000	2.635	0.4005	-16.364
5500	2.557	0.2845	-19.073
6000	2.503	0.1898	-22.403
6500	2.495	0.1405	-24.988
7000	2.485	0.1117	-26.945
7500	2.483	0.09256	-28.571
8000	2.482	0.08018	-29.815
8500	2.482	0.07045	-30.938
9000	2.482	0.0631	-31.895
9500	2.482	0.0574	-32.718
10000	2.482	0.05311	-33.393
20000	2.484	0.02182	-41.126

Figure 6- Raw data from the Breadboard experiment.

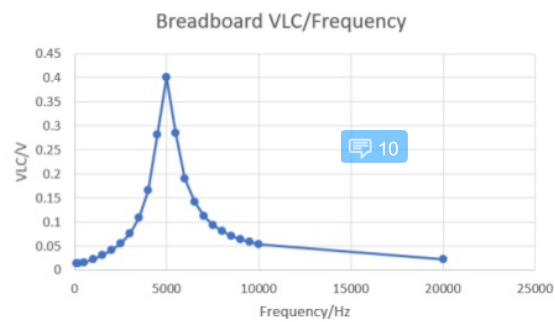


Figure 7- Graph showing the raw data of VLC plotted against corresponding values for frequency for the breadboard experiment. Note the peak at 5000 Hz.

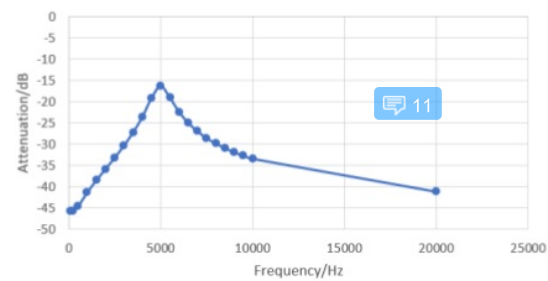


Figure 8- Graph showing the attenuation in decibels plotted

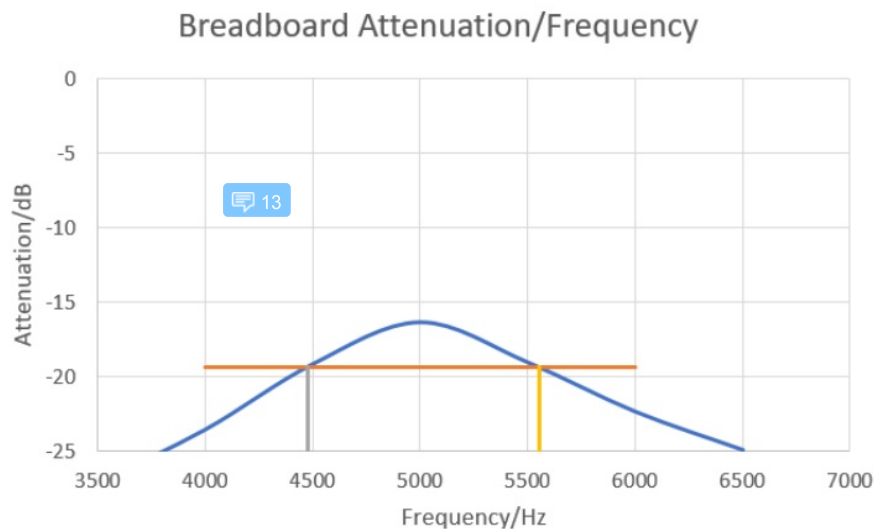


Figure 9- Enlarged view of figure 8, with lines showing the -3dB level from the peak value and the corresponding intercept points with the curve. The intercept values are: f_l (4475, -19.4) and f_u (5555, -19.4).

Analysis

Now having plotted all the graphs the results could be analysed and then compared with basic theory using several calculations (see definitions section in introduction for more information on each of these). To calculate Q factor from the graphs we can use the equation $Q = \frac{f_0}{BW}$ as $BW = f_u - f_l$ and we can obtain the values for f_0 , f_u , and f_l from the graphs as outlined in the process section

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For the Proteus simulation:

$f_0 = 5000$ (Taken from the vertical line at the peak of graph shown in figure 5)

$f_u = 5170$, and $f_l = 4825$

And so, $BW = 5170 - 4825$.

Therefore, $BW = 345$ Hz

$$Q = \frac{f_0}{BW}$$
$$= \frac{5000}{345}$$

≈ 14.493

For the breadboard experiment:

$f_0 = 5000$ (Taken from the vertical line at the peak of graph shown in figure 9)

$f_u = 5555$, and $f_l = 4475$

And so, $BW = 5555 - 4475$

Therefore, $BW = 1080$

$$Q = \frac{f_0}{BW}$$
$$= \frac{5000}{1080}$$

≈ 4.630

We can also calculate f_0 and Q for the circuit using basic theory as $f_0 = 1/2\pi\sqrt{LC}$ and $Q = R\sqrt{\frac{C}{L}}$. We already know the values for R (1000), L (1×10^{-3}) and C (1×10^{-6}) from the assessment brief. And so, using these values we get:

$$f_0 = 1/2\pi\sqrt{1 \times 10^{-6} \times 1 \times 10^{-3}}$$
$$= 5032.92121$$

$$\text{And } Q = 1000 \times \sqrt{\frac{1 \times 10^{-6}}{1 \times 10^{-3}}}$$
$$= 31.6227766$$

Having now calculated Q for both sets of data, we can see that the Proteus simulation has a value of approximately 14.493, and the breadboard experiment has a value of approximately 4.630. The actual value as calculated from basic theory is 31.6227766. This shows that the Proteus value is closer to the expected value, but still only accurate to within 54.17%. These differences in value for Q show several things.

Firstly, they show that using calculations or simulations to work out circuit behaviours is flawed.

It is known that using basic theory and simulations assumes perfect or ideal components, and that these are not a true reflection of an actual circuit. In reality, components are not as simple as the ideal mathematical theory suggests and this, as they are sensitive to other nearby components. [9]

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Additionally, components' properties change with time due to the materials they are made of breaking down, as well as changing due to stress from being used. Other factors such as temperature also play a role in how a component performs within a real circuit. [10]

This explains why the breadboard experiment is different from the simulation and calculated value of Q .

Secondly, it shows that there is still a difference between the simulation and the calculation from basic theory. Despite these being expected to be similar in value. This can be explained by the nature of the results obtained. As Q depends on a value of BW from the graph the more accurate this graph, the greater the accuracy of Q you will be able to obtain. By using more precise equipment and taking more frequent readings for Voltage around the resonant frequency you should be able to obtain a more detailed data set which would provide you with a smaller bandwidth. The reason for such a massive percentage error can be explained by the fact that the relationship between the VLC and frequency is non-linear and so a sharp difference in results can arise from a small difference in precision.

For example, a smaller division size in frequency measurement can greatly alter the shape of a graph. See figure 10 to see how a graph plotted from measurements taken every 2 units and a graph plotted from measurements taken every 1 unit are different. The graph with the more closely spaced measurements has a significantly higher peak due to the relationship between the two axes. If we were to relate this to the experiments, it shows that by taking more precise reading around the expected peak of the graph we could reveal more accurately the true shape of the graph. In this case, a narrower bandwidth. Which would, in turn, lead to a higher value of Q being obtained (approaching the value calculated with basic theory, the more precise we become).

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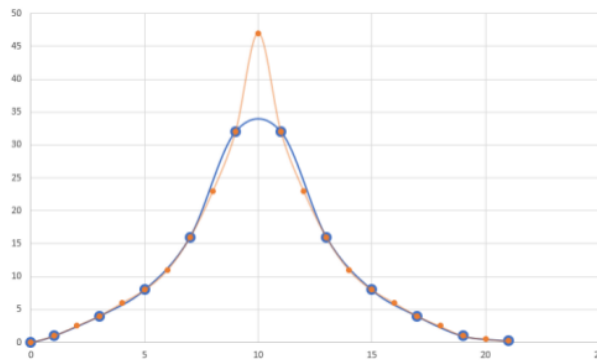


Figure 10- Graph showing how difference in division size for measurements can affect the shape of a graph, and therefore any interpreted data from it. E.g. bandwidth size.

Lastly, the values for resonant frequency both came out as 5000 Hz using the respective graphs. Which is accurate to within 0.66% of the calculated value. This indicates that both the simulation and the breadboard experiment are effective means to find f_0 so long as a suitable range of data is collected.

Conclusion

From the analysis it has been shown how differences in simulated and real circuits can affect results, with simulations being an idealistic version and that it's to be expected that their values will differ from measured values from a real circuit. This being due to tolerances within the components, as well as the way the components interact with each other in an active circuit, affecting them in ways not considered in basic theory, or simulations.  17

Lastly, it can be concluded that the level of precision when measuring, and the frequency of measurements, can greatly affect the difference of an experimental vs calculated value, depending on the relationship between the variables. But indicates that interpolating can be used effectively to infer certain values with regard to RLC circuits.

References

- [1] "El-Pro-Cus," [Online]. Available: <https://www.elprocus.com/major-electronic-components/>. [Accessed 20 12 2019].
- [2] "Electronics Tutorials," [Online]. Available: <https://www.electronics-tutorials.ws/accircuits/series-circuit.html>. [Accessed 20 12 2019].
- [3] A. Raj, "Circuit Digest," [Online]. Available: <https://circuitdigest.com/tutorial/rc-rl-and-rlc-circuits>. [Accessed 2 1 2020].
- [4] C. Davis, AC circuits, 2017.  18
- [5] T. R. Kuphaldt, "All About Circuits," [Online]. Available: <https://www.allaboutcircuits.com/textbook/alternating-current/chpt-6/q-and-bandwidth-resonant-circuit/>. [Accessed 27 12 2019].

- [6] "PCB design and circuit simulator software - proteus," [Online]. Available: <https://www.labcenter.com/>. [Accessed 23 12 2019].
- [7] "Pico Technology," [Online]. Available: <https://www.picotech.com/products/oscilloscope>. [Accessed 23 12 2019].
- [8] "Wiring," [Online]. Available: <http://wiring.org.co/learning/tutorials/breadboard/>. [Accessed 28 12 2019].
- [9] W. McAllister, "Khan Academy - Real-world circuit elements," [Online]. Available: <https://www.khanacademy.org/science/electrical-engineering/ee-circuit-analysis-topic/circuit-elements/a/ee-real-world-circuit-elements>. [Accessed 23 12 2019].
- [10] S. J. Sangwine, Electronic Components and Technology, 2nd ed., CRC Press, 1994, pp. 73-74.

RLC Q factor and Resonance Report

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

69/100

PAGE 1



Comment 1

Good abstract

PAGE 2



Comment 2

Use the third person passive voice. Try saying "For this assignment an RLC circuit layout was provided which will be tested to determine the resonant frequency and Q factor."



Comment 3

Not sure it is necessary to state who owns the licence.



Comment 4

oscilloscope probe

PAGE 3



Comment 5

If it is important enough to write, then it doesn't need brackets.

PAGE 4

PAGE 5



Comment 6

This should be $\log(f)$ on x-axis



Comment 7

Data tables look far more professional when they are made in word rather than snipped from an excel screenshot.



Comment 8

Should be $\log(f)$ on x-axis



Comment 9

Table 1

PAGE 6



Comment 10

Should be $\log(f)$ on x-axis



Comment 11

Should be $\log(f)$ on x-axis



Comment 12

Table 2



Comment 13

Could a more appropriate range of values be chosen for the Y axis? Your data is squashed into the lower half of the graph and would be clearer if stretched to fill the graph.

PAGE 7



Comment 14

Equations should be given the same standing as figures and tables, they should be on a line of their own and captioned then where you refer to them in the text you can describe the variables.

The Q factor can be calculated using equation 1, where f_0 is the resonant frequency in Hz and BW is the bandwidth in Hz

PAGE 8



Comment 15

Do you mean the DC resistance of the inductor?



Comment 16

Good point

PAGE 9



Comment 17

Good conclusions, but what about the physical differences between components and their simulated counterparts. The simulated inductor does not include the resistance of the coil which contributes to the damping seen in the practical circuit.



Comment 18

What type of material is this reference? Where was it published? Who published it?

PAGE 10



Comment 19

Try to use more reputable sources such as textbooks and peer reviewed journal articles etc.

GRADING FORM: SMU GENERIC_SMOSEY

GEORGE TUCKER

69.35

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

3.4

applied.

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 or through effective collaboration. Ability to investigate contradictory information and identify reasons for contradictions. Strong, persuasive, conclusions, justifiable recommendations.

22.5

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



An advanced application of a range of methods, tools and techniques. The context of the application is well considered, with extensive use of relevant examples. Application and deployment extend beyond established conventions. Innovation and creativity evident throughout.

21.3

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.

3.55