

Resonance

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Electrical & Electronic Principles

RESONANCE – COMPARING REAL AND MODELLED RESPONSES OF AN RLC CIRCUIT

INTRODUCTION

This investigation focused on a common RLC circuit ($R = 1000\Omega$; $L = 1\text{mH}$; $C = 1\mu\text{F}$).

Due to their resonant nature, RLC circuits produce a damping effect based on their attenuation vs frequency response. The damping caused by the resistor means oscillations are reduced away from the resonant frequency (f_{res}), creating a tuned circuit. This therefore provides complex RLC circuits with abundant applications in frequency filtering, such as in TV and radio sets [1] [2].

The objective of this investigation was to compare values for voltage across the inductor and capacitor (VLC) measured in the real circuit and those derived from modelling the circuit in Proteus, and explore, in terms of resonant frequency (f_{res}), quality factor (Q factor) and attenuation, why a discrepancy existed. An input voltage (V_{in}) of 2V peak-to-peak was used, and values were measured across the 100-20000Hz frequency range.

SIMULATIONS AND METHODOLOGY

4 separate datasets were created for: the theoretical circuit values, measurements from the real circuit and the Proteus simulations - 'Sim1' and 'Sim2'. For all four datasets the frequency measurement range was 100-20000Hz, and the V_{in} was 2V.

Theoretical f_{res} , VLC and attenuation value were calculated for the RLC circuit ($R = 1000\Omega$; $L = 1\text{mH}$; $C = 1\mu\text{F}$; $V_{\text{in}} = 2\text{V}$) using the following formulae in Microsoft Excel [3]...

$$f_{\text{res}} = 1/(2*\pi()*\text{SQRT}(L*C))$$

$$X_L = \text{COMPLEX}(0,2*\pi()*f*L)$$

$$X_C = \text{COMPLEX}(0,-1/(2*\pi()*f*C))$$

$$Z_LC = \text{IMDIV}(\text{IMPRODUCT}(X_L,X_C),\text{IMSUM}(X_L,X_C))$$

$$Z_T = \text{IMSUM}(\text{COMPLEX}(R,0),Z_LC)$$

$$I = \text{IMDIV}(\text{COMPLEX}(Z_T,0),V_{\text{in}})$$

$$V_{LC} = \text{IMPRODUCT}(I,Z_LC)$$

$$\text{Attenuation} = 20*\text{LOG10}(V_{LC}/V_{\text{in}})$$

The real circuit was set-up using the three RLC components on a breadboard, and VLC measured using probes connected to a Tektronix TDS 2002B oscilloscope, with probe A measuring V_{in} and B measuring VLC. Components used were matched to the values of the circuit; however individual measurements of the values for the components used revealed that they differed marginally from the quoted values.

Two simulations of the circuit were produced in Proteus 8 Professional. Both used generic symbols for the components and respective values were manually inserted. ‘Sim1’ represented a basic simulation, consisting of the three RLC components only, connected to a sine wave generator and the digital oscilloscope, as shown in Fig 1.

Another Proteus simulation was then created, featuring modified RLC component values. The modified values were based on measurements from the components used in the real circuit – all were marginally different to the quoted values. Additionally, three more generic resistors were put in place to simulate: the internal resistances of the power source (R1) and the inductor (R2), and the equivalent series resistance (ESR) of the capacitor (R4). See Fig 2.

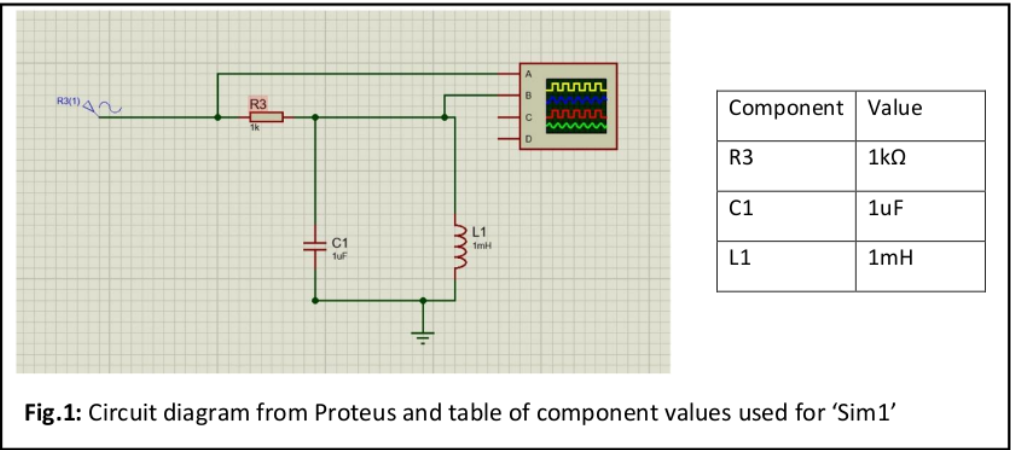


Fig.1: Circuit diagram from Proteus and table of component values used for ‘Sim1’

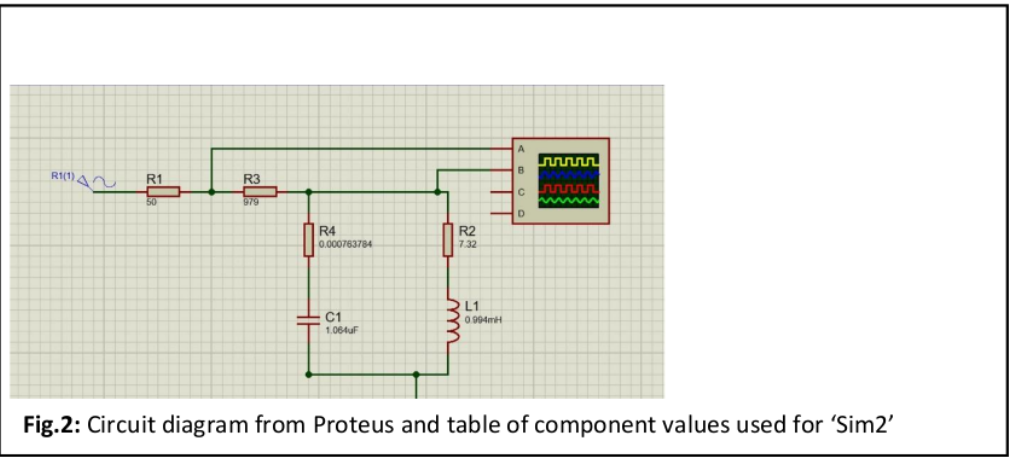


Fig.2: Circuit diagram from Proteus and table of component values used for ‘Sim2’

Component	Value
R1	50 Ω
R2	7.32 Ω

R3	979Ω
R4	0.763784mΩ
C1	1.064uF
L1	0.994mH

Following this, VLC Vs. frequency graphs and were produced for all four datasets. RMS was calculated from the identified peak voltages (formula: peak VLC*0.707). A horizontal RMS line was plotted on each graph. Subsequently bandwidth (BW) was calculated (formula: $F_H - F_L$) by plotting vertical lines for high frequency (F_H) and low frequency (F_L) plotted on the graph, with these adjusted such that they intersected precisely with VLC Vs. frequency line where this intersected with the RMS line (see Figs. 3-6). Q factor was then calculated using the formula ' f_{res}/BW '.

DATA & RESULTS

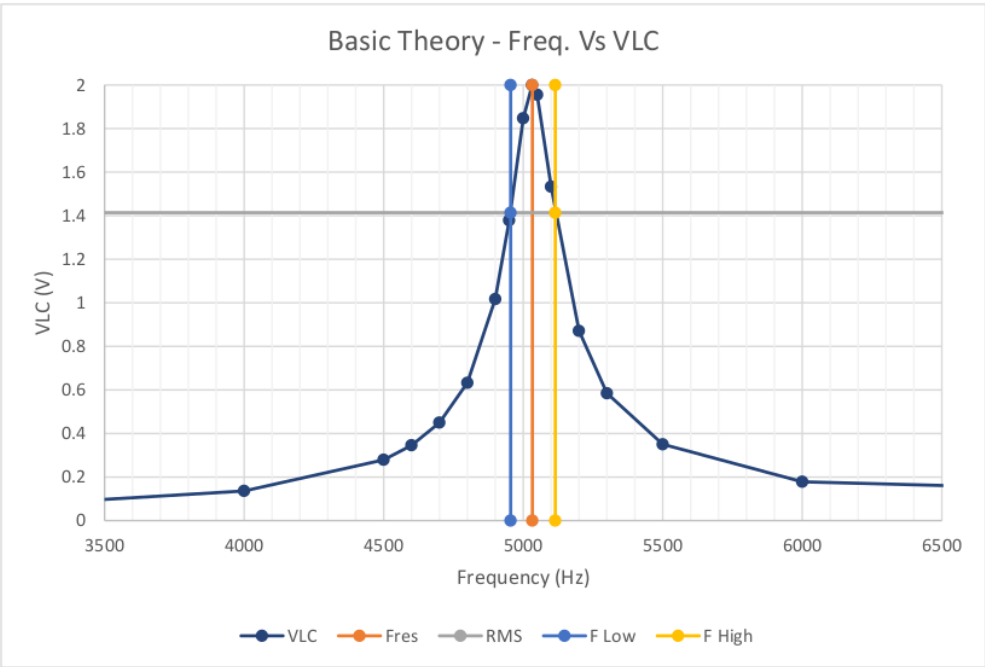


Fig.3: Graph showing theoretical VLC Vs. Frequency (with f_{res} , F_H , F_L and RMS plots)

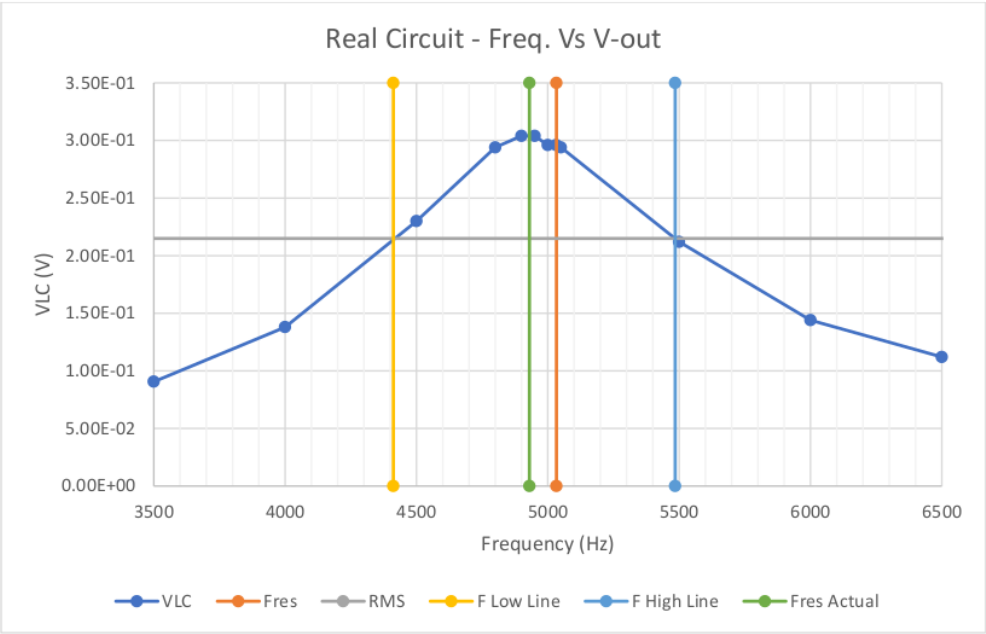


Fig.4: Graph showing VLC Vs. Frequency for the real circuit dataset (with f_{res} , F_H , F_L and RMS plots)

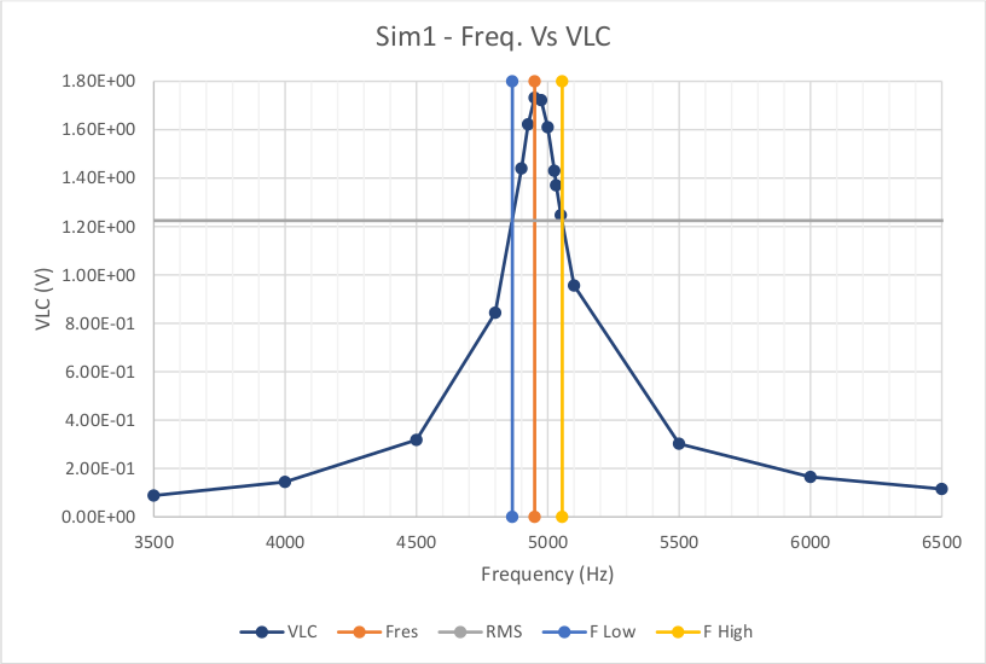


Fig.5: Graph showing VLC Vs. Frequency for the Sim1 dataset (with f_{res} , F_H , F_L and RMS plots)

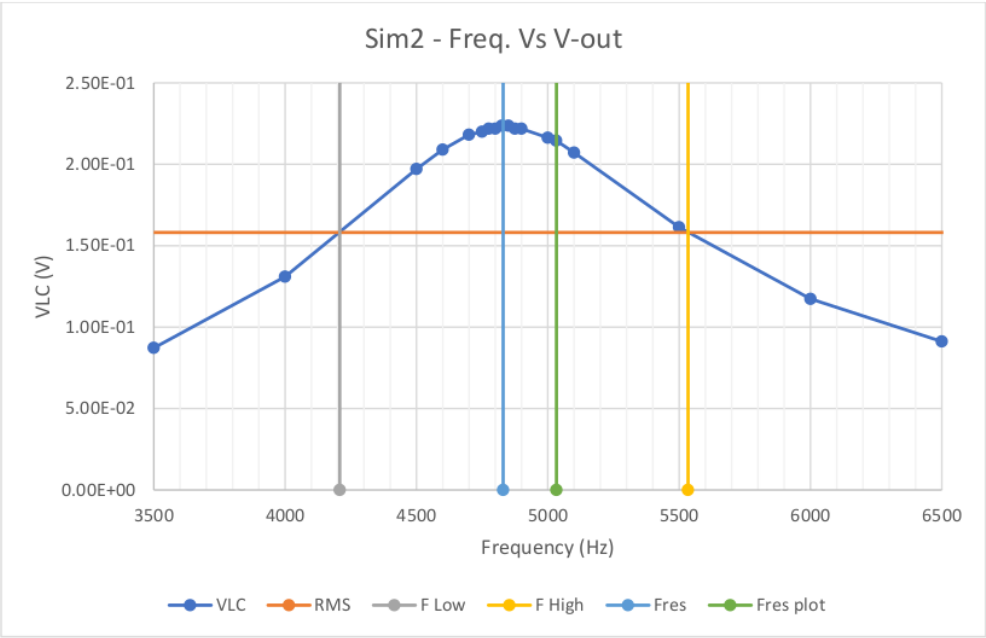


Fig.6: Graph showing VLC Vs. Frequency for the Sim2 dataset (with f_{res} , F_H , F_L and RMS plots)

	Theoretical	Real Circuit	Sim1	Sim2
Peak VLC	1.99 V	0.304 V	1.61 V	0.22 V
F_{res}	5032.92 Hz	4930.00 Hz	4950.00 Hz	4830.00 Hz
F_L	4955.00 Hz	4412.00 Hz	4865.00 Hz	4208.00 Hz
F_H	5115 Hz	5485.00 Hz	5055.00 Hz	5534.00 Hz
BW	160.00 Hz	1073.0 Hz	190.00 Hz	1326.00 Hz
Q factor	31.46	4.95	26.05	3.64

Fig.7: Table comparing VLC vs frequency and derived values from each dataset

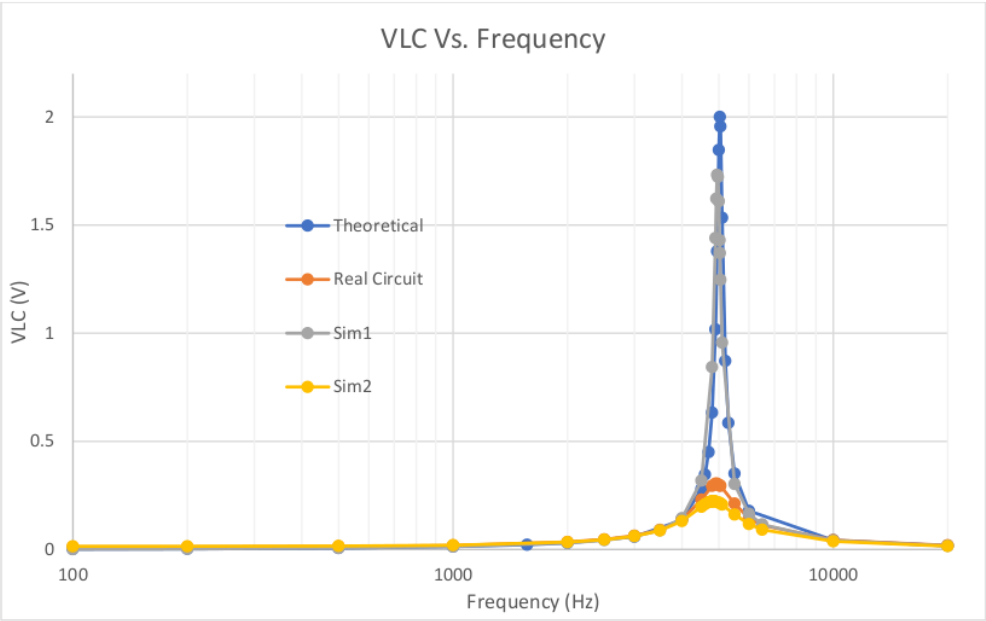


Fig.8: Logarithmically-scaled graph showing VLC vs frequency for all datasets

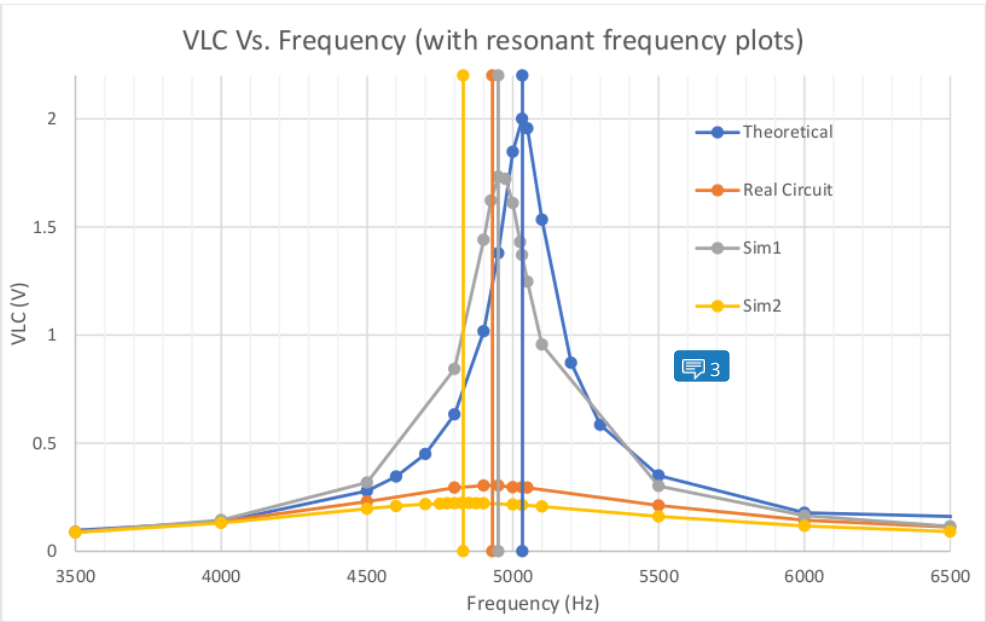


Fig.9: Graph showing VLC Vs. frequency and F_{res} for all datasets

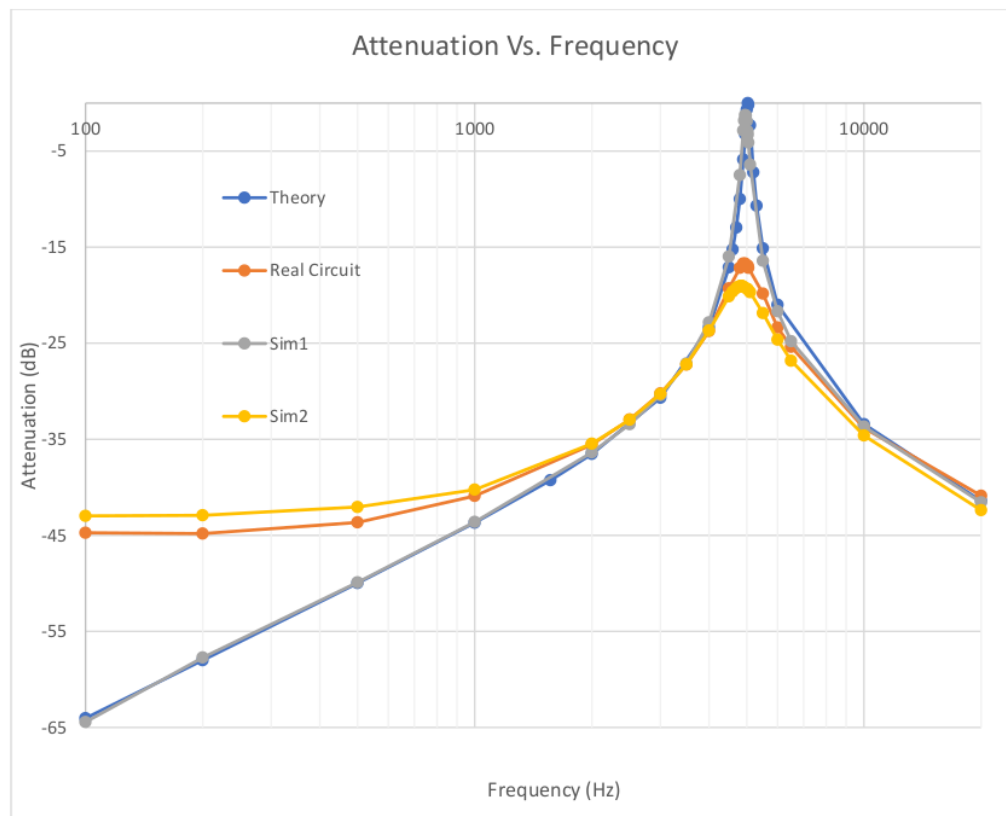


Fig.10: Graph showing attenuation Vs. frequency for all datasets

Comparing the real circuit with the data from Sim1, it is clear that VLC across the frequency range, in particular from 4000-6000Hz (around the f_{res}) was very different. Peak VLC and Q-factor were significantly higher in Sim1 (peak VLC = 1.61V; Q-factor = 26.05) than in the real circuit (peak VLC = 4.95; Q-factor = 4.95). Theoretical values for peak VLC (1.99V) and Q-factor (31.46) were even higher, however the theoretical VLC vs frequency and attenuation vs frequency trend-lines had much similarity with basic circuit model represented in Sim1, with both also having very high Q-factors.

Contrastingly, peak VLC and Q-factor values for Sim2 (0.22V; 3.64), were very similar to the real circuit (0.304V; 4.95) – see Fig.7, and VLC vs frequency and attenuation vs frequency trend-lines were also similar (see Figs.8-10).

In terms of f_{res} , the value derived from each dataset varied, but with all clustering around 4950Hz. However Sim1, in this case, provided a far more similar value to the real circuit than Sim2.

DISCUSSION

The fact that the frequency vs VLC & attenuation trend-lines from Sim2 track those from the real circuit far more closely than the basic model in Sim1 proves that inclusion of internal

the resistance of components and ESR of capacitors is required to produce an accurate model. This is because resistance, alongside reactance, determines the impedance of the circuit, which in turn effects the current and therefore the VLC [2].

However, regarding f_{res} , the impact of modelling the internal resistances in Sim2 has provided a value far less similar to the real circuit than Sim1 and the theoretical value. f_{res} is determined by the frequency at which the impedance of the inductor (L) and capacitor (C)

4 of equal values relative to 0. In this case, this suggests that the unequal ESR for the capacitor and internal resistance of the inductor modelled in Sim2 have changed the impedance and f_{res} . One explanation for this could be that the measured values for internal

5 resistance of the inductor and ESR of the capacitor were slightly too high, therefore causing the discrepancy with Sim2. This would mean that in Sim2 there was likely to be a greater phase lag of current behind voltage, than in Sim1, and that power factor correction through placing of a generic capacitor would need to be added to the simulation to more accurately model f_{res} [2]. 6

CONCLUSION

Measured values for VLC in the real circuit have been compared to those produced from simulating the circuit in Proteus, and those derived from basic theory, across the 100-20000Hz frequency range. Two simulations were created in Proteus, one providing a basic model of the RLC circuit, and the other modelling the circuit with the internal resistance of the components taken into account. Resonant frequency (f_{res}), quality factor (Q factor) and attenuation were subsequently analysed and compared for each dataset, with the factors behind the varying results explored. Similarity between Sim2 and the real circuit has proven that modelling of internal resistances and ESR of capacitors is necessary for accurate modelling of frequency vs VLC. However the discrepancy in f_{res} between Sim2 and the real circuit has been attributed to the altered impedance, and shown that power factor

7 correction would need to be included in the simulation in order to more accurately model f_{res} . Overall the variation in results from the datasets provided in this investigation demonstrates the need for more complex and accurate models, given the importance of the frequency of maximum attenuation in tuned/damping circuits [1] [2].

BIBLIOGRAPHY

Ref Qual 1 Electrical4U, "Oscillators: What Are They? (Definition, Types, & Applications)," October 2020. [Online]. Available: <https://www.electrical4u.com/what-is-an-oscillator/>.

[2] H. Paul and H. Winfred, "Chapter 1: Foundations," in *The Art of Electronics*, Third Edition ed., 8 Third Edition, Cambridge University Press, 2015.

[3] UWTSO School of Applied Computing, "AC Theory," Swansea.

Resonance

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

66/100

PAGE 1



Comment 1

Increasing the damping in RLC circuits actually makes the circuit a worse filter. This is because more damping will reduce the difference between the amplitude response at resonance and away from resonance.



Comment 2

This introduction reads more like an abstract without the results. [which is missing from your report]

You should have discussed the background - what resonance is, what happens at resonance, where this effect is used and what for, the theory behind why it happens, etc..

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6



Comment 3

You should consider making the lines for your data thinner - this will improve readability and make the graphs look neater. Also removing the markers and changing the line style to a thinner dashed style for the vertical lines would improve these plots



Comment 4

Do you mean impedances of equal magnitude?



Comment 5

I didn't measure the components you used - I measured the components I used.



Comment 6

Power factor correction? We were not looking at optimising power transmission and distribution, we were looking at resonance.



Comment 7

Power factor correction seeks to artificially shift the resonant frequency of a power system, such as a large motor or an entire factory, closer to the supply frequency in an attempt to reduce losses within the system. Although this is an application of resonance, it was not specifically explored here.



Ref Qual

You should try to use more high quality reference sources, such as textbooks from reputable academic publishers and articles from peer reviewed journals.

Additional Comment

This website is not always right. I have found errors in it myself.



Comment 8

Should be "P. Horowitz and W. Hill"



Comment 9

More references required

WILL HENRY NOAKES

65.60

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



References to a very limited range of mostly relevant sources. Some omissions and minor errors. Referencing conventions evident though not always applied consistently.

2.1

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.



Sound, logical, analytical thinking; synthesis and evaluation. Ability to devise and sustain persuasive arguments. Ability to communicate ideas and evidence accurately and convincingly. Sound, convincing conclusions.

20.4

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



An advanced application of a range of methods, materials, tools and/or techniques. Creativity evident

21

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