

LWG_1810351_OME_Electrical and electronic principles Assignment - Resonance

by William Groom

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2019

RESONANCE

ELECTRONICS

LAWRENCE GROOM (1810351)

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Abstract

Two experiments were conducted in order to explore the differences between a simulation and practical RLC (resistor, inductor, and capacitor) circuit with AC input. The simulation was built and carried out on Proteus professional v8, a software package designed for modelling circuits. The practical circuit was built on electronic breadboard and used components of the same value as the simulation. The resulting circuits displayed differences in bandwidth, resonant frequency response and Q factor values as a result of internal tolerances present in real world electrical components. These tolerances also include additional resistances within the inductor and capacitor which greatly contribute to the reduction in calculated values. Therefore it is advised that if simulation software is to be used to replicate true circuitry accurately, it is imperative that accurate measurements of all components are taken in order to fully replicate all internal tolerances. It is also advised that any calculations of impedance, reactance and inductance take into account of any potential tolerances that may be present within the equivalent real-world components.



Post experimental findings and analysis from RLC circuitry

1 Introduction

Two experiments were conducted in order to explore the differences between simulation and practical circuitry with regards to a basic AC, RLC (Resistor, inductor, capacitor) circuit and provide a comparison of the resonance **the and** quality factor (Q-factor) between the two types of circuits. Graphs of the inductor voltage plus the capacitor voltage ($V_L + V_C$) over a range of frequencies were plotted for both the practical and simulation circuits in order to compare these features.

1.1 Back ground theory

One of the main useful characteristics of RLC circuitry is its ability to attain resonant frequency over a controllable bandwidth with a relatively high-quality factor through the manipulation of the inductor or capacitor. These properties lend the circuit to use within equipment that requires the use of multiple, but specific, frequencies such as AM/FM radios or any device that required the use of a very narrow frequency range [1]. The relationship between the capacitor and inductor is variable depending of the component values, therefore a tuning effect can be achieved through the adjustment of either the capacitor or inductor and the sharp frequency response is movable to any given point with the components range.

In order to evaluate this relationship two circuits were designed and built, the first being a computer simulation and the second a physical circuit built on electronic bread board. The simulation circuit was designed to provide a near perfect frequency resonance and therefore a high response and Q-factor. The practical circuit was designed with identical components to the simulation in order to replicate the simulation and maintain comparative parameters. Input voltage was also kept identical in both circuits.

In order to quantify the characteristics of the RLC circuits used, the following calculations and definitions were needed.

Reactance "X"

"Is the opposition of change of flow of a current in a circuit" [2], this is not to be confused with resistance which can be stated as "the opposition of flow of current" [2]. Both reactance and resistance are measured in Ohms [2]

Inductor reactance

Equation 1- Inductive Reactance

$$X_L = 2\pi fL$$

Energy is stored in magnetic fields around coils, changes in the current flowing through the coil changes the strength of magnetic field. Changes in the magnetic field in turn induce a voltage (V_L) into the coil in opposition to the applied voltage (V_s) [2]

Capacitive reactance

Equation 2- Capacitive Reactance

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

Work must be done to build up and remove charge from a capacitor. As this cannot be done instantly, an AC resistance is added to the circuit known as the capacitive reactance (X_C).

When capacitors and inductors are present in a circuit the capacitive and inductive reactance's are combined. The phase shift of each component is also taken into account, as capacitors and inductors cause a 90 degree phase shift in opposite directions; they are subtracted from one another. [2]

Equation 3 - Capacitive and Inductive Reactance Combination

$$X_T = X_L - X_C$$

Inductive reactance

Changing the current into an inductor effects the magnetic field used to store electrical energy, this change induces a voltage in opposition to the original supply. This Back EMF is responsible for the voltage drop seen across inductors in and AC circuit [2].

Equation 4-inductive reactance

$$X_L = 2\pi fL$$

Impedance

Impedance is the combination of resistance and reactance, resistance being defined as the opposition to the flow of current within a circuit [2].

Equation 5 - Impedance

$$|Z| = \sqrt{R^2 + X^2}$$
$$\theta = \tan^{-1}\left(\frac{X}{R}\right)$$

Resonance

Resonance is the point at which the sine wave output of a given circuit is at its minimum as a result of a voltage drop due to the minimal resistance present as that specific frequency. Frequency resonance can be calculated using the below equation [2].

Equation 6 - Resonant Frequency

$$f_{res} = \frac{1}{2\pi\sqrt{CL}}$$

Band width "BW"

Bandwidth is calculated by finding 70.7% (3Db) of the input voltage and plotting this point on both the falling edge (f_l) and rising edge (f_h) of the frequency response. The centre point between these two points is the f_c and is found using the equation 5. Typically, the narrower the bandwidth of a circuit, the more efficient the circuit is considered to be.

Equation 7 - centre point of bandwidth

$$f_c = f_{res} = \frac{BW}{2} + f_l = f_h - \frac{BW}{2}$$

Therefore.

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

Q factor

The voltage magnification factor achieved across the coil and capacitor compared with the supply voltage. [2] This can be visualised as the narrowness of the peak of the plot-form generated on a graph displaying the circuit frequency against inductor and capacitor voltage. Fig 6. The higher the Q factor value the more specific the frequency response can be considered to be. This also means the Q-factor is directly proportional to the circuit's bandwidth size.

Equation 8 - Q Factor

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

2 Materials and methods

2.1 List of equipment used

- 1uF capacitor
- 100mH inductor 5
- 330Ω resistor
- Electronic bread board
- Oscilloscope
- Proteus pro V8.0
- 6 • sine wave generator
- generic inductor
- generic capacitor
- generic resistor

3 Experimental procedure

3.1 Software experiment

The software package Proteus was used in order to carry out the experiment. The wave form generator function, set to produce a sine wave, was used as the circuit power source with the same input voltage maintained throughout (4V). Generic components were selected from Proteus' on-board library and placed on the design board as shown in figure 1.fr

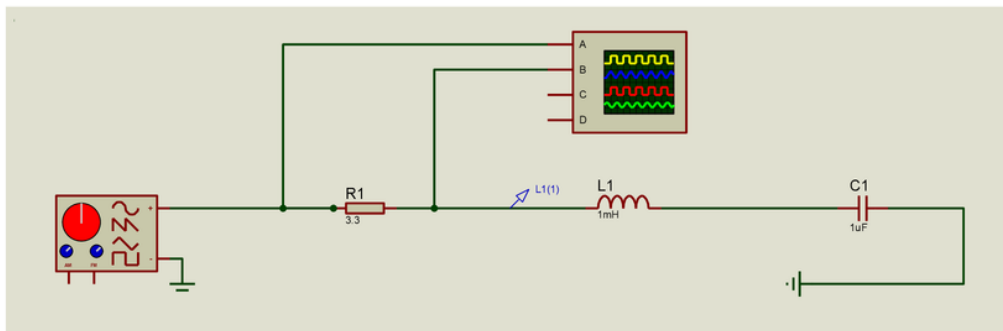


Figure 1-Proteus simulation layout

The wave form generator was wired into the resistor which in turn was wired to the inductor; this was then wired to the capacitor. The capacitor was wired to a ground module selected from the Proteus library. Component values of 3.3Ω, 100mH and 1uF were selected and an oscilloscope was wired into the circuit with channel A reading the wire between the Voltage Generator and resistor and Channel B between resistor and inductor. Channel B measures the voltage across the inductor and capacitor as it is also wired to ground, this is $V_L + V_C$.

A 4V supply was introduced into the circuit with the initial frequency set to 100Hz. The peak to peak value of $V_L + V_C$ (channel B of the oscilloscope) was measured and plotted to a graph. The frequency was then incrementally adjusted up to 20 kHz with measurements taken and plotted at each point

against the given frequency. Voltage input was also measured and plotted against frequency to provide a reference for later analysis.

3.2 Practical experiment

An electronic breadboard and components, of the same value used in the simulation experiment, were used. Additionally, single core insulated wires were required to connect the components across the board.

Components were connect in the same series as in the simulation (resistor, capacitor, and inductor) with an AC power supply unit operating at 4V and an initial frequency of 100Hz connected to the power rail of the bread board. The resistor was wired to the power rail and the inductor, and the capacitor was wired to the inductor and the ground. An oscilloscope was attached to the circuit at the input leg of the inductor with the negative probe attached the ground rail. This provided the measurement of V_L+V_C .

When power was supplied, the peak to peak measurements of V_L+V_C were taken starting at 100Hz and incrementally increased to 20 kHz. These measurements were plotted onto a graph with frequency on the x axis and voltage of the y axis.

4 Results

4.1 Raw data

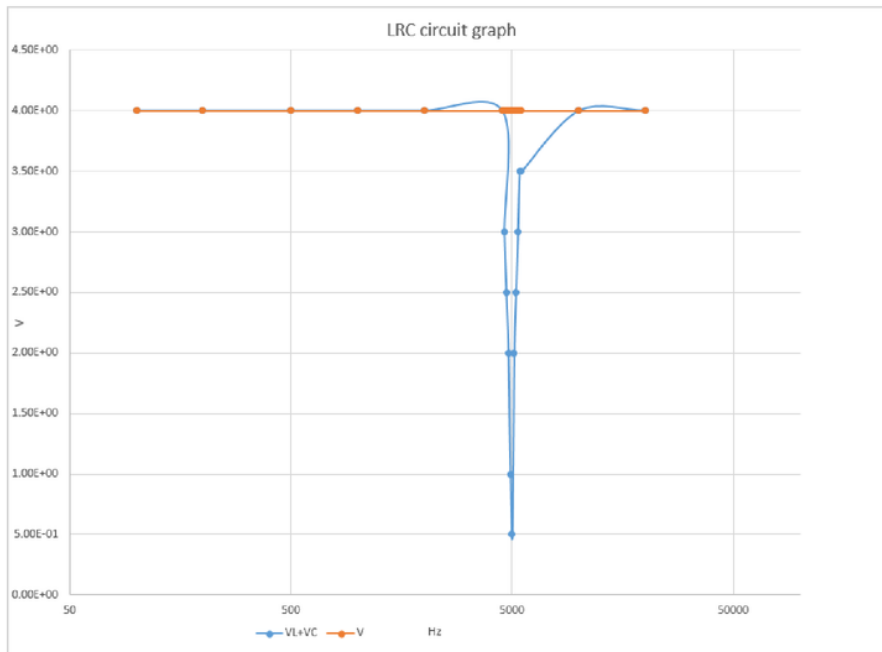


Figure 2 - Simulation data plot

Hz	supply voltage	V
Freq	Vs	VL+VC
100	4	4.00E+00
200	4	4.00E+00
500	4	4.00E+00
1000	4	4.00E+00
2000	4	4.00E+00
4500	4	4.00E+00
4600	4	3.00E+00
4700	4	2.50E+00
4800	4	2.00E+00
4900	4	1.00E+00
5000	4	5.00E-01
5100	4	2.00E+00
5200	4	2.50E+00
5300	4	3.00E+00
5400	4	3.50E+00
5500	4	3.50E+00
10000	4	4.00E+00
20000	4	4.00E+00

Figure 3 - Simulation data

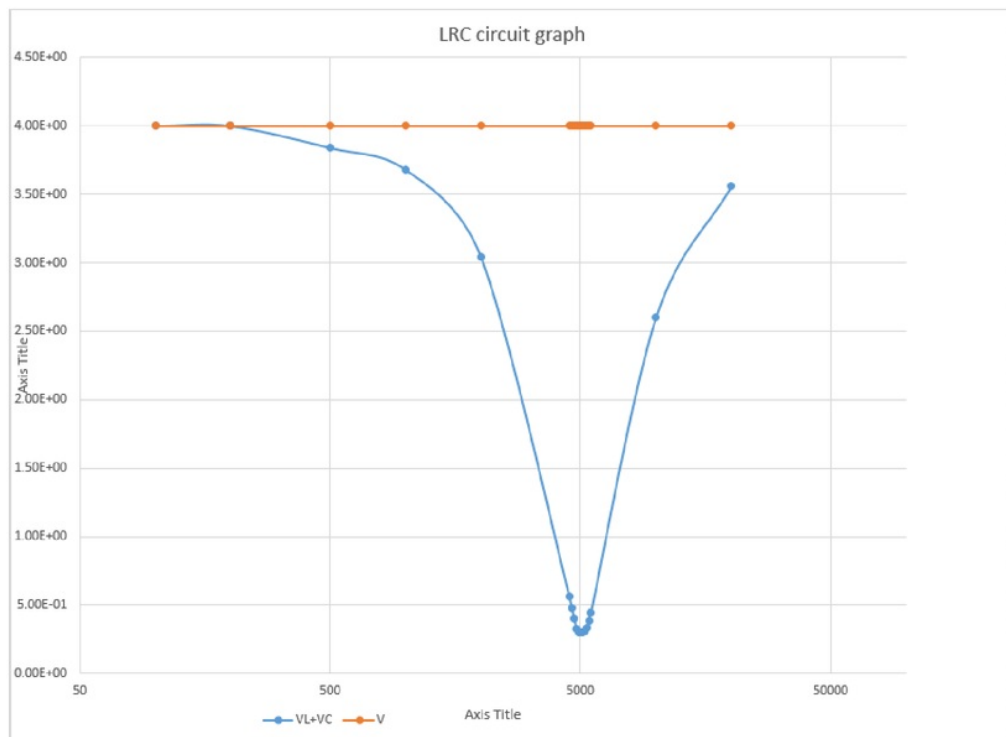


Figure 4- Lab Test data plot

Hz	supply voltage	V
Freq	Vs	VL+VC
100	4	4.00E+00
200	4	4.00E+00
500	4	3.84E+00
1000	4	3.68E+00
2000	4	3.04E+00
4500	4	5.60E-01
4600	4	4.80E-01
4700	4	4.00E-01
4800	4	3.28E-01
4900	4	3.04E-01
5000	4	3.04E-01
5100	4	3.04E-01
5200	4	3.12E-01
5300	4	3.36E-01
5400	4	3.84E-01
5500	4	4.48E-01
10000	4	2.60E+00
20000	4	3.56E+00

Figure 5 - Lab Test data

Table 1-Component Tolerances

Components	Stated value	Measured resistance	Measured capacitance	Measured inductance
Resistor – R1	3.3 Ω	2.89 Ω	N/A	13.7 μH
Capacitor – C1	1mH	N/A	1.013 μF	N/A
Inductor – L1	1 μF	2.89 Ω	N/A	0.977mH

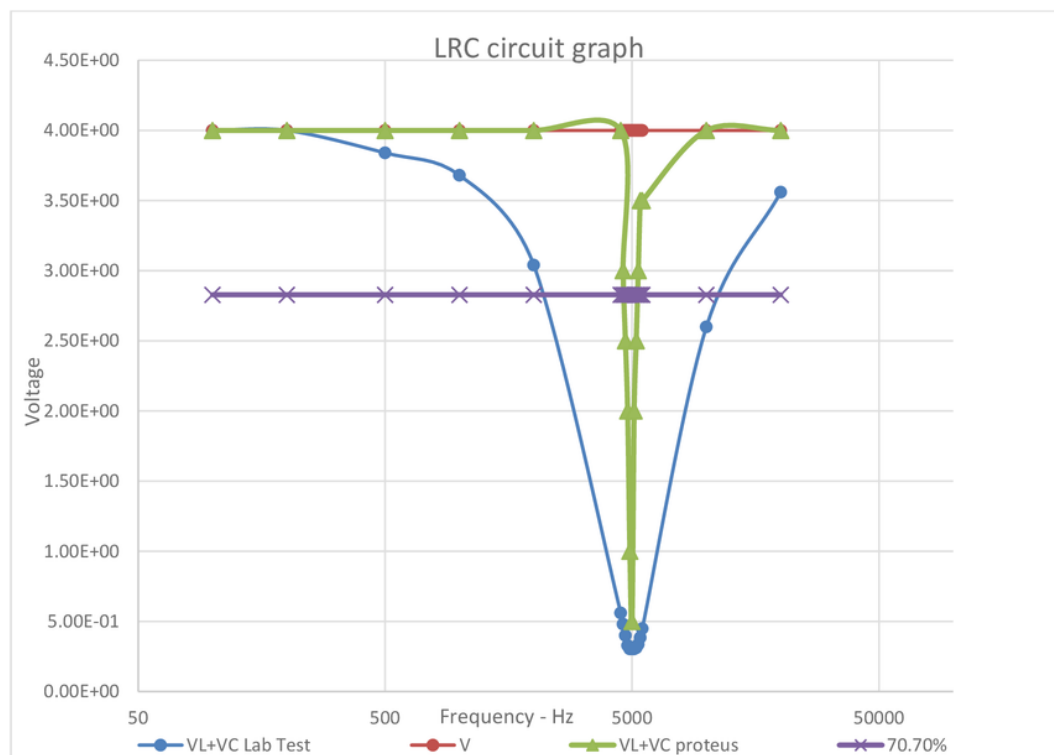


Figure 6 - Combination of both plots

4.2 Important results

Fig 5 clearly depicts the difference in Q factor between the simulation (Proteus) and lab test results. These results suggest that the lab test circuit's frequency response is less efficient than the simulation frequency response when compared to one another. These differences are further shown in tables 1 and 2 as the Q factor value is considerably lower on the lab test table when compared to the simulation values table.

Band width difference

Due to the difference in frequency response between the simulation and lab test, as seen in fig 5. It can be stated that there will be a difference in band width between the two circuits. This is evident when table1 and table2 are compared.

4.3 Calculations

4.3.1 Simulation calculations

Table 2- simulation values

Measurement metric	value	Unit
70.7%	2.282	V
f_l	4600	Hz
f_h	5600	Hz
f_{res}	4950	Hz
BW	700	Hz
Q	7.071429	

4.3.1.1 Q factor calculations

Equation 9 - Simulation Q-Factor

$$Q = \frac{BW}{f_{res}}$$

$$=7.0$$

4.3.1.2 Resonant Frequency

Equation 10 - Simulation Resonant Frequency

$$f_{res} = \frac{BW}{2} + f_l$$

$$=4950 \text{ Hz}$$

4.3.1.3 Bandwidth calculations

Equation 11 - Simulation Bandwidth

$$BW = f_h - f_l$$

$$= 700 \text{ Hz}$$

4.3.2 Lab Test calculations

Table 3 - Lab Test values

Measurement metric	value	units
70.7%	2.282	V
f_l	4500	Hz
f_h	10000	Hz
f_{res}	7250	Hz
BW	5500	Hz
Q	1.318182	

4.3.2.1 Bandwidth calculations

Equation 12 - Lab Test Bandwidth

$$BW = f_h - f_l$$

$$= 5500 \text{ Hz}$$

4.3.2.2 Resonant frequency

Equation 13 - Lab Test Frequency

$$f_{res} = \frac{BW}{2} + f_l$$

$$= 7250 \text{ Hz}$$

4.3.2.3 Q-factor

Equation 14 - Lab Test Q-Factor

$$\frac{BW}{f_{res}}$$

$$= 1.3$$

5 Analysis

5.1 Band width comparison

The difference between calculated bandwidth of the two circuits as shown in equation 10 (simulation bandwidth result) and equation 11 (lab test bandwidth result) can be explained through the additional resistance present in the lab test circuit as real-world components were used. The components used in the lab test circuit can be considered to be made up of miniature circuits, as a result, additional resistances are produced within the components themselves. Furthermore, real world components rarely achieve their exact specification i.e. a 300 Ω resistor may not actually produce that exact resistance. This is accepted as the components tolerance and should normally be taken into account when calculating circuit values. As shown in table 1 it can be seen that the Inductors internal resistance is identical to the Resistors measured value, therefore, it can be stated that the overall circuit resistance of the practical lab test are significantly higher than that of the simulation. This further contributed to the increased Q-factor value as well as the circuit's wide bandwidth. The addition of wiring used to connect the components to the breadboard as well as the resistance within the probe used to connect the oscilloscope further contributed to the increase in overall circuit resistance and therefore in frequency response and bandwidth size.

In comparison the simulation circuit results show a small bandwidth with very precise frequency response, this can be stated as the circuit being highly efficient. This outcome is the result of the simulation circuit containing "generic" components, these simulation components are designed to only output their specified value, i.e. a 300 Ω resistor will only contribute that value into the circuit. They do not contain any tolerances or natural resistances other than what has been stated. This also contributes to the capacitor and inductors rates of change, which are considerably faster when compared to real-world equivalents. Additionally, the wiring used within the simulation does not carry resistances as well as the probes tools used to measure the circuit response. All of these factors contribute to the simulated circuit's narrow bandwidth and overall efficient response.

6 Conclusions

Differences in graphical depiction of the Q value was a result of the increased resistance present in the components used during the practical experiment.

Additional resistances within the practical lab test were introduced in nearly every aspect of the circuit when compared to the simulation. Each component used in the lab test carried internal resistances as stated in the components tolerance specifications, see table 1. It can be argued that the largest contributing factor to the lab test circuits response was the internal resistance found within the inductor coil. This was approximately 2.89Ω , when taken into account with the main resistor value of approximately 3.3Ω ; a large increase in circuit resistance becomes evident. Other resistances can be found within the remaining components, the probes used to connect the oscilloscope, as well as the wiring required to connect the circuit throughout the bread board. Collectively, these increased the overall resistance of the lab test circuit to such a degree that an obvious difference between the lab test circuit bandwidth and the simulation bandwidth was presented.

The simulation graph is a depiction of a “perfect” circuit as components with no tolerances or internal resistances were used. The result of minimal circuit resistance is a small Q value and a narrow bandwidth at resonant frequency.

The use of “generic” components in simulation models should be avoided when attempts are made to realistically reproduce “real world” circuits. It is strongly advised that detailed analysis of any real world components be carried out in order to better replicate any internal properties present within any given component.

7 References

- [1] P. H. a. W. Hill, The Art of Electronics - 1.22 Resonant circuits and active filters, Cambridge: Press Syndicate of the University of Cambridge, 1989.
- [2] S. Mosey, “AC Theory,” UWTSD Swansea, Swansea, 2018.

LWG_1810351_OME_Electrical and electronic principles

Assignment - Resonance

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

59/100

PAGE 1

PAGE 2

PAGE 3



Comment 1

You should have included some information on your main findings, otherwise nice abstract.

PAGE 4



Comment 2

and the

PAGE 5

PAGE 6



Comment 3

-3dB



Comment 4

The bandwidth of a circuit does not directly relate to efficiency, it only indicates the sharpness of its frequency response. The bandwidth of a circuit may need to be low, as in a radio transmitter, or high as in the tone control in an audio amplifier.

PAGE 7



Comment 5

1mH and 3.3Ω



Comment 6

Sin

PAGE 8

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PAGE 13



Comment 7

This seems a little on the high side.

It should also be calculated using the capacitor and inductor values.

$$F = 1/(2 \cdot \pi \cdot \text{SQRT}(L \cdot C))$$



Comment 8

Good point.



Comment 9

Do you mean theoretical pure components?

PAGE 14

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WILLIAM GROOM

58.70

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



References to a limited range of relevant sources. Referencing conventions evident. I was expecting you to use more sources.

2

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.

17.4

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. Can analyse new and abstract data and situations. Ability to use evidence to support the argument. Valid conclusions.

17.7

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



Very good consideration of the context of the application, with perceptive use of examples, where relevant.

18.6

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