

Resonance Report

by Richard Peter Hankinson

FILE	12382_RICHARD_PETER_HANKINSON_RESONANCE_REPORT_226192_2 10724842.DOCX (503.92K)		
TIME SUBMITTED	13-FEB-2020 01:12PM (UTC+0000)	WORD COUNT	3346
SUBMISSION ID	120034225	CHARACTER COUNT	18081

Resonance

Richard Peter Hankinson

P137603

Electrical & Electronic Principles

ACDB4002

Wales Institute for Science and Art

University of Wales Trinity Saint David



Abstract

The effect AC has on a circuit differs from DC due to the rise and fall of voltage and current, over time (frequency). This rise and fall of voltage and current in components such as capacitors and inductors, creates an additional apposing resistance, called reactance [1] [2]. The effects of this reactance must be understood by engineers in order to accurately remove it (by tuning the circuit to resonance) or utilise its affects, in order to modify the current and voltage in a desired and calculated manner. [3]

A parallel RLC circuit has been created and analysed in order to visualise and explain the effect of inductors and capacitors on voltage and current, and their phase relationships when the input frequency is stepped in increments between 0Hz and 10KHz. The results are discussed, once presented as a frequency curve on a graph.

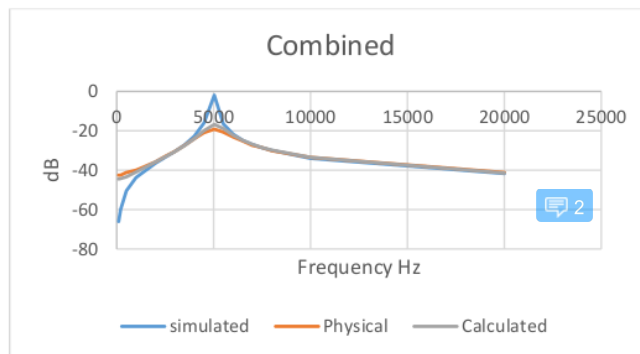


Fig 1

The circuit was simulated, physical created and mathematically calculated. As displayed in the graph *fig 1*, all three lines differ in shape and amplitude, but peak at the same frequency (5032Hz).

The experiment only analyses a parallel RLC circuit. RLC circuit components can be arranged in different configurations to attenuate voltage and current at specific frequencies creating a filter. The parallel RLC circuit creates a 'bandpass' filter, where frequencies above and below a certain frequency are attenuated. [4]

Introduction

In electronics, engineers use both alternating current (AC) and direct current (DC). Certain components are selected for their ability to modify an input voltage and current to a desired output voltage and current. Inductors and capacitors are electronic components that effect the amount of voltage and the flow of electric current in a circuit. When these components are used in circuits combined with resistors, they create RLC (resistor, inductor and capacitor) circuits. These circuits are used whenever alternating current and voltages are to be affected or changed. The capacitor and resistor circuit (RC) is the more versatile circuit that is used in almost all electronic circuits in different combinations. RC circuits can create high and low pass filters, smoothing circuits, AC coupling whilst blocking DC, electrical timers etc [5] [6]. [3]

By introducing an inductor to create an RLC circuit, very narrow bandwidth filters can be created which in turn can be used to focus on a narrow range of frequencies. This is extremely useful in wireless technologies. By selecting or, 'tuning' the circuit to a certain carrier frequency other circuits can then be used to extract the information from the carrier waveform and use the information in whatever way desired. This technology is applicable to analogue and digital data broadcast systems such as radio, television, telecommunications, Wi-Fi, GPS etc [7] [8]. [3]

Before looking into RLC circuits it is key to understand how inductors and capacitors effect voltage and current within AC circuits, see 'Inductors and Capacitors' in the appendices section. This background research helps to grasp the concepts of these components and make sense of the results of the experiment.

Inductors and capacitors both have reactance, known as inductive reactance X_L and capacitive reactance X_C . This reactance occurs whenever there is a change in current. In a purely resistive AC circuit, with no reactance influencing voltage and current, the current and voltage will remain in-phase with each other [3] [4].

When circuit is purely capacitive, the current is at maximum when the voltage is at zero. Then, as the capacitor charges, the voltage increases and the current decreases until the voltage is at maximum and the current is at zero. [3] [4]

The opposite is true for an inductor. When a circuit is purely inductive, the voltage is at maximum when the current is at zero and as the voltage drops the current rises. This continues until the voltage is at zero and the current reaches its maximum. [3] [4]

When represented as a sinusoidal waveform, in a purely capacitive circuit, the current leads the voltage by 90 degrees and in a purely inductive circuit, the voltage leads the current by 90 degrees. This means that the currents flowing through an inductor and capacitor are 180 degrees out of phase from each other. [2] [3]

Red line = Capacitor current

Blue line = Voltage

Green line = Inductor current

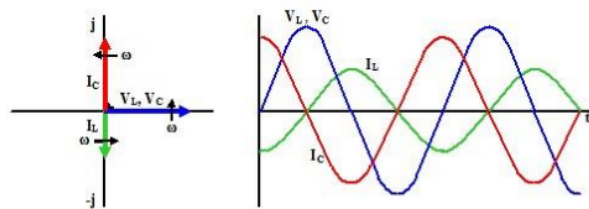


Fig 2 [9]

The formulas to calculate XL and XC are as follows [4]:

$$XL = 2\pi fC$$

Caption required

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

Caption required

Resonance occurs when $XL = XC$, as their reactive effects cancel each other out due to them being opposites [3]. To calculate the resonant frequency, the formula is as follows [3] [4]:

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

Caption required

For the experiment, the circuit diagram shows values for both the inductor and capacitor.

$$L = 1\text{mH (0.001H)}$$

$$C = 1\mu\text{F (0.000001F)}$$

$$f = \frac{1}{2\pi\sqrt{0.001 \times 0.000001}}$$

Caption required

$$f = 5032.92121$$

The calculated resonant frequency of 5032Hz will be taken into consideration in the experiment. This is also an ideal calculation using perfect components which should be accurate with both the simulated and calculated results but not for the physical circuit [6].

In the physical world inductors, capacitors and resistors are not perfect and have tolerances. Stray inductance and capacitance appear in circuits (hopefully in small amounts) which influence voltage and current flow [10]. The impedance of the test equipment will have an influence.

The DC resistance of the cables will cause some resistance as will the skin effect. Which is where, the higher the frequency, the more electrons gather on the outer surface of conductive material when current flows. This has the effect of reducing the diameter of the conductor, resulting in an increase of resistance. The inductor is a single coil of wire as stated earlier, and has DC resistance. A similar inductor used in the experiment was measured for DC resistance at UWTSD SA1 campus and measures around 4Ω . This will not be taken into consideration with the simulated and calculated results, but should be kept in mind for physical results.

The output voltage needs to be converted to Decibels which is a unit of measurement which can represent a circuit's 'gain' [11]. To determine a Q factor, the -3dB point needs to be calculated using a graph of results. To do this the voltage needs to be converted mathematically to decibels. The point either side of the resonant frequency where the voltage reduces by 3dB needs to be used to determine the bandwidth. The bandwidth is the amount of frequencies between these -3dB points. [4]

$$Q = \frac{\text{Resonance Frequency}}{\text{Bandwidth}}$$

Caption required

The higher the Q factor number, the greater the circuit's selectivity which is useful for selecting carrier frequencies. [3]

Series and parallel RLC circuits have opposite effect on voltage and current. In series, as the frequency rises the circuits phase relationship is inductive. As the circuit reaches resonance the voltage drops because the resistance across the inductor and the voltage across the capacitor are 180 degrees out of phase, they cancel each other out. As the circuit rises above resonance there is a phase shift of 180 degrees as the circuit becomes more capacitive. In a parallel circuit the opposite happens. When the circuit is below resonance more current flows through the inductor, reducing the voltage. When the circuit reaches resonance the out of phase current cancels each other out, resulting in less current drawn and a higher voltage. As the circuit frequency increases beyond resonance, the current increases across the capacitor creating a voltage drop. There are no voltage phase shifts when in parallel. [11] [3]

RLC filter circuits hold a crucial part in audio manipulation creating the ability to attenuate and boost frequencies by creating high-pass, low-pass and band-pass filters. They are used to split frequencies to different sets of driver units for efficiency by creating a cross-over network. Sending low frequencies to larger drivers (woofers) via an inductor and higher frequencies to smaller drivers (horns/tweeters). [13]

A parallel RLC circuit was simulated in Proteus, built using breadboard and physical components, then calculated using Windows Excel. The results are compared within this report.



1 Equipment

- 1x PC running electronic circuit simulation software (Proteus) and Windows Excel
- 1x Oscilloscope
- 2x Scope probes
- 1x Function generator
- 1x BNC to two crocodile clips cable
- 1x Breadboard
- 1x 1k Ω resistor
- 1x 1mH inductor
- 1x 1 μ F capacitor
- Strips of insulated, solid core cable

2 Method

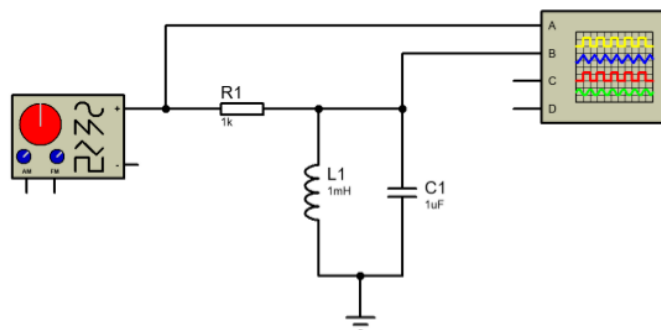


Fig 3 Circuit presented in assignment brief

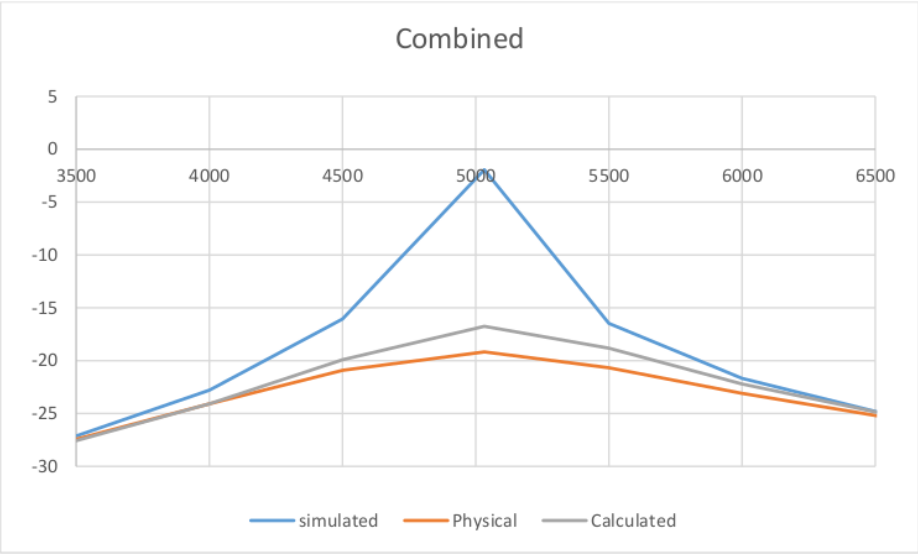
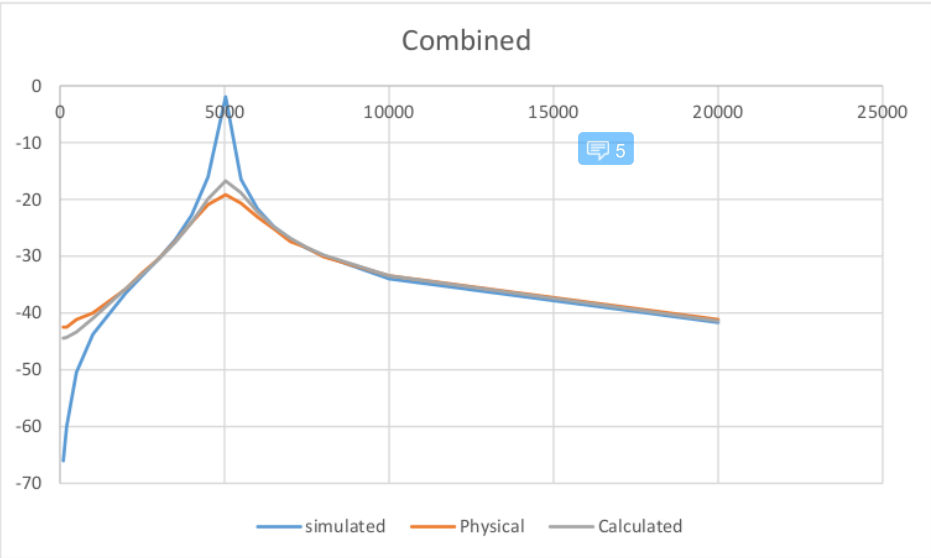
First, a simulation of the circuit using Proteus circuit simulator. Once the circuit had been virtually created, a virtual signal generator was connected to the input to provide the test frequencies. A virtual oscilloscope was used to verify that the circuit worked.

Voltages measurements were taken of test frequencies, using the virtual oscilloscope and placed in Microsoft Excel. The results were converted to dB using the formula
$$\text{Sep. Eqn.} \quad =20 * \text{LOG}10(V_{\text{out}}/V_{\text{in}}) \quad [11] \quad [13].$$
 A results graph was created and analysed to determine the -3dB points, bandwidth and then Q factor.

The experiment was repeated but this time using physical components and equipment. The results were placed into Excel and analysed in the same way as the simulated experiment creating another graph for comparison.

Lastly, the experiment was calculated mathematically using Excel. This involved utilising Excel's ability to deal with complex numbers to calculate reactance and impedance to determine the output voltage and then convert that into dB to create a graph/

3 Results



The simulated results showing considerably more amplitude than calculated and simulated.

Resonance:

Simulated = 5032.92 Hz	Physical = 5032 Hz	Calculated = 5032.92 Hz
------------------------	--------------------	-------------------------

Bandwidth



Simulated = 210 Hz	Physical = 1500 Hz	Calculated = 1120 Hz
--------------------	--------------------	----------------------

Q Factor

Simulated = 23.96628571	Physical = 3.35528	Calculated = 4.4937
-------------------------	--------------------	---------------------

4 Discussion

From the data plotted on the combined graph, the simulated circuit has higher amplitude and Q factor. Yet both the physical and calculated yield more than 15dB lower amplitude which is huge due to the dB scale being logarithmic [13]. This amount of attenuation even at resonance, causes signal strength issues and creates the need for further circuit amplification [5].

It was expected that the physical circuit would differ the most due to many external factors from which the simulated and calculate circuits are unaffected. These are as follows:

- Component tolerances: Components have a tolerance rating from which the amount of fluctuation in value the component can have from its stated value. These can be up to plus or minus 20%.
- Stray inductance and capacitance: When current passes through a conductor a magnetic field is produced. This created a small amount of inductive reactance. The proximity of the insulated coil windings of the inductor create a small capacitance between each winding resulting in added capacitive reactance. These affect the total impedance of the circuit.
- Inductors DC resistance: The inductor being a single cable wrapped into a coil has a certain amount of DC resistance. Usually this is a low resistance, but it affects the total impedance of the circuit. This is not

taken into consideration in Proteus or the calculated circuits as they used ideal values.

- Source impedance: The signal generator used has an impedance due to the circuitry used to create the signals. This will have an effect because it has been placed in parallel with the RLC circuit and will affect the results.
- Human error: Having a human select the frequency using a potentiometer on the signal generator and measure the results on an oscilloscope. Incorrect frequency selection, as the frequencies require minute amounts of rotation of the potentiometer which is extremely difficult and an amount of estimation of the voltage on the oscilloscope.



The fact that the physical circuits resonance frequency aligns with the simulated and calculate results. This shows that the capacitor and inductor used must be very close to the stated values or compensating each other to resonate at the predicted 5032Hz.

The difference between the simulated and calculated resonance amplitude and Q factor are unexpected as neither suffer from the same factors as the physical circuit.

For all three circuits, the amount of attenuations of the voltage becomes similar under 3.5KHz and above 6.5KHz. The simulated result has a very steep incline between 0Hz and 100Hz because the simulation started at 100Hz and not 0Hz so that explains that curve.

5 Conclusions

The combined graph clearly shows that the resonance of all three experiments are aligned but with different Q factors. Considering background research into component tolerances, stray inductance and capacitance, and the skin effect; it was clear that the physical experiment was unlikely to yield the same results as the simulated and calculated ones.

The simulated and calculated results are different in terms of gain and Q factor. This is unpredictable and unexpected. Both circuits (simulated and calculated) used ideal values, therefore shouldn't have had the predicted issues that the physical experiment did.

Possibly reasons could be:

- Proteus has added in an internal DC resistance for the inductor which has given the circuit a higher Q factor.
- Excel and Proteus round up or down equations/results to different decimal places.

Further research would be required to explain the difference in gain of the simulated and calculated circuits.

Within the physical experiment, there are a few small discrepancies which have probably altered results slightly. Selecting the exact frequency on the signal generator became very difficult due to using a potentiometer to select frequency. More accurate results would have been possible by using a signal generator with a digital interface to select the frequency. Reading the physical oscilloscope also introduced scope for slight measurement errors due to counting spaces. The digital scope used did have auto peak-

to-peak but was not used during this experiment. If used, this would have created more accurate results. There could have been dips in voltage from the signal generator as the impedance dropped at the extremities of the frequency range resulting in more current flow.

The experiments have shown the difference between simulated, calculated and physical circuits. Simulated circuits are great for design purposes due to the speed and ease of design and the fact that alterations can be made very quickly. Yet simulation alone does not give a full picture of exactly how a circuit will operate once created. Therefore, tweaks may be needed to match the physical to the simulated.

The experiment provides a pathway to understanding the phase relationships between voltage and current which are fundamental in understanding AC electronic theory.

6 References

- [1] r. b. I. M. S. Edward Hughes, "Hughes Electrical Technology," in *Hughes Electrical Technology seventh edition*, Harlow, Addison Wesley Longman Limited, 1995, pp. 217-280.
- [2] T. Duncan, "Advanced Physics," in *Fields, Waves and Atoms 2nd edition*, London, John Murray LTD, 1981, pp. 149-165.
- [3] T. L. Floyd, "Principles of Electric Circuits," in *Principles of Electric Circuits sixth edition*, New Jersey, Prentice-Hall, 2000, pp. 460-744.
- [4] J. Bird, "Electrical and Electronic Principles and Technology," in *Electrical and Electronic Principles and Technology second edition*, Oxford, Elsevier, 2003, pp. 199-247.
- [5] T. L. Floyd, "Electronic Devices," in *Electronic Devices third edition*, New York, Macmillan Publishing Company, 1992, pp. 762-786.
- [6] J. Watson, "Mastering Electronics," in *Mastering Electronics fourth edition*, Palgrave, 1996, pp. 23,129-137.

- [7] “Wi-fi radio waves and health,” 1 Nov 2013. [Online]. Available: <https://www.gov.uk/government/publications/wireless-networks-wi-fi-radio-waves-and-health/wi-fi-radio-waves-and-health>. [Accessed 12 Feb 2020].
- [8] “United Kingdom frequency allocation table,” [Online]. Available: https://www.ofcom.org.uk/__data/assets/pdf_file/0016/103309/uk-fat-2017.pdf. [Accessed 12 Feb 2020].
- [9] [Online]. Available: http://secure.tutorglobe.com/CMSImages/2326_12.2.jpg. [Accessed 12 Feb 2020].
- [10] Cadence design systems, “How parasitic capacitance and inductance affects your signals,” 2019. [Online]. Available: <https://resources.pcb.cadence.com/blog/2019-how-parasitic-capacitance-and-inductance-affect-your-signals>. [Accessed 12 Feb 2020].
- [11] K. L. Su, Analog Filters, Atlanta: Chapman and Hall, 1996, pp. 1-27.
- [12] w2aew, “#55: Back to Basics: Tutorial on LC Resonant Circuits,” 24 July 2012. [Online]. Available: <https://www.youtube.com/watch?v=hqhV50852jA>. [Accessed 12 Feb 2020].

- [13 T. M. Francis Rumsey, Sound and Recording, Oxford: Focal Press, 2006, pp.
] 14-36.
- [14 J. C. Drury, Ultrasonic Flaw Detection for Technicians, Silverwing Ltd.,
] 2004.
- [15 P. D. -I. V. Deutsch, "History of NDT - Instrumentation," Rome, 2000.
]
- [16 "History of Ultrasonics," Iowa State University, [Online]. Available:
] [http://www.ndt-](http://www.ndt-ed.org/EducationResources/CommunityCollege/Ultrasonics/Introduction/history.htm)
[ed.org/EducationResources/CommunityCollege/Ultrasonics/Introduction/histor](http://www.ndt-ed.org/EducationResources/CommunityCollege/Ultrasonics/Introduction/history.htm)
[y.htm](http://www.ndt-ed.org/EducationResources/CommunityCollege/Ultrasonics/Introduction/history.htm). [Accessed 17 February 2011].
- [17 W. H. Paul Horowitz, "The Art of Electronics Third Edition," in *The Art of*
] *Electronics Third Edition*, New York, Cambridge University Press, 1980, 1989,
2015.

7 Appendices

Inductors and Capacitors

A capacitor consists of two conductive plates separated by an insulating material. There is no physical connection through a capacitor. A capacitor charges and stores energy when a voltage is applied. When an input voltage is applied to a capacitor there is a large amount of current which in turn pulls the voltage down. The amount of time in seconds a capacitor takes to charge to 63% is known as a time constant ($t=RC$). It takes five 'time constants' until the capacitor is considered fully charged and becomes within 1% of the input voltage (99% charged) *see fig 1*. As the capacitor charges, the current reduces as the voltage begins to rise as there is less potential difference between the source and the capacitor. The capacitors resistance to voltage is known as its reactance. Once the capacitor is fully charged there is virtually no current flowing through capacitor. In a DC circuit a capacitor appears as an open circuit once fully charged as there is no physical connection between the plates. [1] [2]

When the source voltage drops below the voltage stored in the capacitor, the capacitor discharges and releases its energy back into the circuit. When a capacitor discharges, it depletes to 37% of its full charge in the time it takes for one time constant (which is 100% - 63%). It also takes five, time constants to be depleted to 1% which is considered empty *fig 2*. [1] [2]

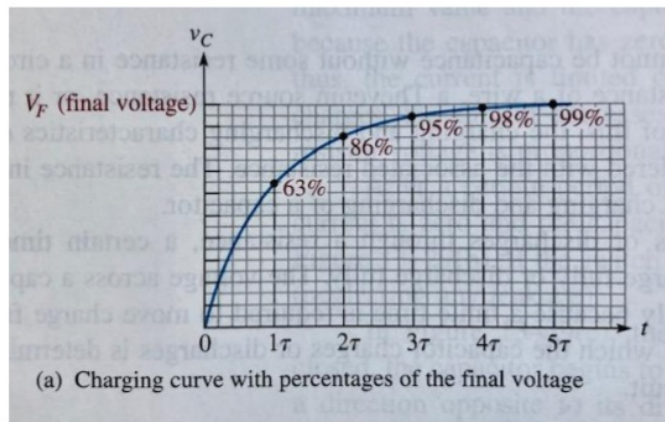


Fig 1 [1]

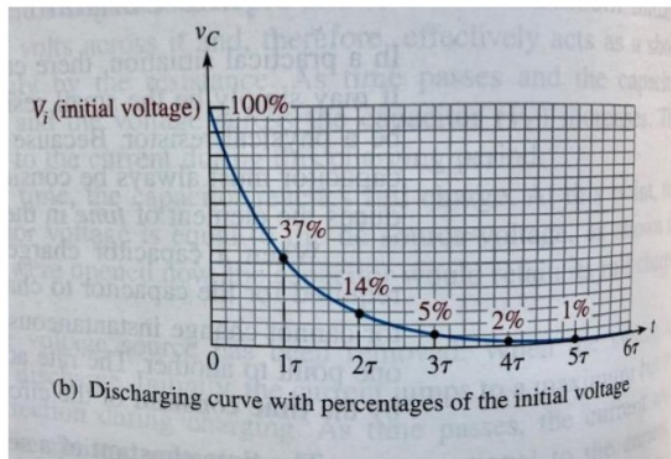


Fig 2 [1]

This is used in many applications such as a smoothing circuit, for smoothing out ripple in voltage rectification *see fig 3* [3]. The larger the capacitance, the longer the time constant time (longer it takes to charge) and the slower it will react to changes in

frequency. The ability to vary the time constant can be applied to create an analogue electronic timer. [1]

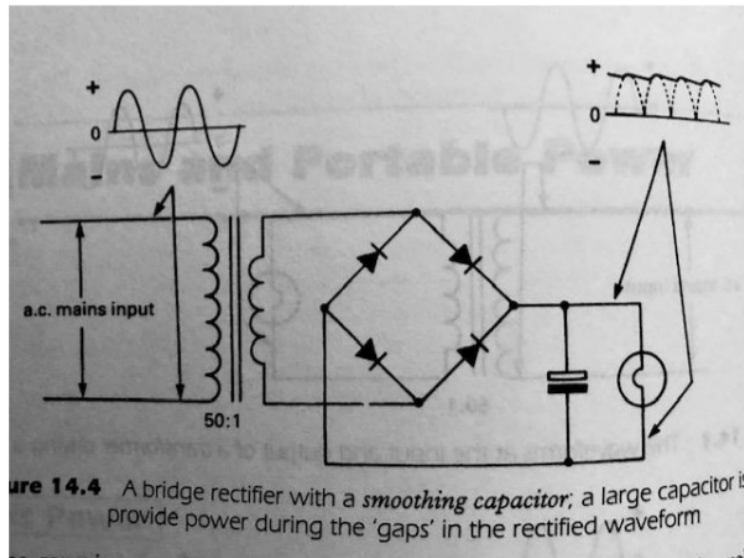


Fig 3 [3]

An inductor is a length of wire that has been wrapped into a coil. Unlike a capacitor, there is a physical connection through an inductor. When current flows through a coil it energises and becomes an electromagnet, creating an electric field. The more current, the stronger this magnetic field becomes. When there is a change in current, such as in an AC circuit, there is a fluctuation in the strength of the magnetic field. When a magnetic field fluctuates it induces a voltage into the conductive material of the inductor creating an EMF (electro motive force). This is known as the inductor's reactance. This voltage opposes the direction of the changing current, generating a back (reverse) EMF. When a voltage is applied to an inductor the current is restricted by the generated back EMF. The time it takes for the current in an inductor to reach 63% of the total current is also known

as its time constant ($t = L/R$) but unlike a capacitor it is now current, not voltage, that takes five times constants to reach maximum (99%). When the inductor deenergizes the current depletes to 37% after one time constant and takes five, time constants to become 1% which is considered, deenergised. [1] [2]

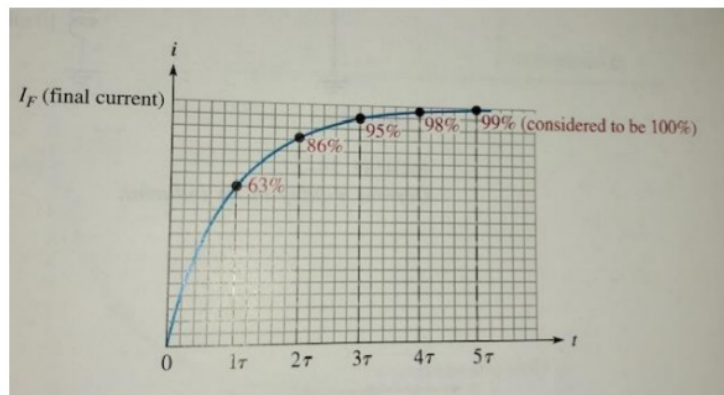


Fig 4 [1]

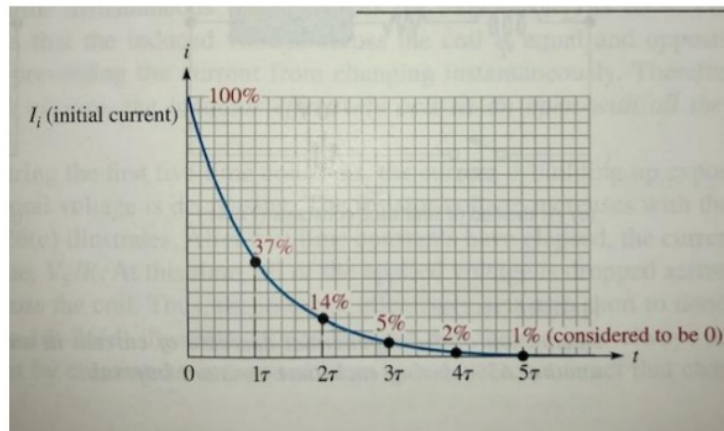


Fig 5 [1]

Unlike the capacitor, inductors are not particularly common in modern circuits. Some of their uses are as 'chokes' for power factor correction, to balance out what would be a

highly capacitive circuit such as in a fluorescent light unit. Transformers are essentially two or more inductors in proximity, sharing the same core material. Utilising induction to create voltages and currents in the other inductors coil. Each coil influences the voltage and current in the circuit it is directly connected to because it acts like an inductor. [1]

References

- [1] T. L. Floyd, "Principles of Electric Circuits," in *Principles of Electric Circuits sixth edition*, New Jersey, Prentice-Hall, 2000, pp. 460-744.
- [2] r. b. I. M. S. Edward Hughes, "Hughes Electrical Technology," in *Hughes Electrical Technology seventh edition*, Harlow, Addison Wesley Longman Limited, 1995, pp. 217-280.
- [3] J. Watson, "Mastering Electronics," in *Mastering Electronics fourth edition*, Palgrave, 1996, pp. 23,129-137.

Resonance Report

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

68/100

Instructor

PAGE 1

PAGE 2



Comment 1

opposing



Comment 2

Although a statement of results is expected in an abstract, a graph (or any other figure) is unusual in an abstract.

PAGE 3

PAGE 4

PAGE 5

PAGE 6

QM

Caption required

You should always include a caption on figures, equations and tables to allow you to refer to them in your text.

e.g. An illustration of this can be seen in figure 2. The relationship of the variables is shown in equation 2. Table 1 shows the results of the first experiment where the control variable, temperature in degrees celsius is shown in the first column....

QM

Caption required

You should always include a caption on figures, equations and tables to allow you to refer to them in your text.

e.g. An illustration of this can be seen in figure 2. The relationship of the variables is shown in

equation 2. Table 1 shows the results of the first experiment where the control variable, temperature in degrees celsius is shown in the first column....

QM

Caption required

You should always include a caption on figures, equations and tables to allow you to refer to them in your text.

e.g. An illustration of this can be seen in figure 2. The relationship of the variables is shown in equation 2. Table 1 shows the results of the first experiment where the control variable, temperature in degrees celsius is shown in the first column....

QM

Caption required

You should always include a caption on figures, equations and tables to allow you to refer to them in your text.

e.g. An illustration of this can be seen in figure 2. The relationship of the variables is shown in equation 2. Table 1 shows the results of the first experiment where the control variable, temperature in degrees celsius is shown in the first column....

PAGE 7

QM

Caption required

You should always include a caption on figures, equations and tables to allow you to refer to them in your text.

e.g. An illustration of this can be seen in figure 2. The relationship of the variables is shown in equation 2. Table 1 shows the results of the first experiment where the control variable, temperature in degrees celsius is shown in the first column....

PAGE 8



Comment 3

Very good introduction.

PAGE 9

PAGE 10

QM

Sep. Eqn.

Separate Equations:

Equations should be given their own line and caption to allow you to discuss them in your text. You should also identify and describe each of the variables in the equation.



Comment 4

I would have liked more information on this - what equations did you use?

PAGE 11



Comment 5

A few points about your graph:

1. Your axis should have titles to inform the reader of what quantity is being displayed
2. The x-axis should be logarithmic
3. You should always make the most of the space available - in this case, you should limit the x-axis to values where you have valid data.

PAGE 12



Comment 6

Would this have been better as a table?

PAGE 13

PAGE 14



Comment 7

All good points

PAGE 15

PAGE 16

PAGE 17

PAGE 18

PAGE 19



Comment 8

You have only cited upto number 13 in your report. Why are there more than 13 references if you've only used 13?

PAGE 20

PAGE 21

PAGE 22

GRADING FORM: SMU GENERIC_SMOSEY

RICHARD PETER
HANKINSON

67.70

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



A comprehensive range of research informed literature embedded in the work. Excellent selection of relevant and credible sources. High-level referencing skills, consistently applied

3.75

KNOWLEDGE & UNDERSTANDING

Knowledge of the basic underlying concepts and principles of a subject.



Excellent knowledge and understanding of the main concepts and key theories. Clear awareness of challenges to established views and the limitations of the knowledge base.

21.6

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, and to review the reliability, validity & significance of evidence. Ability to communicate ideas and evidence accurately and convincingly. Sound, convincing conclusions / recommendations

19.5

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.

20.1

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.

2.75