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Design Of A 'Luminator' Using A Resonance Circuit

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ABSTRACT

This work on the design of a 'luminator' for control of light bulb brightness is primarily a basic design Using simple components of resistors, inductors and capacitor to achieve it. Light control is a very useful part of our daily life, it is done so as to use light efficiently (cost effectiveness), for comfort, in theater for effects and so on. This study is to show the principles behind it's actualization electronically. The study comprehensivly dealt with the mathematical theories and principle behind the design and carried out an experiment using RLC circuit supplied with a frequency varying device as the alternating current supply source, all in series. The resonance of this device was obtained at 159.15H_z, when the inductive impedance and the capacitive impedance were both 10.04Ω, the peak current was 0.22A at resonance increasing before and decreasing afterwards, just like the impedance decreases, (at resonance Z =R = 1000Ω) reaching maximum and increasing afterwards.

Key words: 'Luminator', Impedance, Reactance, Resonance and frequency

1. INTRODUCTION

Laminator is a word derived from two key words "LUMEN" (Light unit) and "REGULATOR". It is a device used to control and adjust the light intensity of a bulb to achieve specific goals such as energy efficiency, mode of creation, task optimization, visual comfort or effect in a room, office or theater. This gives the reason and need for this system [1][2][3]. It is common knowledge that traditional lighting system are operated as fixed in brightness, thus leading to inefficiency and visual discomfort. This work seeks to address through the design and implementation of a light bulb brightness regulator (LUMINATOR). The idea is that the laminator will be capable of adjusting the brightness of a light bulb in real time. By regulating the brightness, this system aims to reduce energy consumption, improve visual comfort and improve the overall light voltage. Through experimental results from the circuit design and discussion of the laminator highlighting its potential application and benefit to be attained, one can further appreciate the system.

1.1. Theoritical Framework

In studying component that are possibilities in the lighting bulb brightness regulator ("Luminator") it will give a better understanding of how it works. These components are resistor, capacitor and inductor primarily. It's important to understand their characteristics individually and when connected together, collectively. For resistors and inductors direct current (DC) can pass through them as well as alternating current (AC) but for capacitor DC can't pass through it, only AC can pass. As current passing through it, is due to AC that are continually charged and discharged [4] [5].

1.1.1 AC (Alternating Current) through a capacitor

The current through a capacitor from the main, (in Nigerian's case 220v, 50Hz). Continually charging and discharging and charging the other way round, the current thus flow round the circuit and can be measured by an AC milliammeter. If the alternative voltage is v, and the charge on the plate of the capacitor is Q, and by definition

$$Q = CV \quad - \qquad (1)$$

Where C is a constant, called capacitance enter new line Q is related to Current I by

$$I = \frac{dQ}{dt} \quad - \qquad (2)$$

As current is defined as the rate of flow of charges in Ampere (A).

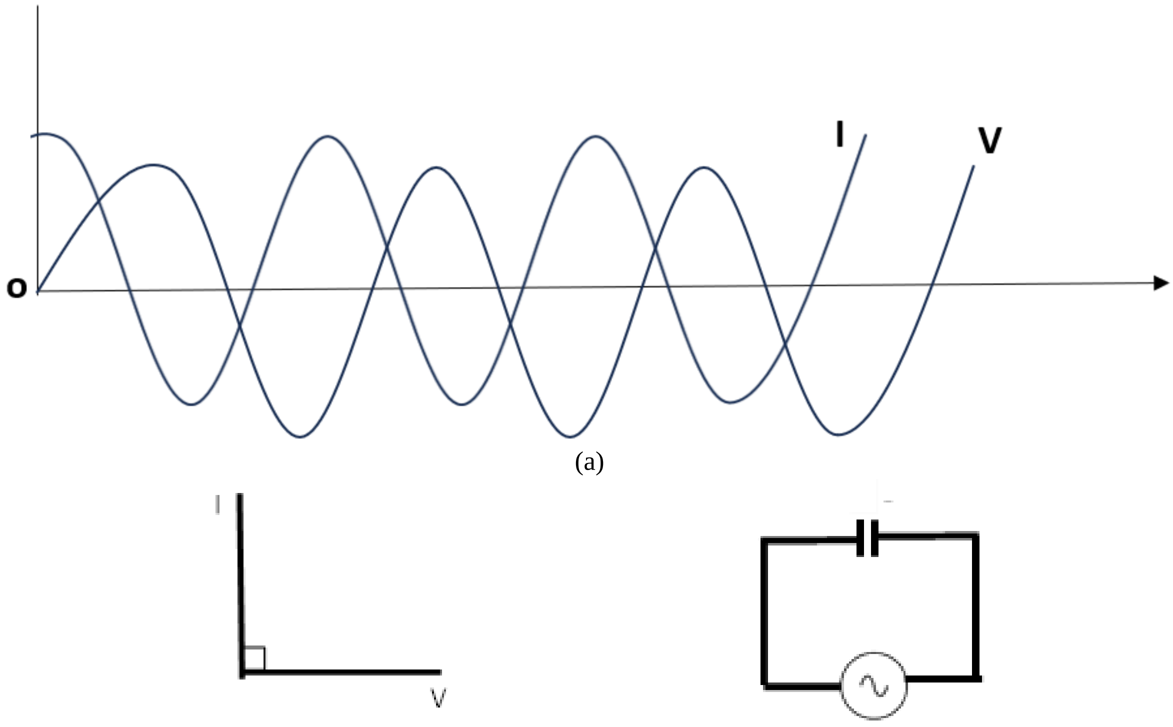


FIG 1. *Illustration of (a) current leading voltage by 90º in a capacitive circuit, (b) phase relationship between voltage and current in capacitive circuit and (c) capacitive circuit*

The relationship of I and V as illustrated in the graph above is that current leads the voltage by 90^0

1.1.2 Calculation of I

In calculating the exact variation of I with time given that the peak or amplitude voltage is V_m and peak current is I_m, as V_m increases, I_m also increases.

Assuming a sinusoidal voltage variation, the instantaneous voltage at any time t is

$$V = V_m Sin2\pi ft \quad (3)$$

And from eqn 3 Q can be rewritten thus

$$Q = CQ = CV_m Sin2\pi ft \quad (4)$$

Current flowing, can be written as, for Q as shown in equ. (4).

$$I = \frac{dQ}{dt} = \frac{d}{dt}(CV_m \, Sin\, 2\pi ft \quad (5)$$

After differentiating I is

$$I = 2\pi fCV_m cos2\pi ft \quad (6)$$

1.1.3 Reactance of C

The reactance of a capacitor is it's opposition in ohms to the passage of alternating current (AC). It symbol is X_c and it is defined thus

$$X_c = \frac{V_m}{I_m} \quad (7)$$

Or simple $$X_c = \frac{V}{I} \quad (8)$$

From equ (6) the amplitude or peak current I_m is given by

$$I_m = 2\pi fCV_m \quad (9)$$

Thus from equ 7 becomes

$$X_c = \frac{1}{2\pi fc} \quad (10)$$

It can be written thus

$$X_c = \frac{1}{\omega c} \quad (11)$$

1.1.4 AC Through Inductor

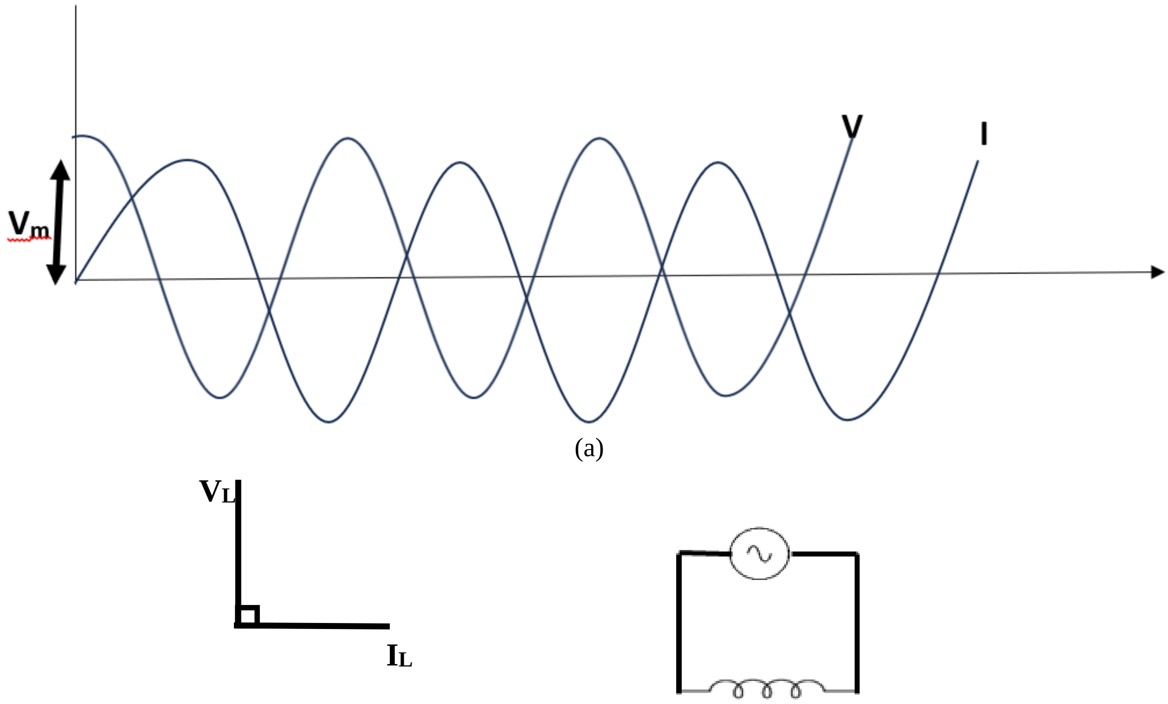
Since coils are made from conductors, it is not a problem for AC to pass through them but if the coil has appreciable self-inductance, the current is less than would flow through a non-inductive coil of the same resistance according to Lennz law, we can see how self-inductance opposes changes of current, therefore coil with self-inductance will oppose AC that is continuously changing.

Assuming a negligible resistance and a sinusoidal Current

$$I = I_m Sin2\pi ft \quad (12)$$

Where I_m is amplitude current and L inductance of the coil, the changing current sets up a back EMF in the coil of magnitude

$$E = L\frac{dI}{dt} \quad (13)$$



(b) (c)

FIG 2. *Illustration of (a) voltage leading current by 90º in an inductive circuit, (b) phase relationship between voltage and current in inductive circuit and (c) inductive circuit respectively*

From graphical illustration voltage leads current here by 90^0

1.1.5 Calculate V

Given a sinusoidal value for current I

$$I = I_m Sin2\pi ft \quad (14)$$

By differentiating with respect to t

$$V = \frac{LdI}{dL} \quad (15)$$

$$V = L\frac{dI}{dL}(I_m Sin2\pi ft) \quad (16)$$

$$V = 2\pi ft I_m Cos2\pi ft \quad (17)$$

$$.V_m = 2\pi fLI_m \quad (18)$$

$$.X_l = \frac{V_m}{I_m} = 2\pi fL \quad (19)$$

Where X_l is called reactance of an inductor, which is the opposition offered to the flow of current by an inductor.

1.1.6 AC through an RLC circuit in series

For the purpose of this work, we will dwell on analysis or framework on resistor, Inductor and capacitor connected in series to and AC supply

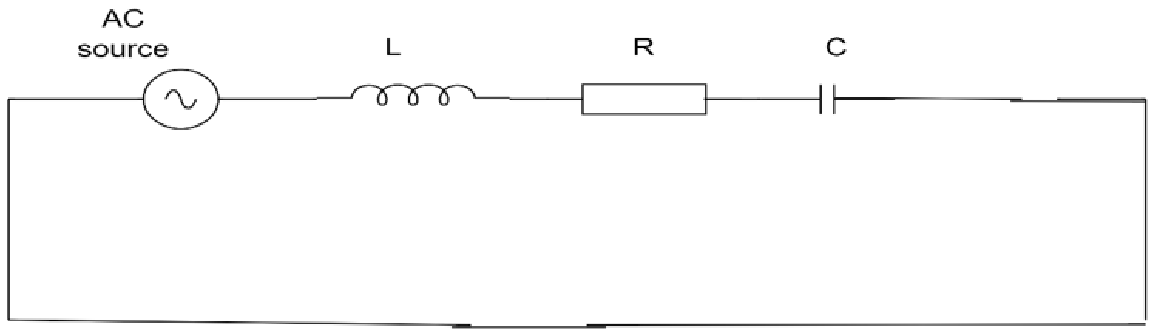


FIG 3: *RLC Circuit In Series*

This current is most time called the resonance circuit, bearing in mind that the various component in this circuit have current and voltage related differently as regard phase relationship, for R both current and voltage are in phase, for inductors, voltage lead current by 90^o and for capacitor, current lead voltage by 90^o. see figure 4

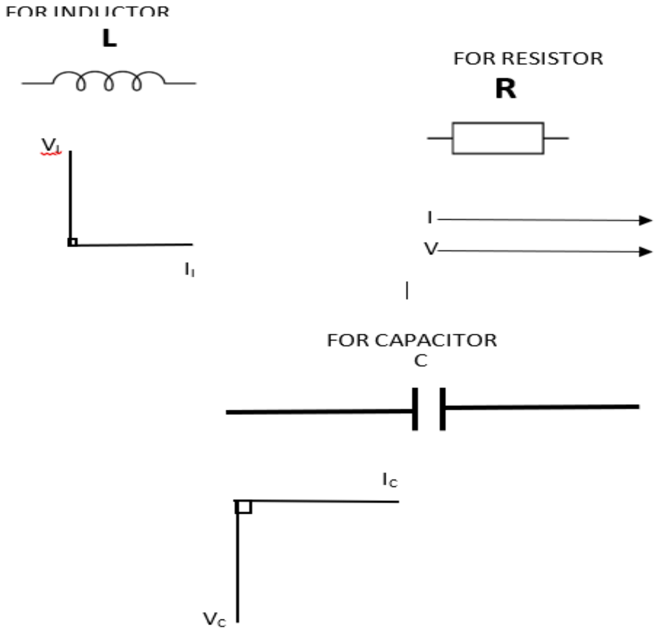


FIG 4: *Components and their Phasor Diagrams*

Since circuit components are in series

$$I_c = I_r = I_l = I \quad (20)$$

For an RLC series circuit therefore see figure 5

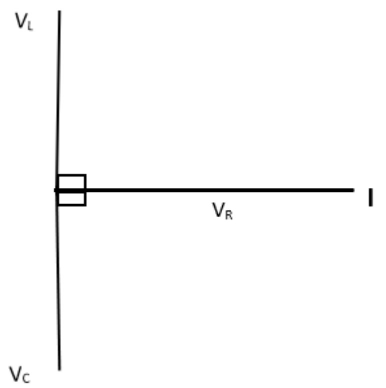


FIG 5. *Voltages and current relationship for RLC in series*

1.1.7 The Relationship of Component with Frequency

From equ 10, X_c is inversely proportional to the frequency

$$X_c \propto \frac{1}{f} \quad (21)$$

That is graphically

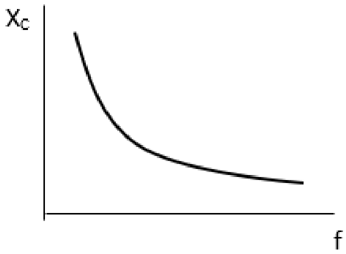


FIG 6: *Graphical illustration of realationsip between x_c and f*

And from equation 17

$$X_l \propto f \quad (22)$$

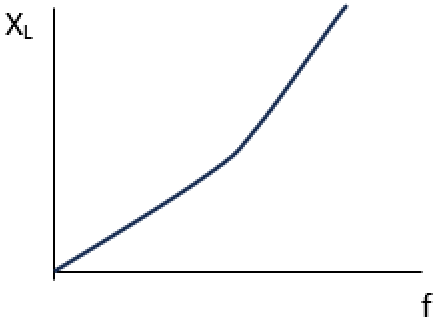


FIG 7: *Graphical illustration of realationsip between x_L and f*

R does not change with frequency

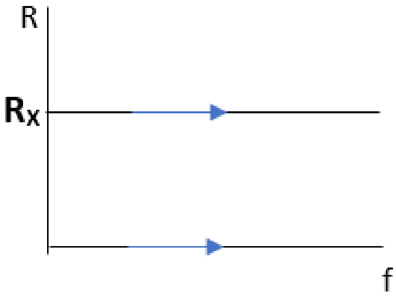


FIG 8: *Graphical illustration of realationsip between R and f*

When all components are connected in series (Resonance Circuit)

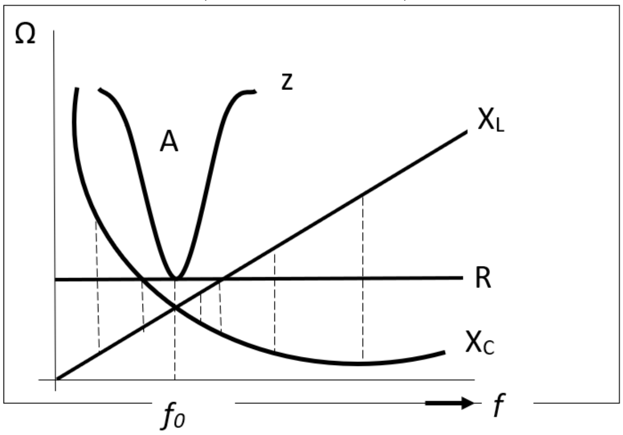


Fig 9: *Graph of inductive reactance capacitance reactance, Resistance and impendence vs frequency.*

.f_0 is called the resonance frequency,
Resonance occurs when (conditions for resonance)

i. $X_l = X_c$ (23)

ii. $Z = R$ (24)

iii. I is at maximum (see figure 10)

iv. Z is at minimum (see figure 9)

Thus,

$$X_l = X_c \quad (25)$$

$$`2\pi f_0 L = \frac{1}{2\pi f_0 c} \quad (26)$$

$$`f_0 = \frac{1}{2\pi\sqrt{Lc}} \quad (27)$$

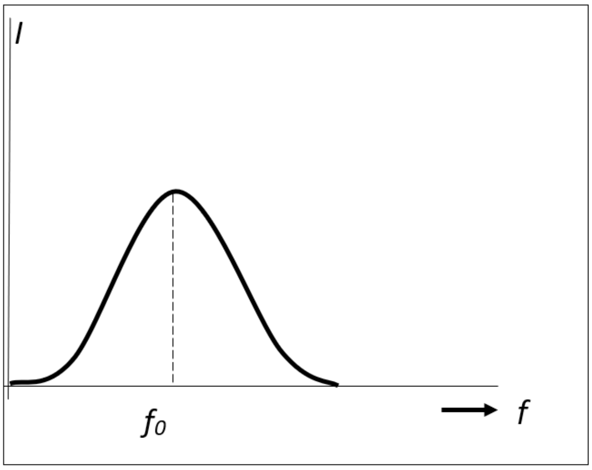


Fig 10. *Graph of current flow in the system against frequency.*

2. LITERATURE REVIEW

Brightness regulation in lighting system has undergone various studies [1] where the importance of energy efficiency of lighting was at the fore front. Dimming control system for light emitting diode (LED) bulbs, for a beautiful environment and comfort [2] emphasized the need for adjustable brightness levels. Nilson's work focuses on energy efficiency lighting solutions including dimming control systems, highlighting the environmental and economic benefits. This work contributes to dimming control system, energy efficiency LED lighting and system design through theoretical analysis, simulation, and practical examples.

In his work, The lighting hand book [3] the fundamentals of lighting was comprehensively dealt with showing the overview of lighting, which include brightness regulation, principle of light, lighting system and application with focus on practical design and implementation.

Steffy work has significant implication for design and implementation of light systems as can be seen in energy efficient lighting, visual comfort and so on.

Susan M. Winchip in her work on visual comfort and lighting explore the relationship between lighting and how it affects their psychic in the design of a lighting system. Factors like eye strain and overall wellbeing of the human was considered. Other key factors dealt with include brightness, contrast, glare, and colour temperature [6], human factor like human psychology, including eye strain, headache, mood. With practical guidelines for designing the suitable lighting system.

Other very important contributors in the design of a light brightness control system like [7] who worked on brightness control using pulse width modulation (PWM). He presented a Comprehensive study of a brightness control of LED light using PWM's principle and all it's benefits. His work covers area like PWM fundamentals, LED lighting brightness control and experimental results using MATLAB simulation techniques. Findings of Kim's work highlighted the advantage of PWM, brightness control, dimming curve and efficiency improvement.

Patel in his work, design and development of a brightness regulator for LED lighting systems [8]. This design presents a combination of analog and digital circuit to achieve smooth and efficient brightness control. This hybrid system integrates a micro controller with analog components. A PWM dimming device to achieve smooth brightness transition, with high accuracy.

[9] ad a novel approach to this work using proportional- integral derivative (PID) control, for adjusting brightness levels based on ambient light and user preference developing PID control algorithm for ambient light sensoring, using sensors to detect changes in environmental lighting conditions. Users' preference, capabilities and system stability and robustness was achieved with stability analysis of the overall system.

Wang designed a smart lighting system with brightness regulator, that is smart, it can regulate brightness based on various factors such as ambient light, time of the day and user preference. The system uses a combination of sensors, micro – controllers and LED drives to achieve smooth and efficient brightness control. In the process he developed a smart lighting algorithm which was a novel with high energy efficiency and user-friendly interface which adjust brightness levels scheduling and monitoring energy usage, it also has high accuracy in brightness, with minimal deviation from desired levels [10].

[11] used fuzzy logic control for his development of light brightness level controller with LEDs. The brightness level was based on the environment light and user preference. He developed a fuzzy logic algorithm, that works with ambient light sensoring capability. Incorporated into the fuzzy logic is the ability of users inputting their preferences. It very specials feature is the smooth brightness transition devoid of flicker and discomfort.

3. METHODOLOGY

For the circuitry the following materials were used

L inductor (Constant) = $10\mu H$

C capacitor (Constant) = $10\eta F$

R resistor = 1KΩ (for current limiting)

V variable frequency source

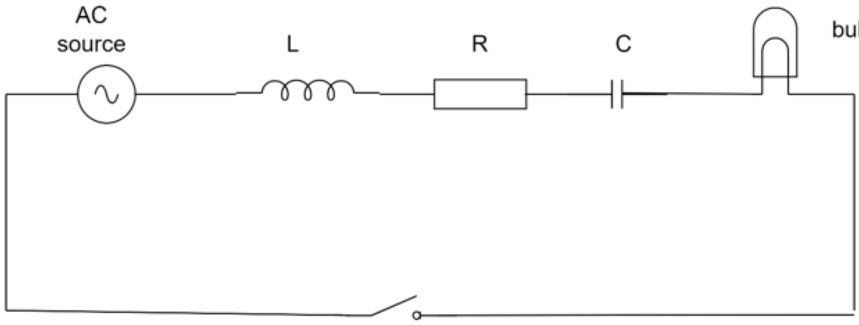


FIG. 11. *Circuit Design of The Luminator*

The frequency is varied using the varying frequency source (V) (oscilloscopes) to change the impendence of the LC circuit and the observation is that the brightness of the bulb varies from very bright to very dim and their increasing in brightness again. An ammeter probe and voltage probe was use to measure the current and voltage as the frequency varies and at various times and calculation of impedance z calculated using ohms law

$$Z = \frac{V}{I} \quad (28)$$

Record of frequency against impendence and current at various times was collected

4. RESULTS

Table 1: Results from experiment

Frequency (Hz)	Xl (Ω)	Xc	R(Ω)	Net Reactance (Ω)	Z (Ω)	I (A)
260	16.33	-10.45	1000	26.78	1002.253	0.2194411
220	13.79	-12.17	1000	25.96	1002.213	0.2194449
180	11.31	-8.77	1000	20.08	1002.013	0.2194495
160	10.05	-9.95	1000	20	1002.001	0.2194499
159.15	10.04	10.04	1000	10.04	1000	0.2200000
140	8.79	-11.36	1000	20.15	1002.026	0.2194443
120	7.54	-13.26	1000	20.8	1002.165	0.2194399
90	5.65	-17.68	1000	23.33	1005.445	0.2189519
20	1.26	-39.48	1000	40.74	1004.923	0.2194491
50	3.14	-25.13	1000	28.27	1002.531	0.2194439
70	4.39	-18.03	1000	22.42	1002.514	0.2194441
Resonance	0	-1000		1000	1000	0.2200000

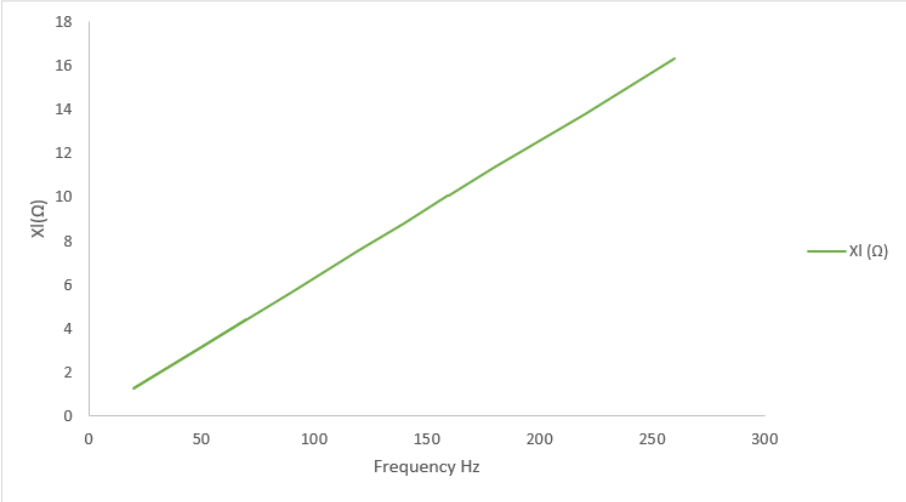


Fig 12. *Graph of X_L against frequency*

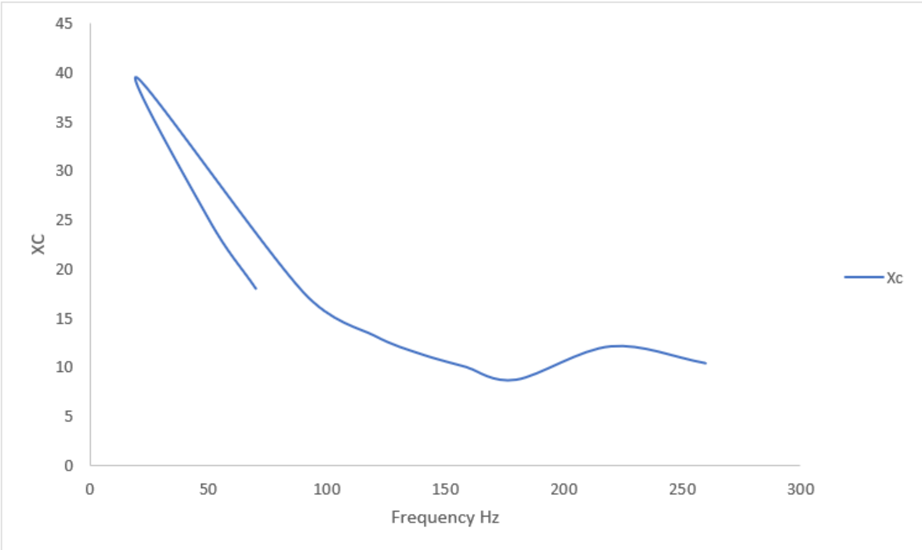


Fig 13. *Graph of X_c against frequency*

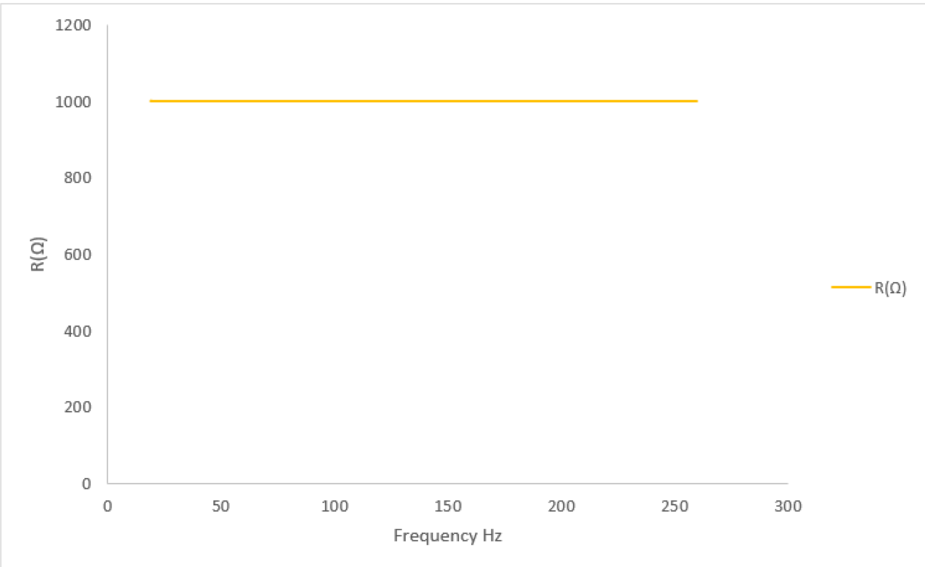


Fig 14. *Graph of R against frequency*

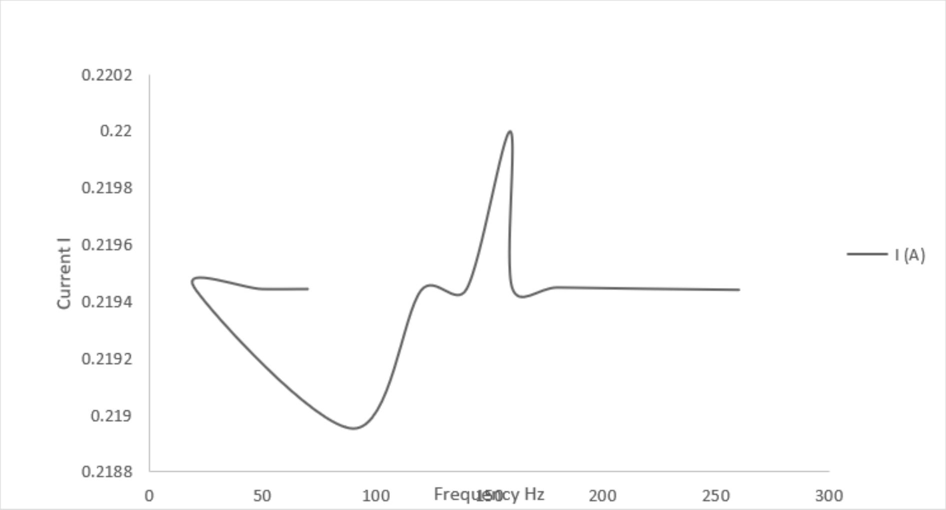


Fig 15. *Graph of curent against frequency*

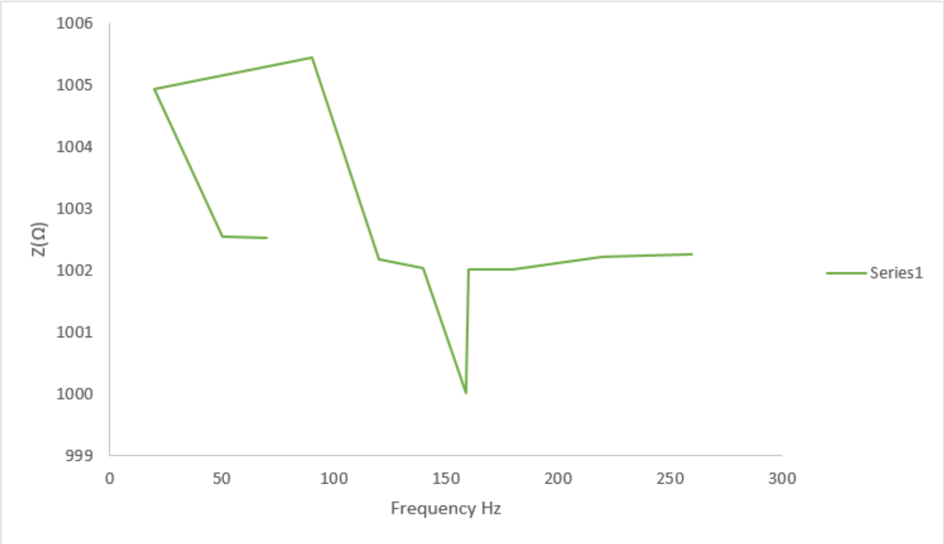


Fig 16. *Graph of impedance against frequency*

5. DISCUSSION

When the frequency is varied in the circuit as illustrated in fig 11 using the AC source (an oscilloscopes), the impedance Z of the circuit decreases as can be seen in fig 16, to a minimum value at a frequency of 159.15 (resonant frequency) and start increasing again thereafter.
It is this same frequency X_L and X_c are equal ($X_{L} = X_c$) in table 1 and Also Z = R as shown in table 1.
Since the current flowing in the circuit increases and the impedance decreases, and the lamp experiences an increase in brightness, at 159.15H_z. it was brightest indicating maximum current as shown in Fig 15. And dimmed down afterwards, thus the brightness of lamp was maximum at resonance. This experiment agrees totally with the theoretical framework previously analyzed and graphically illustrated from fig 9 and fig 10. It also confirms that at resonance Z = R (it is pure resistive)

6. CONCLUSION

The work on the designing of a laminator was conceived primarily to explore the use of RLC serial circuit in practical terms and to increase the literature that are abound in these areas, through more innovative work like smart systems in this area. Understanding the basic principles behind those sophisticated systems is key for students and scientists alike.
The laminator as given here, explore simple component to achieve a manual system and serve as a good learning tool for schools. As a stepping stone, more of such system design should be encouraged, as it validates the theories we teach in class; such as this one has validated the principles behind the characteristics of RLC circuit in series.

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