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Simulation of RLC series Circuit

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Abstract- This study explores the behaviour of an RLC series circuit when subjected to sinusoidal and pulse signals. The circuit consists of a resistor (R), inductor (L), and capacitor (C) connected in series, enabling the analysis of resonant frequency and impedance. By adjusting the frequency of the input signal, we observe how the output voltage across the load, represented by an LED, changes. Key factors influencing the output include the phase shift between voltage and current, as well as the amplitude of the voltage, which depends on the frequency relative to the circuit's resonant frequency. Additionally, the output waveform is analyzed by varying the duty cycle in the pulse signal. The results demonstrate resonance, where the voltage across the LED peaks at the resonant frequency, affecting its brightness. This experiment provides a deeper understanding of RLC circuit dynamics in response to AC signals and highlights their practical applications in electronics.

Keywords: **RLC Series Circuit, AC Analysis, LED Response, Pulse Signal, LED Brightness Control, Flickering.**

INTRODUCTION

The RLC series circuit is an electrical circuit that includes a resistor (R), an inductor (L), and a capacitor (C) connected in single loop. These components interact to create a circuit in different forms. When an alternating AC is applied, the resistor dissipates energy, the inductor stores energy in magnetic field, and the capacitor stores energy in an electric field. The circuit exhibits resonance at a specific frequency, where inductive and capacitive reactance cancel each other out, leading to a maximum current. RLC circuits are commonly used in filters, oscillators etc. AC analysis in an RLC series circuit involves studying how the circuit responds to an alternating current (AC) source at different frequencies. This analysis revels the circuit's impedance, phase shifts, and resonance frequency, where maximum current occurs due to the balance between inductive and capacitive reactance.

LED Brightness Control

LED brightness control in an RLC series circuit can be achieved by adjusting the circuit's impedance or frequency. By varying the AC frequency or adjusting resistance, inductance, or capacitance values, the current flowing through the LED changes, which in turn controls its brightness. At resonance, maximum current flows, making the LED brightest, while off-resonance conditions reduce brightness due to lower current.

LED Response

In an RLC series circuit with an LED, the response depends on the values of resistance (R), inductance (L), and capacitance (C), as well as the characteristics of the LED. When an AC signal is applied, the LED will light up when the voltage across it exceeds its forward voltage threshold. The RLC components influence the circuit's total impedance and phase shift, affecting how the current flows through the circuit.

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Resistor (R): limits the current, protecting the LED.

Inductor (L): opposes changes in current, causing phase delay.

Capacitor (C): stores and releases energy, also affecting phase.

At resonance, where the inductive and capacitive reactance balance, the current is maximized, possibly making the LED brighter. Off-resonance, the LED's brightness and response change with the circuit's impedance.

LITERATURE REVIEW

This [1] explores RLC circuits—comprising resistors, inductors, and capacitors—covering their types, theoretical connections (series and parallel), and practical applications in electronic devices like radios. It includes equations to demonstrate relationships among circuit elements and discusses how different configurations enable wave reception and filtering. The article concludes by summarizing its key insights. [2] In a series RLC circuit, resonance occurs when the inductive reactance (XL) and capacitive reactance (XC) are equal in magnitude but opposite in phase. At this resonant frequency, these reactance cancel each other, leaving only the resistance (R), resulting in minimum impedance and maximum current flow. Thus, the resonant frequency is the point where XL and XC balance, maximizing current through the circuit. [3] This article introduces a smartphone-based method for analyzing RLC series circuits, using one smartphone as a signal generator and the other as an oscilloscope. The setup accurately measures voltage and resonance frequency, aligning well with theoretical predictions. This portable, affordable alternative addresses gaps in educational resources for circuit studies [4]. This paper highlights the importance of monitoring RLC series circuits, particularly regarding over-voltage conditions, which can be either beneficial or detrimental. It provides a practical application for students to observe over-voltage phenomena, enhancing their understanding of phasor representation and phase differences in sinusoidal steady-state conditions for varying inductance, capacitance, and frequency values [5]. This study explores the resonance and damping characteristics of series RLC circuits, focusing on their use in physics education. Experimental setups were developed to observe real-time responses of the circuit under various damping conditions, allowing students to visualize the impact of resistance, inductance, and capacitance on resonance behavior. Results emphasize the importance of RLC circuit analysis in understanding oscillatory systems and developing practical skills [6]. This paper presents an innovative approach using smartphones to study the response of series RLC circuits, where one smartphone acts as a signal generator and another as an oscilloscope. This low-cost, accessible setup allowed for accurate measurement of resonance frequency and voltage response, with results aligning closely with theoretical values. The research validates the use of smartphones as portable, effective alternatives to conventional lab equipment in circuit analysis [7]. Focusing on the quality factor of series RLC circuits, this study examines conditions that lead to over-voltage at component terminals, which may be desirable or accidental. The findings indicate that specific circuit configurations can cause amplified voltage across capacitors or inductors, presenting both practical applications and risks. This research contributes to a deeper understanding of RLC circuit behavior under high-resonance conditions. This article delves into the frequency response of series RLC circuits, examining how impedance changes with frequency [8]. The study provides insights into resonance conditions, where inductive and capacitive reactance's balance out, leaving only resistance. The experiment outcomes highlight key points of

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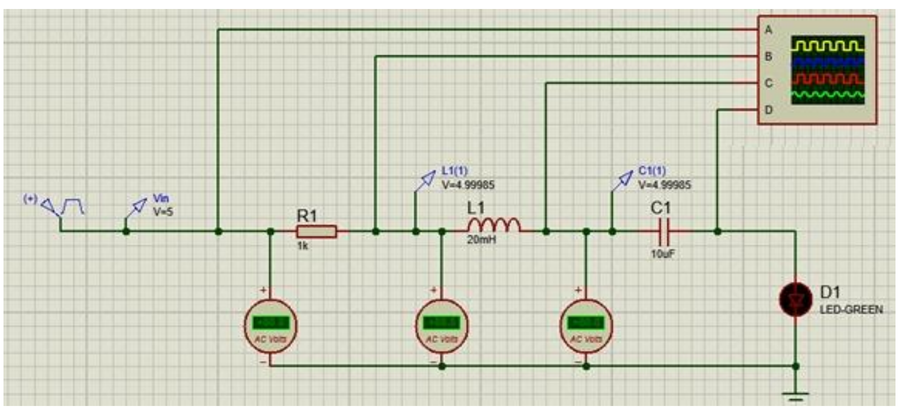
resonance, maximum current flow, and implications for circuit design and applications in filter circuits [9]. This research compares series and parallel RLC circuits in their applications for wireless signal processing. It investigates the differences in impedance matching and energy transfer efficiency at resonance, demonstrating that series RLC circuits provide more efficient energy transfer at lower impedance levels. This work aids in understanding optimal configurations for signal transmission and filter design in wireless systems [10]. The paper discusses the effectiveness of phasor diagrams in teaching students about sinusoidal steady-state analysis of series RLC circuits. By analyzing voltage and current phase differences for varying frequencies and component values, students gained a deeper comprehension of resonance and power factor. This approach reinforces fundamental concepts of AC circuit theory and is recommended for enhanced learning in electronics courses.

METHODLOGY

The RLC series circuit designed for this experiment consists of the following components connected in series: Resistor (R1) = 1 kΩ, Inductor (L1**)** = 20 mH**,** Capacitor (C1**)** = 10 µF**,** Green LED (D1) with a forward voltage of 2.2V and a maximum drive current of 10mA.The circuit is powered by a pulsed voltage source, with the LED's brightness observed to determine whether it glows, dims, or remains off based on the pulse width and other operating conditions.

Fig.1 This figure shows the input circuit of series RLC.



Simulation Setup:

The simulation is conducted using the Proteus software, and the following configurations are employed. Pulse Signal Source: Pulse Width=3.4 ms, Frequency: 50 Hz, Initial Voltage**:** 0 V, Pulsed Voltage**:** 5 V.

Initial Conditions:

All circuit elements have an initial voltage set to 0 V. The LED’s forward voltage is configured to 2.2 V, at which point it is expected to begin glowing if the circuit achieves sufficient voltage across it. This threshold serves as the primary reference for determining LED behavior.

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Procedure:

The RLC series circuit is designed in the Proteus environment, with each component (R1, L1, C1, and LED D1) connected in series. The pulse generator is configured with the specified pulse width of 3.4 ms units and frequency of 50 Hz, delivering a pulsed voltage of 5V to the circuit.

Running the Simulation:

The simulation is initiated, and the pulse signal is applied to the circuit. Voltage and current at key points within the circuit are observed to assess the circuit's response to the pulsed input.

Observing Output via LED:

The primary indicator of circuit behavior is the LED, where its brightness reflects the circuit's response to the applied pulse signal. Changes in pulse width are applied, and the LED's response—whether it turns on, dims, or remains off—is recorded as an indicator of the circuit's output under varying conditions.

CRO Observations:

In instances where the LED is removed from the circuit, waveform patterns are observed through a Cathode Ray Oscilloscope (CRO) to analyze the circuit's response independently of LED behavior. However, since the focus of the experiment is on the LED's reaction, output is typically observed directly through the LED's behavior as the primary indicator.

Fig.2 This figure shows the pulse waveform with the LED

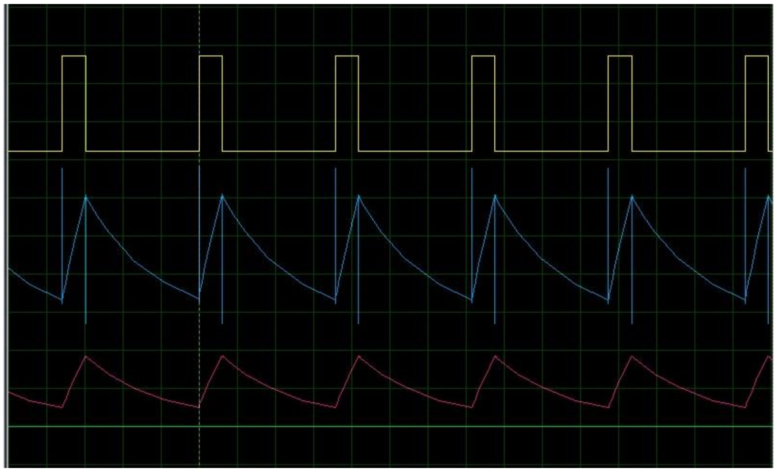

Fig 2. Output without a LED

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LED brightness is observed to vary with changes in pulse width. The LED turns on, dims, or remains off depending on the pulse signal conditions, providing insight into the circuit's response. When the LED is removed, the circuit's waveform response is observed using the CRO. However, the LED response is the primary metric, offering a straightforward interpretation of the circuit output. The LED's behavior under various pulse conditions is compared against theoretical expectations to validate the results. The LED's forward voltage threshold of 2.2 V serves as a critical reference for determining if and when the LED should illuminate. Several potential sources of error may introduce minor discrepancies in a physical circuit. Variations in pulse width significantly impact LED brightness, and real-world disturbances or environmental factors could affect the results if conducted outside the simulation environment.

RESULTS AND DISCUSSION

The simulation of the RLC series circuit was conducted by varying the pulse width of the input signal, with the frequency held constant at 50 Hz. The following observations were made regarding the LED's behaviour. No Glow at Lower Pulse Widths**:** At pulse width 200 µs and pulse width 2ms, the LED did not glow at all. This indicates that the energy delivered to the circuit was insufficient to reach the LED's forward voltage threshold (2.2V).

Flickering at Pulse Width 3.4 ms**:** At pulse width 3.4 ms, the LED started flickering. This suggests that the voltage across the LED reached its forward voltage intermittently, causing it to turn on and off rapidly. Dim Light at Pulse Width 5msec**:** At pulse width 5msec, the LED blinked so fast that a dim light was observed. The LED was turning on for slightly longer durations, but the overall energy delivered was still not enough to achieve full brightness. Increased Brightness at Pulse Widths 6ms and 8ms**.** At pulse widths 6ms and 8ms, the LED exhibited slightly higher brightness compared to the previous settings. However, the brightness increase was marginal, and the LED remained dim overall.

Gradual Brightening at Pulse Widths 10 ms, 12 ms, and 18 ms**:** At pulse width 10ms, the LED glowed slightly brighter than at width 8ms, and the brightness continued to increase gradually as the pulse width was set to 12 ms and 18 ms. The longer pulse widths allowed more current to flow through the LED for extended periods, contributing to the brighter glow. Flickering of Bright Light at Pulse Width 20 ms and Beyond**:** At pulse width 20 ms, the LED exhibited a flickering pattern with bright light. This flickering behaviour continued as the pulse width was increased further, up to 200 ms. The LED appeared to flash on and off with a bright glow during each pulse cycle.

The output waveform of the pulse signal was observed using the CRO when the LED was removed from the circuit. The waveform maintained a square pulse shape with a frequency of 50 Hz and varying pulse widths as configured. At lower pulse widths, the waveform showed narrower high periods and longer low periods, consistent with the LED not receiving enough voltage to turn on. As the pulse width increased, the high periods of the waveform became longer, allowing the LED to receive more energy and glow more brightly.

The LED's behaviour is highly dependent on the pulse width of the input signal. At low pulse widths (200 µs, 2 ms), the LED does not receive sufficient voltage to reach its forward voltage, resulting in no glow. As the pulse width increases, the LED begins to flicker (at pulse width 3.4 µs) and then gradually glows brighter as the width is increased to 5 ms, 6 ms, 8 ms, and beyond. The relationship between pulse width

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and LED brightness demonstrates the concept of Pulse Width (PW), where the average power delivered to the LED is controlled by varying the pulse width. Longer pulse widths deliver more energy, resulting in a brighter glow.

Table 1: pulse width vs LED behavior

Pulse width	LED behavior
200 µs	No Glow
2 ms	No Glow
3.4 ms	Flickering Begins
5 ms	Rapid blinking with dim light
6 ms	Slightly brighter than 5ms
8 ms	Similar at pulse width 6ms
10 ms	Slightly brighter than at 8ms
12 ms	Brighter than at 10ms
18 ms	Bright light observed
20 ms-200 ms	Flickering with bright light continuous.

The flickering observed at pulse widths of 3.4 ms, 20 ms, and beyond suggests that the LED is turning on and off at a frequency that is visible to the human eye, particularly when the pulse width is near the LED's forward voltage threshold. At pulse widths of 20ms and beyond, the LED flickers with a bright light, indicating that it receives sufficient voltage to turn on during each cycle, but the rapid on-off nature of the pulse creates a flickering effect. The inductor and capacitor in the series RLC circuit influenced the overall voltage and current distribution. However, due to the nature of the pulse input, the resonant behaviour of the RLC circuit did not significantly affect the LED’s operation within the pulse width range used. The primary factor governing the LED’s behaviour was the pulse width of the input signal.

Conclusion:

The simulation demonstrated that the LED's brightness in an RLC series circuit is highly dependent on the pulse width of the input signal. At very low pulse widths, the LED does not turn on. As the pulse width increases, the LED starts to flicker (at width 3.4 ms) and gradually becomes brighter at higher pulse widths (6 ms, 10 ms, 12 ms, 18 ms). At pulse width 20ms and beyond, the LED exhibits bright flickering. These findings highlight the importance of pulse width control in determining the behaviour of LEDs in pulsed circuits, particularly in applications involving Pulse Width Modulation (PWM).

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