# Innovative Approach for the Study of Tuning Circuit with Open Source Tools

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## Abstract

In the new age of an online teaching-learning process, present instructional approach expects students to be an active learner, which necessitates a new instructional tool that can provide opportunity for active learning. The use of technology in teaching-learning has become a key factor which helps in conceptual understanding. Simulation being one of the valuable instructional tools renders an opportunity to visualize the concepts and facilitate to build the mental model. The present work proposes a study of electrical circuit experiments performed using open source tools such as XCOS and expEYES. These tools facilitate in developing higher order critical thinking and analysis skill. XCOS being one of the tool in Scilab provides the visual simulation environment for varying the input parameters of the model. The RL, RC and RLC tuning circuits are virtually modeled by using the XCOS and the real circuits made with expEYES, which facilitates the study of response curves with ease. In the later case, the results obtained by using expEYES compared with the results of XCOS. In addition, study explains how such response of simple linear circuits can be extended in different applications. Demonstrations and visualization of the response curve and phase flow of linear circuits will overlay the way to understand experimental and numerical results. This innovative approach can be used in the classroom demonstration of a harmonic oscillator and resonant circuits in advance level physics and engineering laboratories.

## Introduction

Physics learning in particular is far perceived to be complex. Teaching does not appear to have the expected effect, with students possessing only a vague memory of unconnected ideas and a hazy mental picture of equations, symbols and graphs(1). As real learning that enables the learner to understand, predict and verify an idea which is glaringly absent. Hence student′s resort to the next possible option of the rote memorization of facts which has short term relevance, but will not provide any learning experience. Research has shown that traditional classroom lectures fail to make any tangible impact which only accomplishes simple transmission, hence often referred as a transmissionist model (2). This being the case, a new area of research that probes into the details of how a learner processes information has become the central focal point of the new area of Education Research (3).

The pedagogical adaptations range from escalating an active engagement of students in large lecture class to reconfiguring of the instructional environment (4). Reformed courses demonstrate improved conceptual understanding as students are actively engaged in constructing their own knowledge. Studies on the influence of transformed course approach describe how a pedagogical strategy promotes in the advancement of physics. This drives, students to be creative in implementing Physics concepts in real life applications (5). Whereas, traditional teaching methods, are less encouraged in the direction of developing thinking skills. In Physics, conceptual understanding is influenced by the set of principles and physical laws. In this direction, to train students in developing critical thinking skill is most important in science education. Critical thinking entails the skill to identify relationships, illustrate inferences, analyze and solve problems (6, 7).

The Physics course text books give a full theoretical description of the DC and AC circuits containing capacitors, inductors and resistors are connected in series. The aim of the paper is to examine the use of computational teaching approach in the study of tuning circuits like RC, RL and RLC using XCOS and expEYES (8). The understanding of tuning circuits requires the coherence of Physics with Mathematics (9, 10). Since, tuning circuits generate complex waveforms, which are the analytical tools for studying, simulating dynamical systems and differential equations (11, 12). The computational teaching approach uses XCOS of Scilab tool devoted to the modeling and simulation of dynamic systems (13, 14). XCOS consist of a graphical editor platform to represent models as block diagrams by linking the blocks (14). The practical demonstration is attempted and the successful connection of an RL, RC and RLC using DC voltage source described using XCOS and expEYES respectively (15).

## Methodology

**Modeling of circuits and physical experiments:**

The present work uses the computational approach in the domain of tuning circuits, such as RL, RC and RLC using XCOS and expEYES open source tools (7, 16). The study presents a design and implementation of a tuning circuit experiment using an expEYES device (17). This device has 4 channel oscilloscope with 1 Msps, provides an input voltage of +/- 5 V and +/- 3.3 V and gives 12 bit analog resolution. To discern electrical circuits (RL, RC and RLC) involves critical thinking (predicting, analyzing and reasoning) skills in teaching-learning Physics concepts with differential equations (18-20). The results of physical experiments conducted using expEYES open source hardware validated using the XCOS simulation.

XCOS performs numerical computation, data analysis, plotting, system modeling and simulation. The modeling created to study the tuning circuits for damped oscillations necessitates Kirchhoff's Voltage law. XCOS consists of 2 windows i.e., edit window and palette browser. A palette browser presents a set of predefined blocks and in edit window library blocks are assembled to construct a model. The blocks arranged and connected according to the flow of signal/data. Set the block parameters and simulation parameters to run the model. The model of a harmonic oscillator designed in edit window as block diagram helps in learning the underlying concept of harmonic oscillation in a tuning circuit. The model built on an edit window, starting with simple RL, RC and RLC circuit for an electrical oscillator. This helps learner to create their own mental model which enrich critical thinking skills such as analyzing and reasoning based on the graphical output (10, 20-22).

The essential requirements for modeling and Physical experiments using XCOS and expEYES are inductor, resistor, a capacitor, voltmeter, DC source and CSCOPE. As the students turn out to be an expertise with the experiments, analysis of data become easy. This comprises the setting of initial parameters, defining variables, examining data in a step-by-step procedure. This gives more time for the learner to analyze and the validation of extracted data. The study investigates the dynamics of a first and second-order linear electrical circuit for DC source. The experimental results of expEYES circuit with XCOS simulation by highlighting the significance of learning the tuning circuits are presented in this paper.

## Results and Discussion

**Study of RL Circuit:**

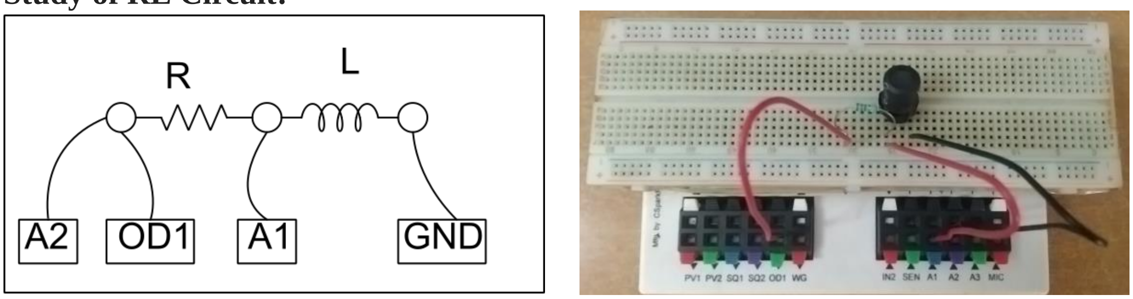


Figure 1: RL circuit using expEYES

In an RL circuit, resistor (R = 180 Ω) and an inductor (L = 0.1 mH) are connected in a series with the DC voltage (OD1) is set to 0 to 5V is as shown in figure 1. According to Kirchhoff's voltage law, the nature of voltage studied by measuring the voltage across an inductor with varying time. The coefficient of the exponential term R/L can be extracted from the graph of voltage across the inductor is called time constant (τ).

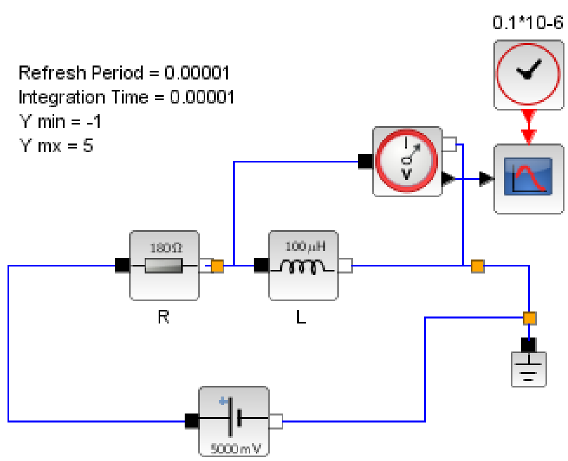


Figure 2. RL circuit using XCOS

In RL series circuit as shown in figure 2, the resistor(R= 180 Ω) and an inductor (L=0.1 mH) are connected to a voltage source. In XCOS, for modeling RL series circuit, we imported components such as inductor, resistor, voltmeter, DC voltage source, CSCOPE and ground from palette browser to edit window. Initial parameters are set before running the simulation is as follows, refresh period fixed to 10 µs, voltage is set to 5 V. Integration time is set according to refresh period time and clock time is set to 0.1 µs.

Inductor behaves as an open circuit at time t = 0 and current in the circuit is zero. When t > 0, current $I(t) = I_0\left(1-e^{-Rt/L}\right)$ increases exponentially and voltage $V(t) = V_0 e^{-Rt/L}$ across inductor decreases exponentially reached to the steady state is as shown in figure 3 and 4. The time constant(τ = 0.55 µs) is measured as L/R and final steady state voltage value attained after the five time-constant values. It is observed that the inductor presents a prominent role in the transient period, but in steady state, it behaves as a short circuit. Learner will be able to identify the following points. Higher the value of an inductor more is the transient period. Similarly, when supply voltage is reversed (-5 V), voltage across the inductor increases exponentially due to energy dissipation from an inductor.

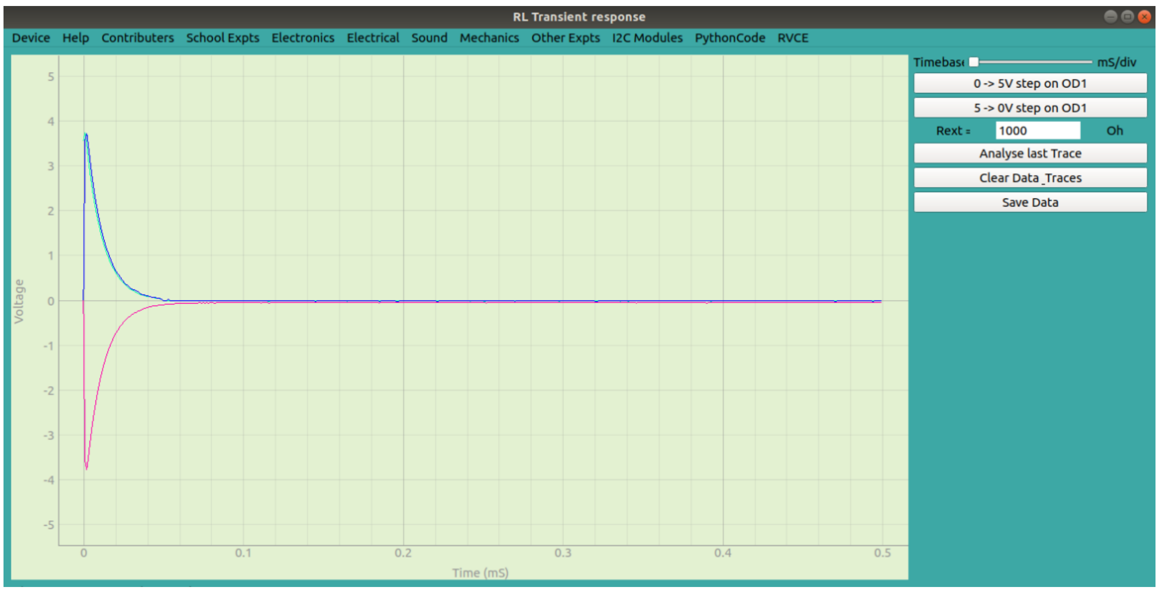

Figure 3. RL transient response of expEYES circuit

The experimental results of RL transient response obtained using expEYES is validated with XCOS simulation. The time constant found from voltage decay and growth curve is found similar to experimental value (τ = L/R = 0.55 µ s) is shown in figure 4.

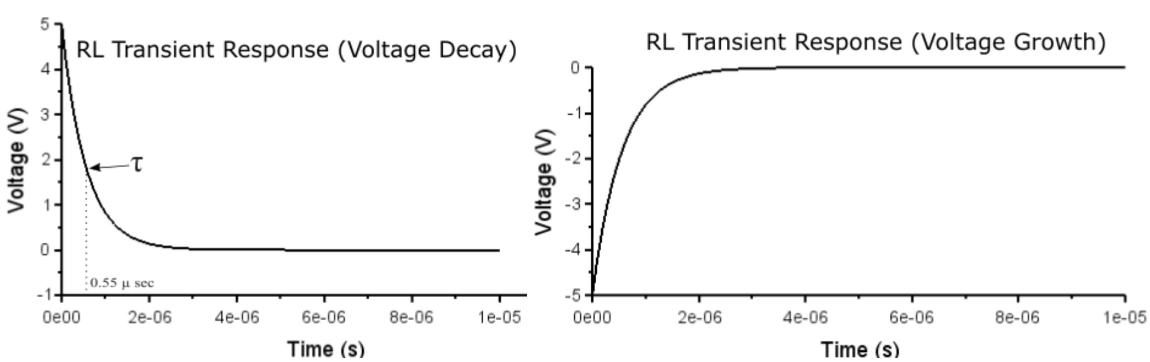

Figure 4. RL transient response of XCOS simulation

**Study of RC Circuit:**

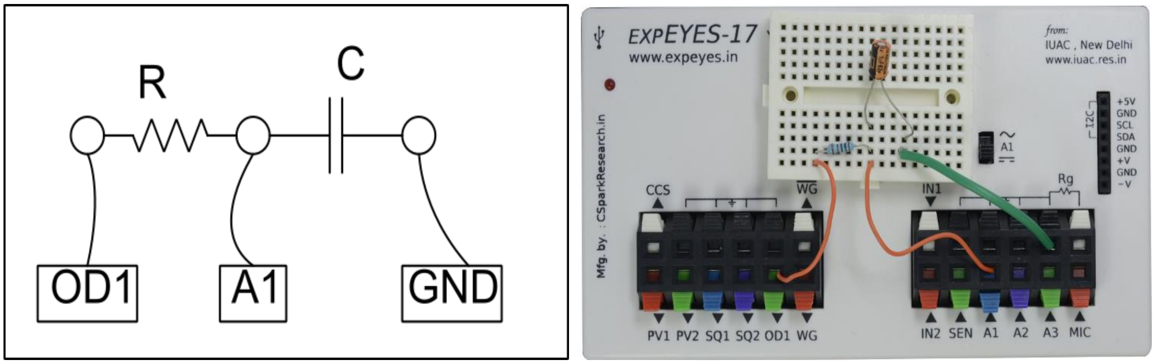


Figure 5. RC circuit using expEYES

Figure 5 shows, a capacitor (C= 1 μF), a resistor (R= 1 KΩ) are connected in a series with digital output 1 (OD1) forming RC charging circuit. The study focused on the transient response of a series RC circuit by applying voltage (5 V) and capturing the voltage variation across the capacitor at A1. At time t = 0 s, when the circuit is closed, the capacitor starts charging gradually through the resistor until the voltage across it is equal the supply voltage. Applying 0 to 5 V step makes the voltage across the capacitor to rise exponentially and 5 V to 0 steps makes the voltage across the capacitor decreases exponentially. We can extract the RC time constant and find the value of capacitance from it.

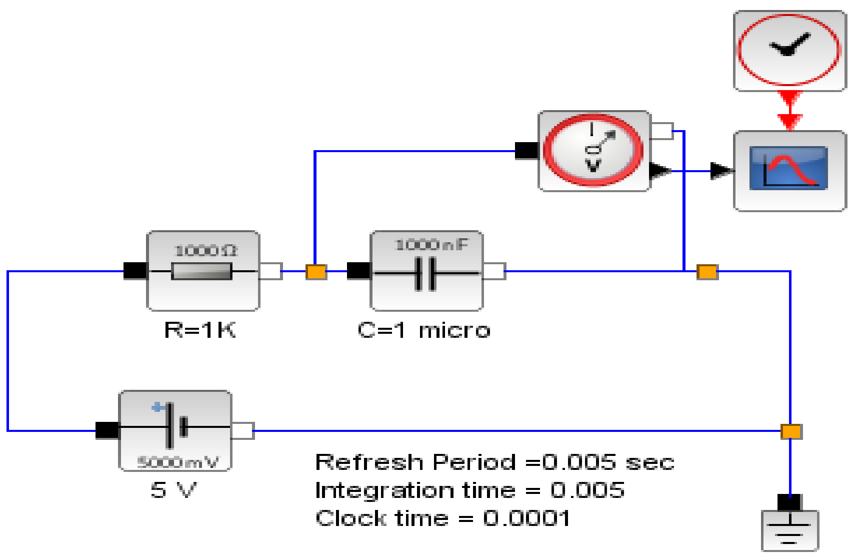


Figure 6. RC circuit using XCOS

The XCOS model is built to carry out time-domain solution of RC series circuit is shown in figure 6. For modeling the RC series circuit, we imported components such as a capacitor, resistor, voltmeter, DC voltage source, CSCOPE and ground from palette browser to the edit window. The resistor and capacitor are connected in series with the voltage source in the edit window. To study voltage – time graph, voltmeter across the capacitor connected to CSCOPE to get the output graph. The initial parameters are set as follows, R= 1 KΩ, C= 1 μF, refresh period fixed to 5 ms, source voltage is set to 5 V. The integration time is set to 5 ms according to refresh period time and the clock time is set to 0.1 ms before running the simulation.

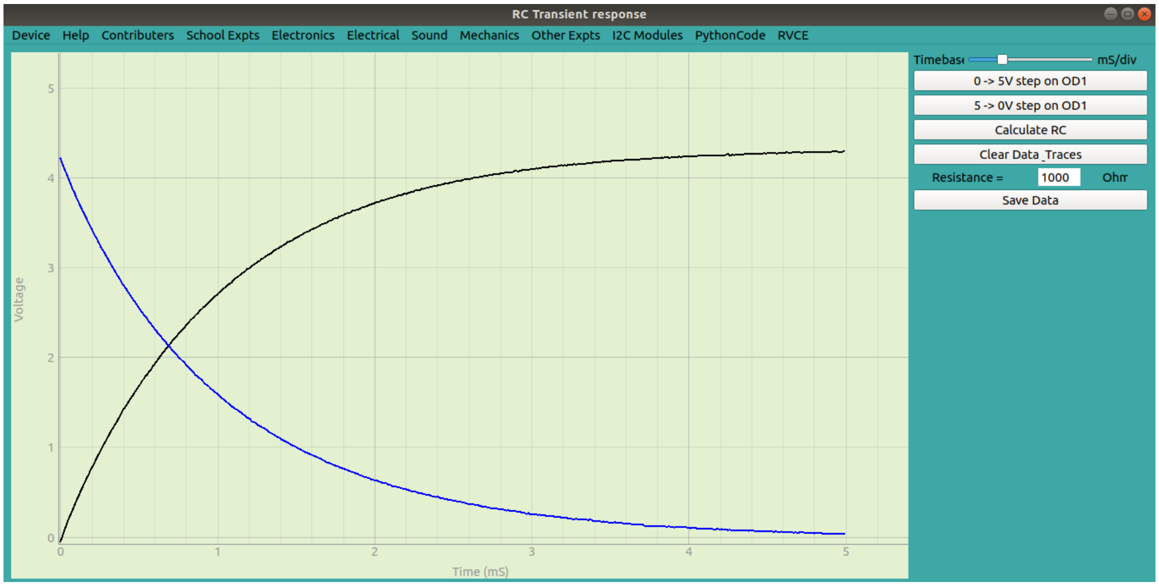

Figure 7. RC transient response of expEYES circuit

The capacitor charging and discharging graphs are shown in figure 7 and 8 respectively. The rise in voltage across the capacitor is steeper initially and the rate of charging is faster, but soon tapers off exponentially as the capacitor acquires an additional charge at a slower rate and attains a steady state. As the capacitor charges up, the potential difference across its plates begins to increase as $V(t) = Vo\left(1 - e^{-t/RC}\right)$. Where $V_0$ is the supply voltage, V is the voltage across the capacitor and t is the elapsed time. The time taken for the charge on the capacitor to reach 63% of its maximum voltage (4.2 V), being known as one time constant ($\tau = RC = 1$ ms).

From the charging graph, time period equivalent to 4τ (4 ms), the voltage developed across the capacitors plates has now reached to 98% of its maximum value. The time duration from 0 to 4 ms is known as the transient period. After a 5 ms, the voltage across the capacitor approximately equal to the supply voltage. Therefore, no more current flows in the circuit, so I = 0. This is known as the steady state period.

The experimental results of RC transient response obtained using expEYES are validated with XCOS simulation is shown in figure 8. The charging and discharging response curve obtained and time constant for the transient response is found similar to experimental value ($\tau = 1$ ms). This helps the learner to identify the importance of time constant in various applications like flash camera, vipers, artificial pacemaker etc.

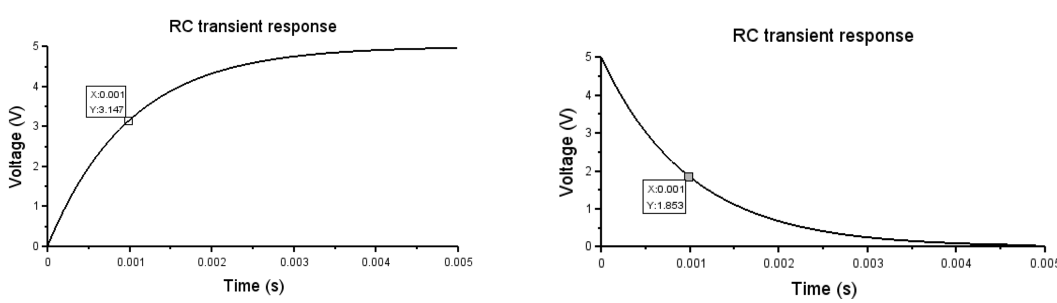

Figure 8. RC transient response of XCOS simulation

**Study of RLC circuit:**

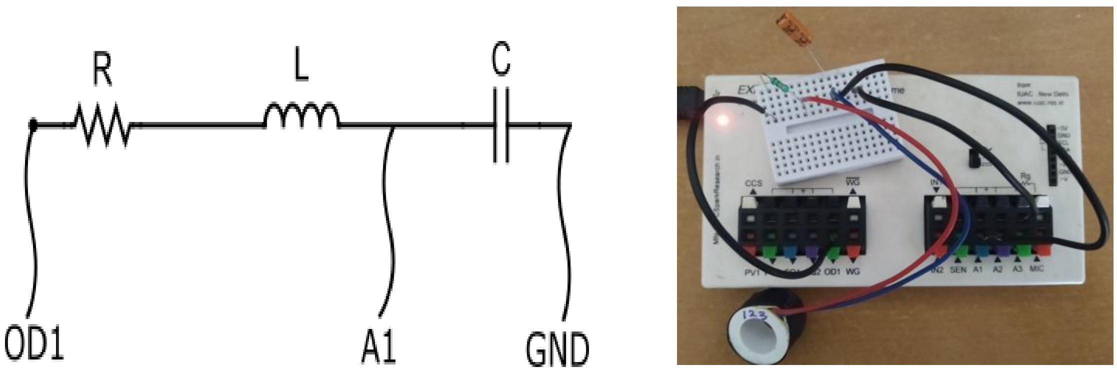


Figure 9. RLC circuit using expEYES

The RLC circuit is suitable for demonstrating and understanding of damped oscillations (12). This circuit is the electronic equivalent to a spring mass system with damping**.** Consider an electric circuit containing an inductor L, capacitor C and a resistor R in series a with voltage source (OD1) and A1 to measure the voltage across the capacitor as shown in the figure 9.

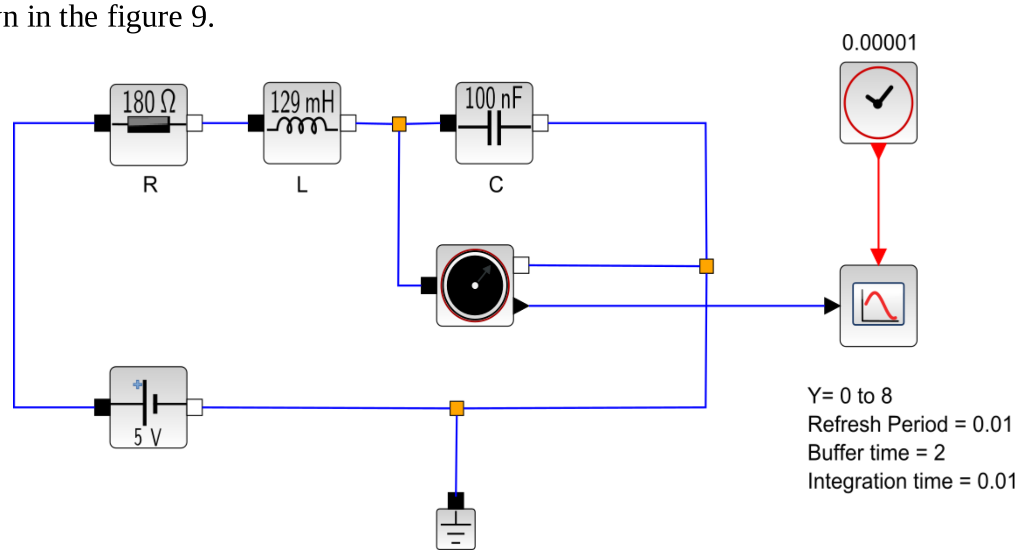


Figure 10. RLC circuit using XCOS

In this section, step-by-step illustration to construct the RLC model using XCOS is as shown in figure 10. For modeling the RLC series circuit, we imported components such as a capacitor, resistor, voltmeter, DC voltage source, CSCOPE and ground from palette browser to edit window. The components such as resistor, inductor and a capacitor are connected in series with the voltage source in the edit window. To study voltage – time graph, voltmeter across the capacitor connected to CSCOPE to get the output graph. The initial parameters are set as follows, R= 180 Ω, L= 0.129 H, C= 100 nF, refresh period fixed to 0.01 s, source voltage is set to 5 V. The integration time is set to 0.01 s according to refresh period time and the clock time is set to 10 µs before running the simulation.

The circuit can be modeled by using second order linear differential equation for the electrical damped harmonic oscillator:

$$\frac{d^2I}{dt^2}+\left(\frac{R}{L}\right)\frac{dI}{dt}+\left(\frac{1}{LC}\right)I=0$$

The characteristic equation using the quadratic formula is given below:

$$\alpha = \frac{-R \pm \sqrt{R^2 - 4L/C}}{2L}$$

By substituting the variables for b and $\omega$, $\alpha$ *can be written as*

$$\alpha = -b \pm \sqrt{b^2 - \omega^2}$$

$$Where\ b = \frac{R}{2L}\ \ and\ \ \omega^2 = \frac{1}{\sqrt{LC}}$$

The voltage across the capacitor is studied by varying R and keeping L and C as constant as per table 1. The natural frequency of a series RLC circuit is given by $\omega = \frac{1}{\sqrt{LC}}$ and damping factor $b = \frac{R}{2L}$ . Depending upon the value of b and ω the response could be under-damped, critically-damped or over-damped is as shown in figure 11 and 12.

**TABLE I: RLC transient variables (b and ω) for three different damping cases**

| Parameters (L=0.129 H, C=100 nF) | b ($s^{-1}$) | ω ($s^{-1}$) | $b^2$ | $\omega^2$ | Observation | Output waveform |
|---|---|---|---|---|---|---|
| R= 10 kΩ | 38759 | 8804 | 15 x $10^8$ | 77.5 x $10^6$ | $b^2 > \omega^2$ | Heavy damped |
| R= 2 kΩ | 7752 | 8804 | 60 x $10^6$ | 77.5 x $10^6$ | $b^2 \approx \omega^2$ | Critically damped |
| R= 180 Ω | 698 | 8804 | 49 x $10^4$ | 77.5 x $10^6$ | $b^2 < \omega^2$ | Under damped |

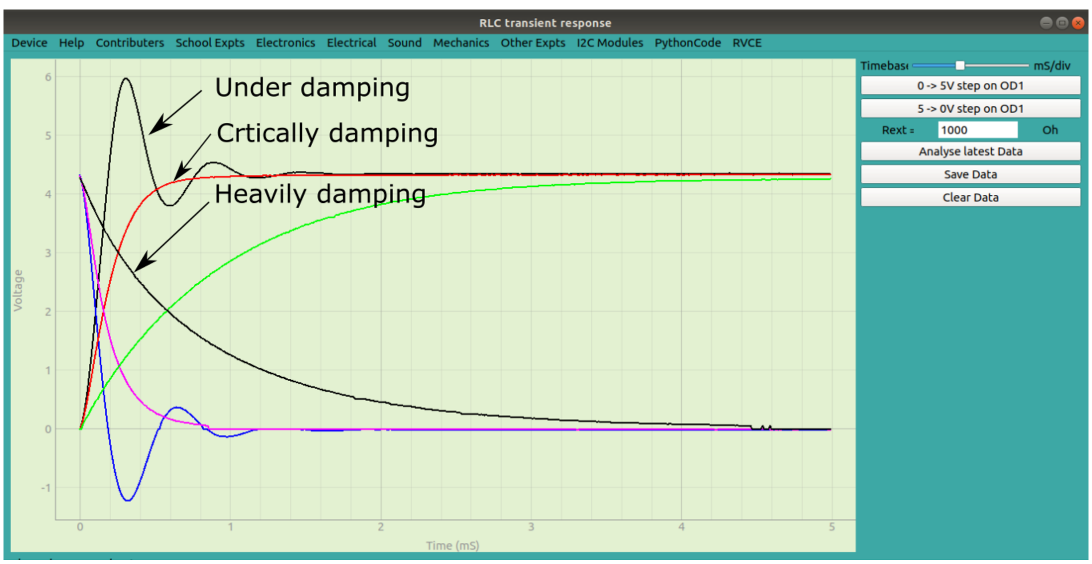


Figure 11. Transient charging and discharging response of the RLC circuit using expEYES

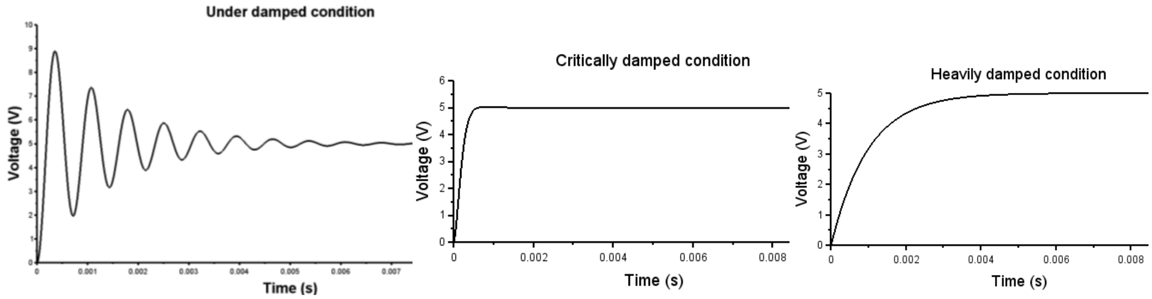


Figure 12. Transient charging response of the RLC circuit using XCOS simulation

The transient discharging response of the RLC circuit is constructed using XCOS by keeping the source voltage as zero and the voltage across the capacitor is set as 5 V. Y axis is set as -6 to 6 in CSCOPE. The charge on a capacitor is discharged through an inductor and a resistor is oscillatory or under damping for a small value of resistance (180 Ω). Critically damped and heavily damped condition is observed for the resistance of 2 KΩ and 10 KΩ respectively is as shown in figure 13. This is an essential condition required in design thinking of filter circuits, lock-In amplifiers etc. This inculcates the concept in the learner through critical thinking by analyzing the output waveforms of under-damped, critically damped and over-damped condition of damped harmonic oscillator.

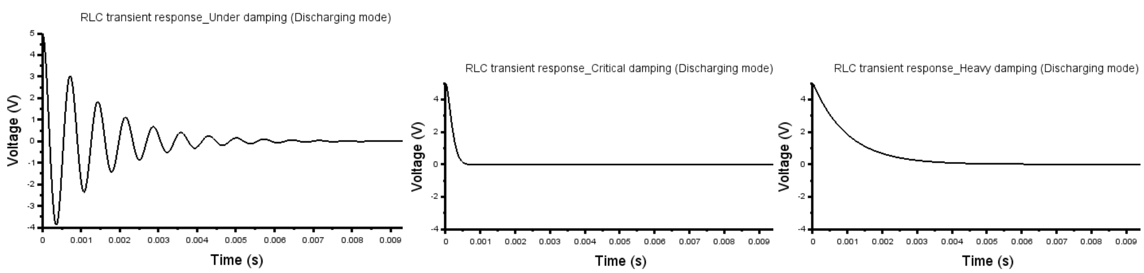


Figure 13. Transient discharging response of the RLC circuit using XCOS simulation

## Conclusion

The RL, RC and RLC circuits are the core concepts of any electrical system. Electrical circuit analyses were not easily accepted by students when they are taught in a traditional teaching method. A better understanding of these circuits will help to design electrical/electronic circuits. This paper is planned to explain the fundamentals of RL, RC and the RLC circuit, which provides practical demonstration using XCOS and expEYES shows excellent agreement for the same. The charging and discharging curve of RL and RC helps the learner to better understand the transient response and steady state nature. This innovative approach is complement to the traditional experimental method. With this new approach, students can quickly compare experimental data and develop their ability in designing circuits in minimum time. This critical thinking skill will help to assemble and analyze DC circuits for a different set of component values with ease. These interactive tools provides better understanding of the RLC circuit, which will help the learner to discern the nature of oscillatory motion, whether it is under damped, critically damped and heavily damped based on the real time results.

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