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experiment 6

LC & RLC Circuits

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PHYS143
Physics for Engineers

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Understanding Faraday’s Law

Michael Faraday developed the idea of electromagnetic induction, which explains how electricity is generated by the relative motion of a magnet and conductor. Through his tests, Faraday established that a coil of wire will conduct electricity when a magnet is moved in either direction. Numerous modern technological applications are based on this phenomenon, which is known as Faraday's law of electromagnetic induction.

Faraday's investigations yielded numerous crucial conclusions about the nature of induced currents. The deflection of a galvanometer needle showed an occurrence of an electrical current in the coil, with the direction and speed of deflection corresponding to the direction and rate of induced current. In addition, the magnitude and direction of induced current were affected by variables such coil turns, magnet polarity, and the speed at which the magnet was moved. The relationship between these factors can be given by the equation $\varepsilon = -\mathrm{N}\frac{d\Phi_B}{dt}$, where $\frac{d\Phi_B}{dt}$ is the change in magnetic flux and N denotes the number of loops of the wire.

Bicycle dynamos are a well-known example of electromagnetic induction. An electromotive force (EMF) or current is introduced into a coil as a bicycle turns, due to the dynamo's contact with the tire, which changes its magnetic field. This current is used to power the front and back lights, demonstrating the practical use of Faraday's discovery in daily gadgets.

In essence, Faraday's studies on electromagnetic induction transformed the concept of how electricity is generated and laid the foundations for several technical advances. From lighting bicycle lights to driving generators in power plants, Faraday's principles continue to impact our modern world.

Making a Motor

To construct a simple motor, collect a D battery, magnet wire, a small neodymium magnet, two giant metal paper clips, fine-grit sandpaper, tape, scissors, and a Sharpie. Begin by bending the paper clips to support the wire and taping them to the battery ends. Wrap the wire around the marker to make a coil, leaving about 3cm on each end, and fix the shape by looping the wire ends. Sand off the insulation from one wire end fully and halfway to the other. Insert the wire into the paper clip supports, ensuring it spins freely and modifying the shape as needed. To start the motor, place the magnet under the coil and push it to initiate motion.

The motor operates on the basis of electromagnetism. When current travels through a coil, it generates a magnetic field surrounding the wire. The permanent magnet interacts with the magnetic field, generating a force which drives the coil to rotate. The rotation keeps on going as long as current flows through the coil, resulting in constant movement. The direction of the magnetic field is perpendicular to the direction of the current flow and can be determined using the right-hand rule.

Adjusting the number of magnets or the coil size has a substantial impact on the motor's performance. Increasing the number of magnets or the coil size can improve the motor's torque and power output, potentially leading to faster and more efficient operation. Conversely, limiting the number of magnets or the size of the coil may reduce performance while increasing energy efficiency.

Current Generator

Michael Faraday established the idea of electromagnetic induction, which is used by electric generators to transform mechanical energy from a rotating turbine into electrical energy. Positioning a coil of wire in a magnetic field causes an electric current to flow through it. As it rotates, the wires pass through the magnetic field, producing electricity that can be utilized to power equipment.

The direction of the induced current depends on whether the wire is moving up or down in the magnetic field, as determined by Fleming's Right Hand Rule. As the coil rotates, the current reverses direction each time the coil reaches a perpendicular position to the magnetic field.

To transfer the generated electricity to an external circuit, slip rings are used. These metallic rings rotate with the coil but allow stationary brushes to maintain electric contact, preventing the wires from tangling. The current also reverses through the external circuit every half rotation as the direction of current in the coil switches.

This type of generator with alternating current (AC) has advantages for transmitting electricity over long distances. The current from the power station to households is AC. To generate direct current (DC) that flows in one direction, split ring commutators are used. These continually switch the brush contacts from one side of the coil to the other each half rotation, maintaining unidirectional current flow.

In summary, spinning a coil in a magnetic field induces an alternating electric current due to electromagnetic induction. Slip rings allow this AC current to be transferred to an external circuit. For DC current instead, split ring commutators continually switch the brush contacts each half rotation to maintain current flow in one direction. This is how electric generators are able to convert mechanical energy from turbines into usable electricity based on Faraday's law of electromagnetic induction.

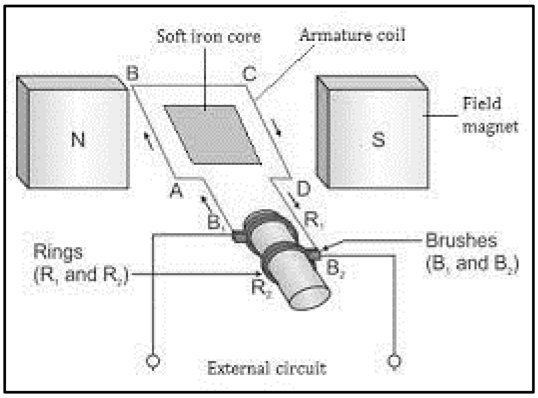

Figure 1: Internal structure of an Alternating Current (AC) Generator [1]

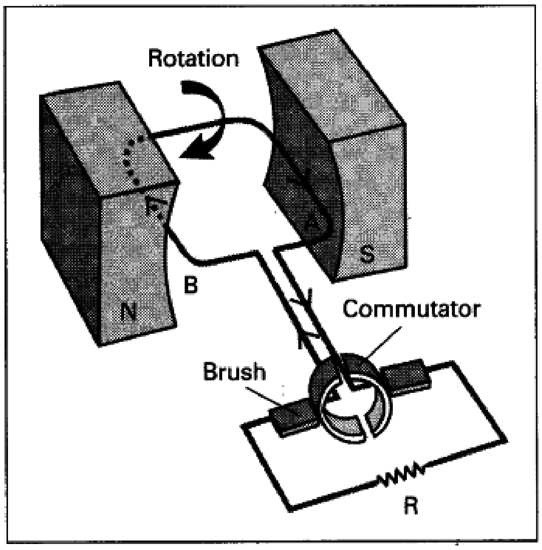

Figure 2: Internal structure of a Direct Current (DC) Generator [1]

[1] "AC and DC Generator," Unacademy, Apr. 08, 2022. Available: https://unacademy.com/content/jee/study-material/physics/ac-and-dc-generator/

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RL Circuit

The following equation illustrates how a series RL circuit responds to a DC voltage:

$$I_{max} = \frac{V_0}{R}$$

Here, I_{max} refers to steady state current, V_0 is the applied voltage and R is the total resistance of the circuit.

Because the inductor produces a back emf in reaction to the rise in current, it takes a while to reach this steady-state current. The current in the circuit rises exponentially, and can be given by the following differential equation:

$$I(t) = I_{max}(1 - e^{-(R/L)\cdot t}) = I_{max}(1 - e^{-\frac{t}{\tau}})$$

Here, $I(t)$ refers to the current at time t, I_{max} is the maximum current, L is the inductance of the circuit and $\tau = {}^{L}/_{R}$ is the inductive time constant.

The inductive time constant denotes the time taken for the current to reach 63.2% of its steady-state value. The time taken to reach half maximum is given by:

$$\tau = \frac{t_{1/2}}{\ln(2)}$$

The voltage across the inductor is directly proportional to the time rate of change, and is given by:

$$V_L(t) = L\frac{dI}{dt} = {}^{LI_{max}(e^{-t/\tau})}/_{\tau} = RI_{max}(e^{-t/\tau})$$

The voltage across the resistors is given by the formula:

$$V_R = V_0 - V_L = V_0(1 - e^{-t/\tau})$$

Where V_R is the voltage across the resistor and V_L is the voltage across the inductor. The voltage across the resistor rises along with the exponential increase in current, while the voltage across the inductor falls. It's crucial to remember that this derivation makes the assumption that the inductor has no internal resistance.

When the voltage is turned off, the inductor maintains current flow by creating a reverse emf in the opposite direction of the applied voltage. The voltage across the resistor and the current in the circuit both decrease exponentially with time, with the rate set by the circuit's time constant τ. The following equation describes how the circuit behaves after the voltage is turned off.

$$IR + L\frac{dI}{dt} = 0$$

$$I = I_{max}e^{-t/\tau}$$

$$V_R = V_0 e^{-t/\tau} V_L$$

The potential difference across the inductor is negative because the inductor acts like a battery.

$$V_L = -Ve^{-t/\tau}$$

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Purpose

To observe how an RL circuit works and how the voltages across the resistor and inductor change over time.

Hypothesis Statement

As the current increases exponentially, the voltage across the resistor increases and the voltage across the inductor decreases. Additionally, the sum of the voltage across the resistor and the voltage across the inductor will be equal to the max input voltage.

Materials

- Function Generator
- Inductor
- Oscilloscope
- Resistor
- Wires

Procedure

1. Calibrate the oscilloscope and function generator by setting the function generator to produce a square wave of 1000Hz frequency and 5V amplitude.
2. Connect an RL circuit with R = 300Ω and L = 300mH.
3. Connect channel 1 of the oscilloscope to measure the voltage through the resistance and channel 2 to measure the voltage through the inductor.
4. Use a square wave to "turn on and off" the RL circuit. The square wave produces the same effect as a battery being switched on and off periodically.
5. Construct the circuit as shown in Figure 1. Route the square wave to the input of the circuit. Direct the output from the resistor to channel 1 and the output from the inductor to channel 2 of the oscilloscope.
6. The frequency of the input signal should be $\frac{1}{f_{signal}} = T \gg \tau = L/R$. This allows for the observation of fully charging and discharging process.
7. Plot V_L and V_R from the oscilloscope while the inductor is charging.
8. Plot V_L and V_R from the oscilloscope while the inductor is discharging.

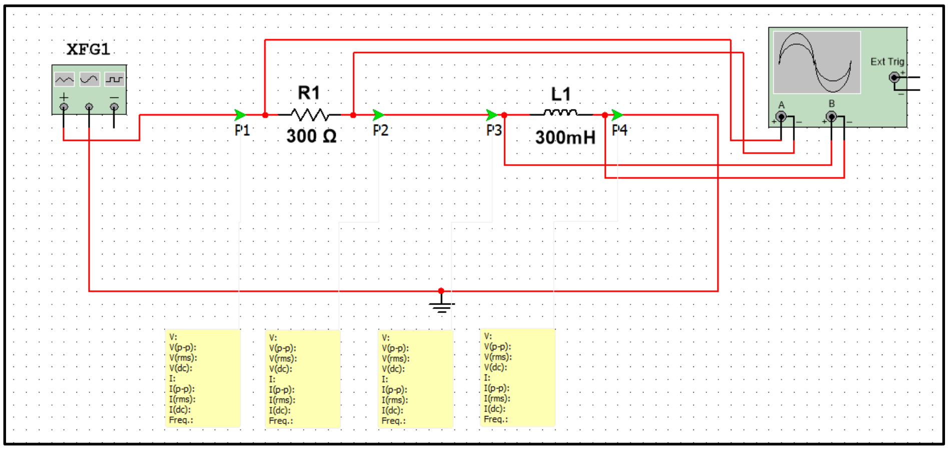

Figure 1: Circuit to be implemented.

Data & Graphs

R (Ω)	L (mH)	$\tau_{theoretical}$	V_{max}	f (Hz)	T (ms)	$\tau_{oscilloscope}$	V_R (V)	V_L (V)	$V_{max} - V_R$	$V_{max} - V_L$
300	300	0.001	5	1000	1	7.21×10^{-4}	2.62	3.94	2.38	1.06

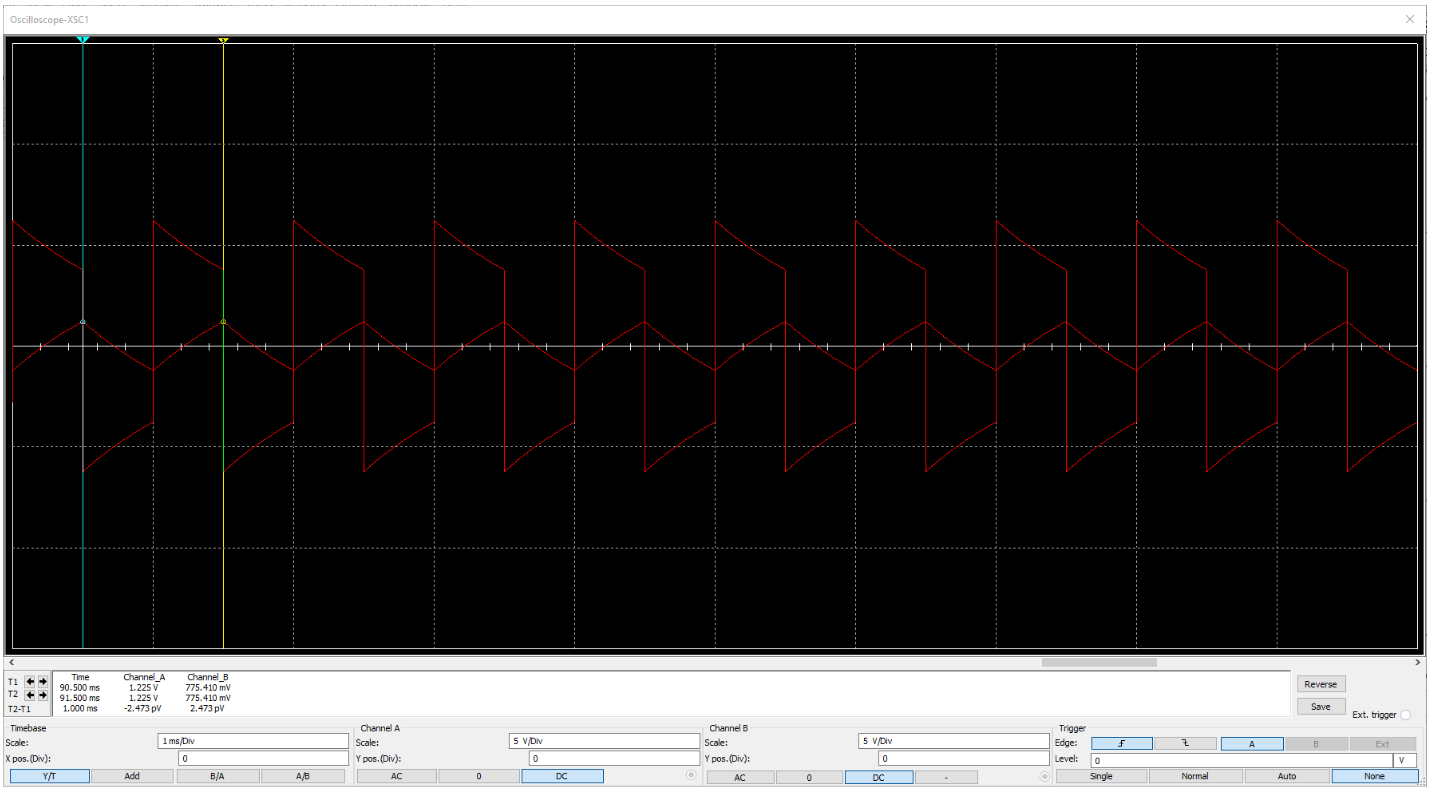

Figure 2: Oscillator output across both channels.

Observations

We dealt with two scenarios in the lab where the inductor is charging as well as discharging. The following observations were noted:z

When the inductor is charging:

The inductor has energy stored when the charging process starts. Therefore, because the inductor resists changes in current, V_L is initially high, and V_R is low. The voltage across the inductor drops as it charges. The circuit's time constant—which is established by the resistance and inductance—determines the pace at which V_L decreases. A phase shift between V_L and V_R is seen. V_L may lag behind V_R due to the circuit's inductive nature.

Conclusion

1. What was the purpose of this lab?

The purpose of this lab was to observe how an RL circuit works and how the voltages across the resistor and inductor change over time.

2. How does the lab we performed relate to what we are studying in class?

The lab we performed is linked with concepts of inductive reactance and time constants which have been applied to analyze the behavior of the RL circuit.

3. Give a brief recap of the procedure used.

To calibrate the oscilloscope and function generator, set the generator to produce a square wave with a frequency of 1000Hz and 5V. Connect an RL circuit with R = 300Ω and L = 300mH, measure voltage through resistance and inductor channels, and plot V_L and V_R while inductor charges and discharges.

4. What problems did you have during the lab? Did you have to modify your procedure?

One of the main problems that occurred during the lab was incorrect wiring. This involved connecting wires to the wrong terminals and components being connected in the wrong order. However, after thorough observation of the figure provided, the team recouped and continued in the right direction. Additionally, the software had limitations in showing us the discharging of a capacitor as it lacked the capability to do so.

5. Do your results make sense? What are the sources of error?

Yes, the results do make sense because the theoretical time constant matched the experimental time constant with an extremely low margin of error, as predicted. The results of this study could have been impacted by a number of things. An oscilloscope's measurement capabilities are vulnerable to external interference. Errors may also result from inaccurate resistance, inductance, and frequency measurements. Inconsistent data collection techniques can also have affected the outcomes.

6. What did you learn from this lab?

This experiment sheds light on how LC and RLC circuits interact, which is helpful for scientists and engineers who develop and work with electrical systems.

7. If you were to repeat this lab in the future, how would you modify or improve the procedure?

If the team were to repeat this lab in the future the following could be done to improve the procedure:

- Safety measures can be implemented to protect the members and equipment such as using current limiting resistors, fuses to prevent voltage spikes.
- Calibrating the oscilloscopes and multimeters to obtain accurate and precise readings.

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Purpose

To understand RLC circuit resonance and observe underdamped and overdamped oscillations in RLC circuits.

Hypothesis Statement

It is expected that the higher resistance graph will be more damped.

Materials

- Capacitor
- Function Generator
- Inductor
- Oscilloscope
- Resistor
- Wires

Procedure

1. Set up RLC circuit by connecting the resistor, inductor and capacitor in series.
2. Connect the function generator to the circuit. Connect channel 1 of the oscilloscope to the capacitor to measure the voltage across it.
3. Turn on the function generator and observe the oscillations on the oscilloscope.

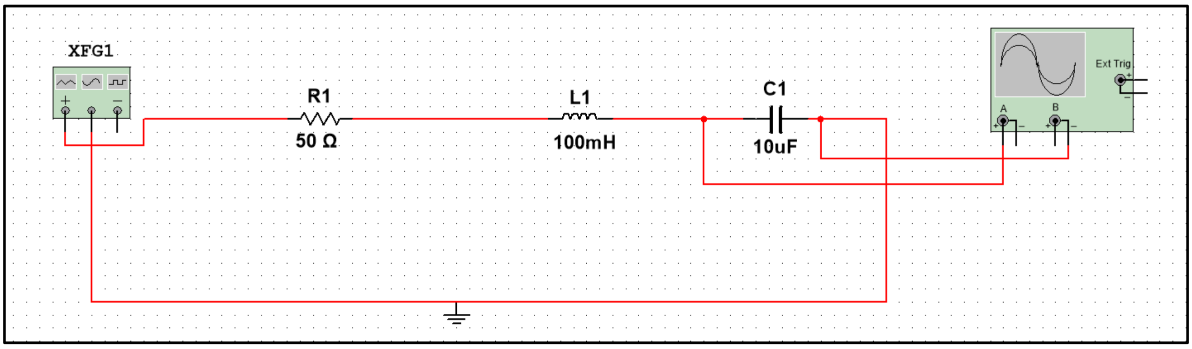

Figure 3: Circuit to be implemented.

Data & Graphs

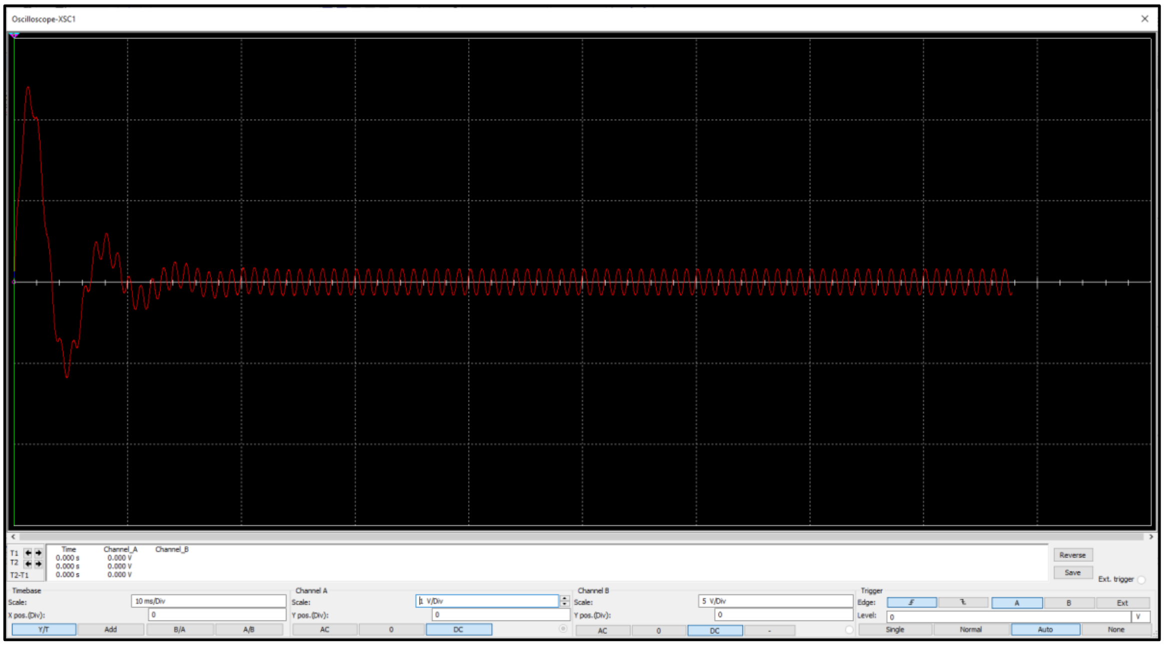

Figure 4: Voltage across capacitor at 50Ω

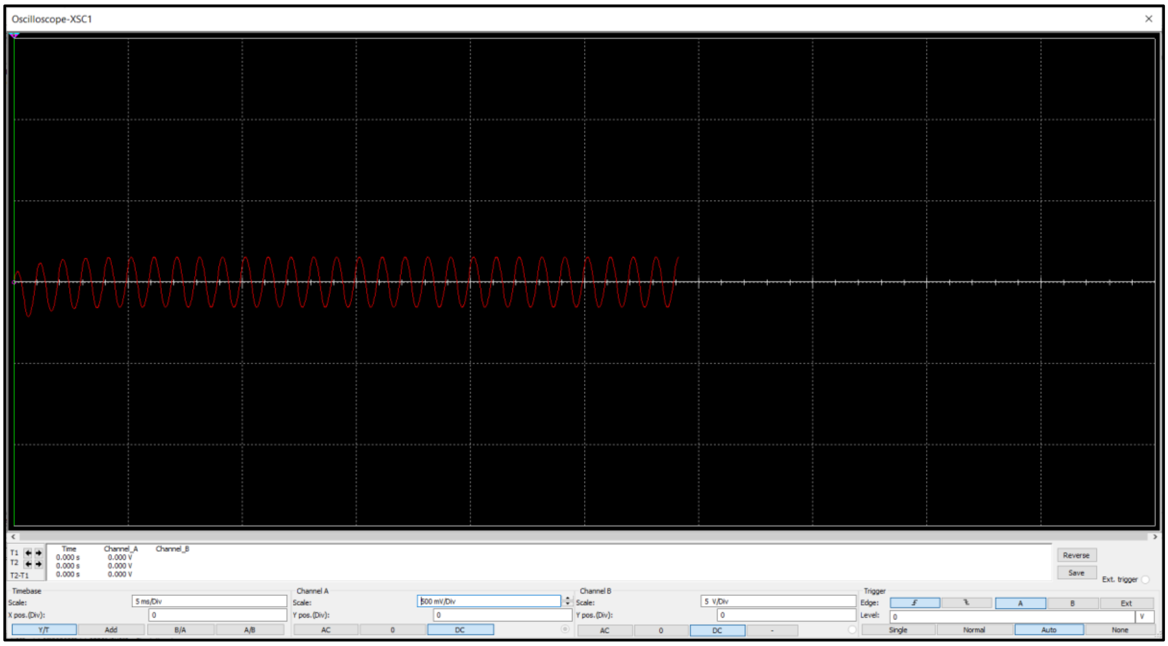

Figure 5: Voltage across capacitor at 200Ω

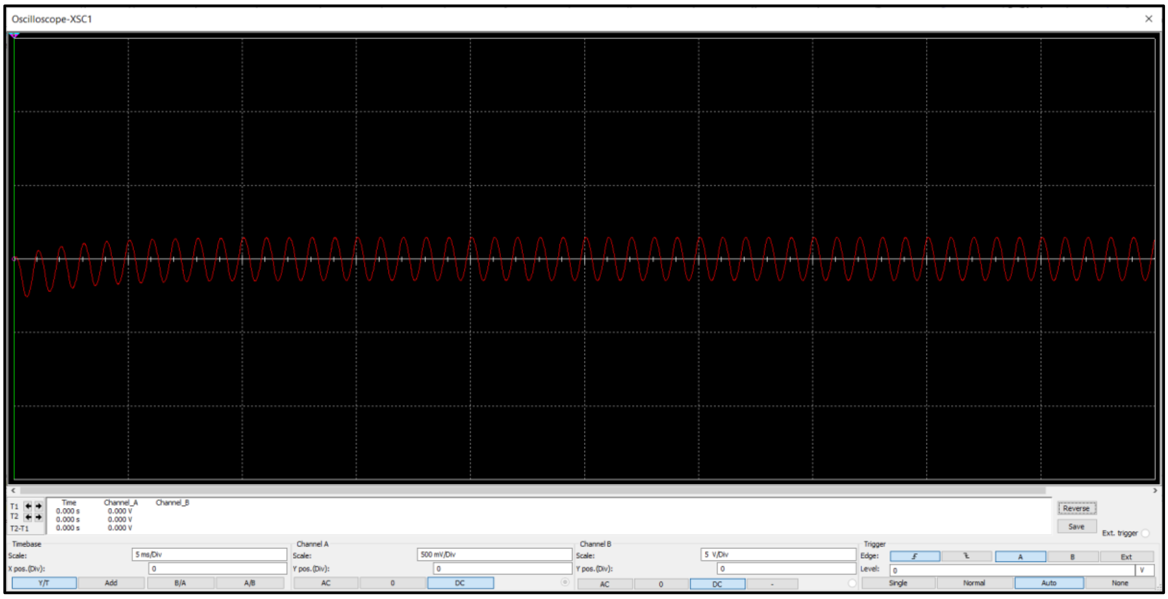

Figure 6: Voltage across capacitor at 300Ω

Observations

The experiment's observation explains how, at various resistance values, the voltage across the capacitor behaves in an RLC circuit. By noting the oscillations' shape and frequency, we can observe whether its overdamped (oscillations diminish quickly) or underdamped (oscillations gradually decrease).

Conclusion

1. **What was the purpose of this lab?**

The purpose of the lab was to gain a better understanding of resonance in RLC circuits by observing underdamped and overdamped oscillations.

2. **How does the lab we performed relate to what we are studying in class?**

This lab is directly related to the study of electrical circuit theory, specifically the behavior of RLC circuits, which includes investigating resonance phenomena and damping effects in such systems.

3. **Give a brief recap of the procedure used.**

The procedure consisted of connecting an RLC circuit in series with varying resistance to a function generator and measuring and observing the voltage oscillations across the capacitor with an oscilloscope.

4. **What problems did you have during the lab? Did you have to modify your procedure?**

As such no problems were encountered during the lab as a virtual setup using Multisim was used. However, the software had limitations in showing us the discharging of a capacitor as it lacked the features to do so.

5. **Do your results make sense? What are the sources of error?**

Yes, the results of the experiment make sense and are in line with the lessons taught in class about RLC circuits. The results confirm the hypothesis about the effect of resistance on damping. There were as such no errors encountered during the lab experiment as software (Multisim) was used to replicate an RLC circuit and results were obtained with ideal conditions resulting in zero sources of errors.

6. **What did you learn from this lab?**

The lab helped us gain hands-on experience with replicating RLC circuits with multi-sim and improved our comprehension of how variance in resistance in a resistor affects the RLC circuit's behavior.

7. **If you were to repeat this lab in the future, how would you modify or improve the procedure?**

If we were to repeat the lab in the future, in order to improve the learning experience, future lab iterations could include the setting up of an actual RLC circuit with accurate equipment calibration and also include verification of theoretical predictions against obtained experimental results.

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