Department of

Electrical & Electronics Engineering

Abdullah Gül University

Project Report for Relaxation Oscillator Circuit

Department of

Electrical & Electronics Engineering

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Project Report

EE1100 ESD Capsule

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OBJECTIVE

The purpose of this experiment is to understand the working logic of capacitors using the simple relaxation oscillator circuit in Figure 1. A relaxation oscillator is a type of electronic oscillator that generates a periodic waveform through the repeated charging and discharging of a capacitor. It is a fundamental building block in electronic circuits and is used in a wide range of applications, including timing circuits, signal generators, and frequency synthesizers. In the given circuit, a neon lamp is used in addition to the capacitor. Depending on the voltage values of the capacitor, the intervals in which the neon lamp lights up will be observed.

The report will begin by introducing the basic concepts and principles behind relaxation oscillators, including their operating principles and the components used to build them. This will include a discussion of the circuit's design and configuration, such as the choice of components and their values, and how they affect the circuit's behavior. Finally, the report will conclude with a summary of the key findings and recommendations for using and designing relaxation oscillator circuits. This will include a discussion of best practices for circuit design and optimization, as well as future research directions in the field.

The report will also cover the materials used in capacitor fabrication, including paper, glass, and other some materials, as well as the methods used for depositing, patterning, and processing these materials. It will also discuss the importance of controlling the thickness, composition, and uniformity of the capacitor layers in order to achieve the desired electrical properties.

Furthermore, the report will examine the factors that affect capacitor performance, including capacitance, voltage rating, temperature stability, and leakage current. The report will explore how these factors are impacted by different fabrication techniques and materials, and how they can be optimized for specific applications.

Overall, the objective of this report is to provide a comprehensive understanding of capacitor fabrication, from the underlying principles to the practical considerations involved in producing these essential components of modern electronics. By exploring the different approaches to capacitor fabrication, this report aims to provide a valuable resource for researchers, engineers, and students who are interested in this important and evolving field.

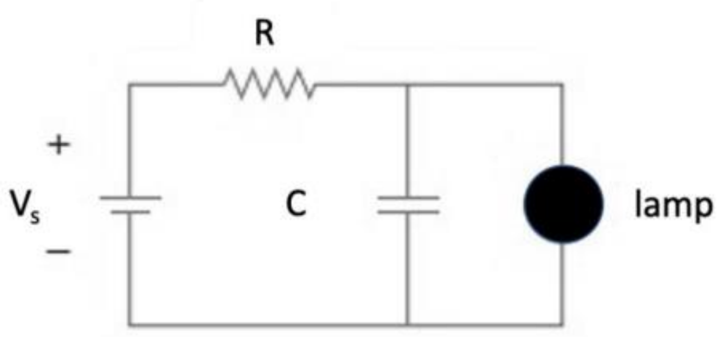


FIGURE 1

FIGURE 2

BACKGROUND

Relaxation oscillators have been used for over a century to generate periodic waveforms in electronic circuits. They are simple, low-cost circuits that are easy to design and implement, making them a popular choice for many applications. In this report, we analyzed a simple relaxation oscillator circuit, examining its behavior, characteristics, and practical applications. We studied the basic principles behind relaxation oscillators, discussed the circuit's design and configuration, analyzed its performance under different operating conditions, and explored its advantages and limitations in various electronic systems and applications. In addition, by making use of the charge storage feature of the capacitor, the neon lamp was turned on. Burning time of neon lamp found. In addition to these, capacitors were designed as requested from us. After the design part of the capacitors, capacitors were produced in the laboratory environment and their capacitance values were measured experimentally. The values of capacitors made in laboratory environment were compared experimentally and theoretically. The reason for the difference between them was tried to be explained.

ANALYTICAL AND SIMULATION PROCEDURES

a. Steps of Experiment

In this project

- LTSPICE
- Aluminum Foil
- Paper
- Scissors
- Glue
- Glass Jar
- Multimeter
- Water

- Salt
- Electric Wire

are used.

1- We assembled the relaxation oscillator circuit on a breadboard using the same components and topology as in the simulation. Experiments were performed to validate the simulation results and identify any inconsistencies or limitations. This process helps validate electronic circuits and gives insight into their real-world performance.
2- The burning time of the lamp was calculated theoretically. This calculation is important for optimizing the efficiency and effectiveness of the lamp.
3- Considering variables such as capacitance, resistance and voltage, the recharge time of the capacitor was calculated theoretically after each cycle. This calculation is important for understanding and optimizing capacitor performance and can help identify potential problems and limitations.
4- A voltage plot across capacitor VC(t) was drawn using LTSPICE. The findings are illustrated on a drawing that represents how the system works, with key time and voltage values marked.
5- Parallel plate and cylindrical capacitors with a capacitance of 6 micro Farad on paper were calculated theoretically by assigning area and distance values.
6- Two capacitors were fabricated in the laboratory. Some materials were used in this fabrication such as paper, aluminum folio and glass jar. The one of the capacitors is a cylindrical capacitor and the other one is a parallel capacitor. After fabricating the capacitors, the theoretical results of the capacitance of the capacitors were calculated by hand and then the experimental results were measured and compared with each other.
7- Considering the discrete time step $\Delta t = 0.01$ ms, the discrete time series for the capacitor voltage VC(t) was written and the convergence properties of the series were investigated.
8- Finally, the Maclaurin series expansion for VC(t) has been written. The Maclaurin series expansion for VC(t) is written, which provides a polynomial approximation of the function that captures its local behavior around the origin.

Abstract Stages of Experiment

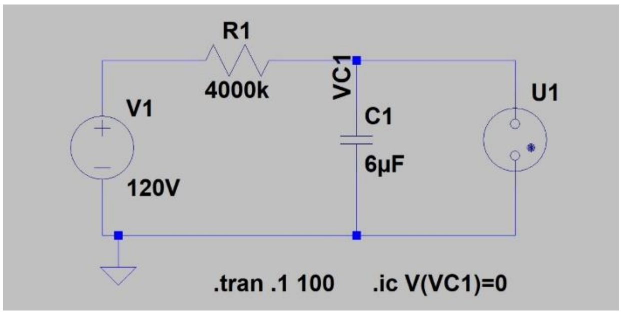


FIGURE 3

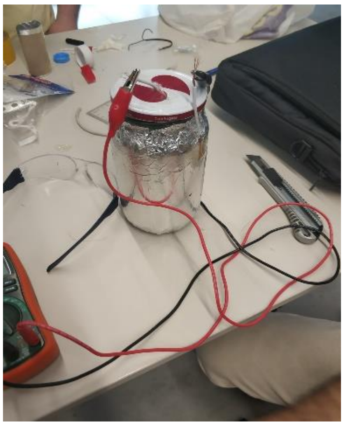
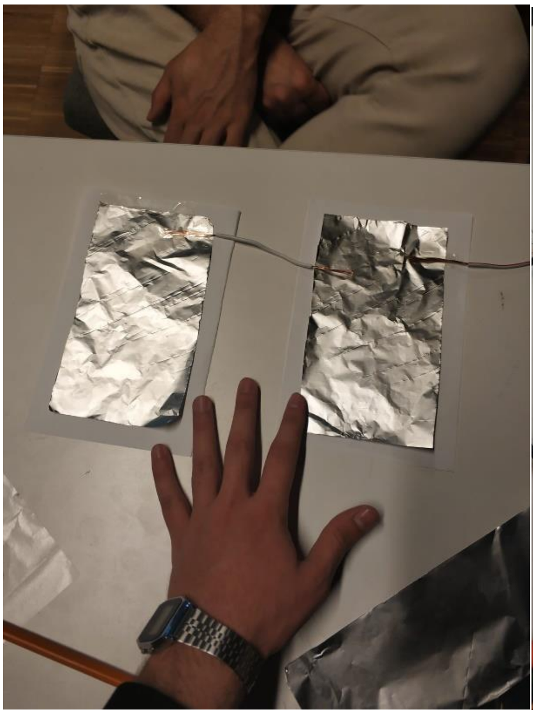


FIGURE 4

- Figure 3 represents the output waveform obtained from the relaxation oscillator circuit when it was simulated using LTSPICE with a specific set of component values and topology. This included a voltage source of 120V, a resistor of 4M ohm, a capacitor of 6µF, and a neon bulb. In addition, the simulation allowed us to analyze and understand the circuit's behavior under different conditions and to optimize its performance.
- As part of our efforts to showcase the practical applications of the relaxation oscillator circuit, we explored the charge storage property of a capacitor and how it can be leveraged to turn on a neon lamp. This process involved connecting the capacitor to the oscillator circuit and observing the behavior of the neon lamp when the capacitor was charged and discharged. Specifically, when the capacitor was charged to a sufficient voltage, it would trigger the neon lamp to turn on, creating a bright and visible glow. This effect was due to the fact that the charge stored in the capacitor provided enough energy to ionize the gas inside the neon lamp and cause it to conduct electricity.
- To explore the characteristics of capacitors and their dependence on geometry and dielectric materials, we constructed two types of capacitors using aluminum foil and paper as the dielectric material. These included parallel plate capacitors, as shown in Figure 5 and Figure 6, and cylindrical capacitors, as shown in Figure 4. After constructing the capacitors, we measured their capacitance values using a multimeter in the laboratory environment.



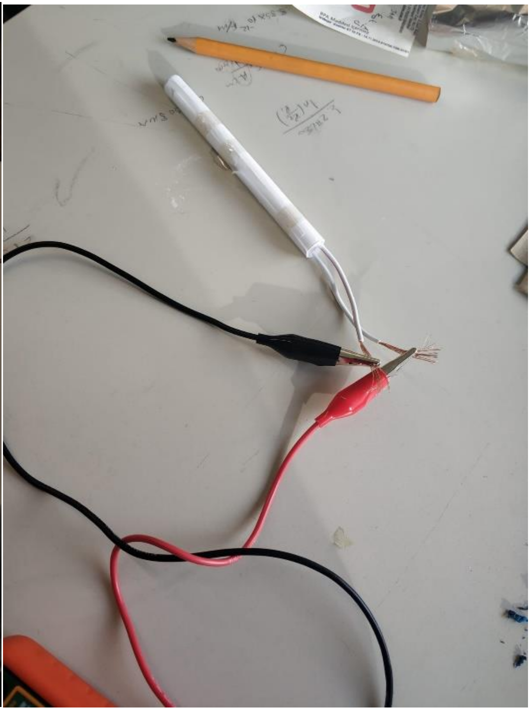


FIGURE 5 **FIGURE 6**

- The measured capacitance values were compared to the theoretical values calculated using the geometry and dielectric constant of the capacitor and used to assess the accuracy and reliability of the construction process. In addition to measuring the capacitance values, we also explored the effects of different factors, such as the distance between the plates and the thickness of the dielectric material, on the capacitance of the capacitors. Overall, the process of constructing and measuring the capacitance values of the parallel plate and cylindrical capacitors represents a fundamental aspect of capacitor theory and provides valuable insights into the behavior and characteristics of these important electronic components.

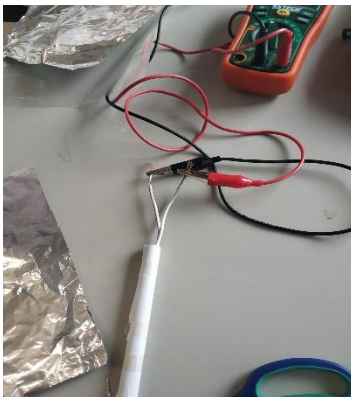


FIGURE 7

a. Evaluation of Problems

In this experiment, we analyzed the behavior and characteristics of a simple relaxation oscillator circuit that consists of a lamp and a capacitor. The circuit used in this experiment was a basic relaxation oscillator circuit with a lamp that fires when its voltage reaches 80V and turns off when its voltage drops to 40V. The lamp's resistance is 120 Ω when on and infinitely high when off. The initial voltage of the capacitor was assumed to be 0, and the circuit was powered by a voltage source of 120V with a resistance of 4MΩ and a capacitance of 6µF.

The lamp is on from 80V until 40V. During that time, it is assumed that there is a 120 Ω resistor in parallel with a 6µF capacitor. The lamp does not allow the capacitor to fill more than 80 volts, that is, the value of the capacitor voltage cannot reach 120 volts. As soon as the capacitor reaches 80 volts, lamp starts to pass current. To calculate how long the lamp lights up each time the capacitor discharges, the following steps were followed:

$$VC(t) = V_0 \; x \; e^{\frac{-t}{RxC}}$$

V_0 = the initial voltage of capacitor = 80V

The product of resistance and capacitance gives the time constant τ.

$\tau = R \; x \; C$ = the time constant= 120 Ω x 6µF = 0.72 ms = 0.00072 s

$$40V = 80 \; x \; e^{\frac{-t}{0.00072s}} \; V$$

$$e^{\frac{-t}{0.00072s}} = \frac{1}{2}$$

$$\ln\frac{1}{2} = \frac{-t}{0.00072s}$$

$$-t = -0.00049906597s$$

$$t = 0.49906597 \; ms$$

As a result of these operations, it is obtained that the lamp lights for 0.49906597 ms.

The following formulas were used to calculate the time required for the capacitor to charge after the first cycle:

Since the lamp and capacitor are in parallel, the lamp will turn on as soon as the capacitor reaches 80 volts. When it drops to 40 volts, the lamp will turn off and the capacitor will use the voltage source to reach 80 volts again. So, V(t1) value is 40 volts while V(t2) value is 80 volts.

$$V(t) = V_\infty + (\,V_0 - V_\infty)\,e^{\frac{-t}{\tau}}$$

$$V(t1) - V_\infty = (V_0 - V_\infty)\,e^{\frac{-t1}{\tau}}$$

$$V(t2) - V_\infty = (V_0 - V_\infty)\,e^{\frac{-t2}{\tau}}$$

$$\frac{V(t1) - V_\infty}{V(t2) - V_\infty} = e^{(t2-t1)/\tau}$$

$$t2 - t1 = \tau \ln \frac{V(t1) - V_\infty}{V(t2) - V_\infty}$$

Since $\tau = R\ x\ C = 4M\Omega \text{ x } 6\mu\text{F} = (4 \text{ x } 10^6)\Omega \text{ x } (6 \text{ x } 10^{-6})F = 24\ s$

$$t2 - t1 = 24 \ln \frac{(40 - 120)}{(80 - 120)}$$

$$t2 - t1 = 24 \text{ x } \ln 2$$

$$t2 - t1 = 16.6355323\ s$$

Plotting the voltage across the capacitor VC(t) using a simulation tool is the data obtained:

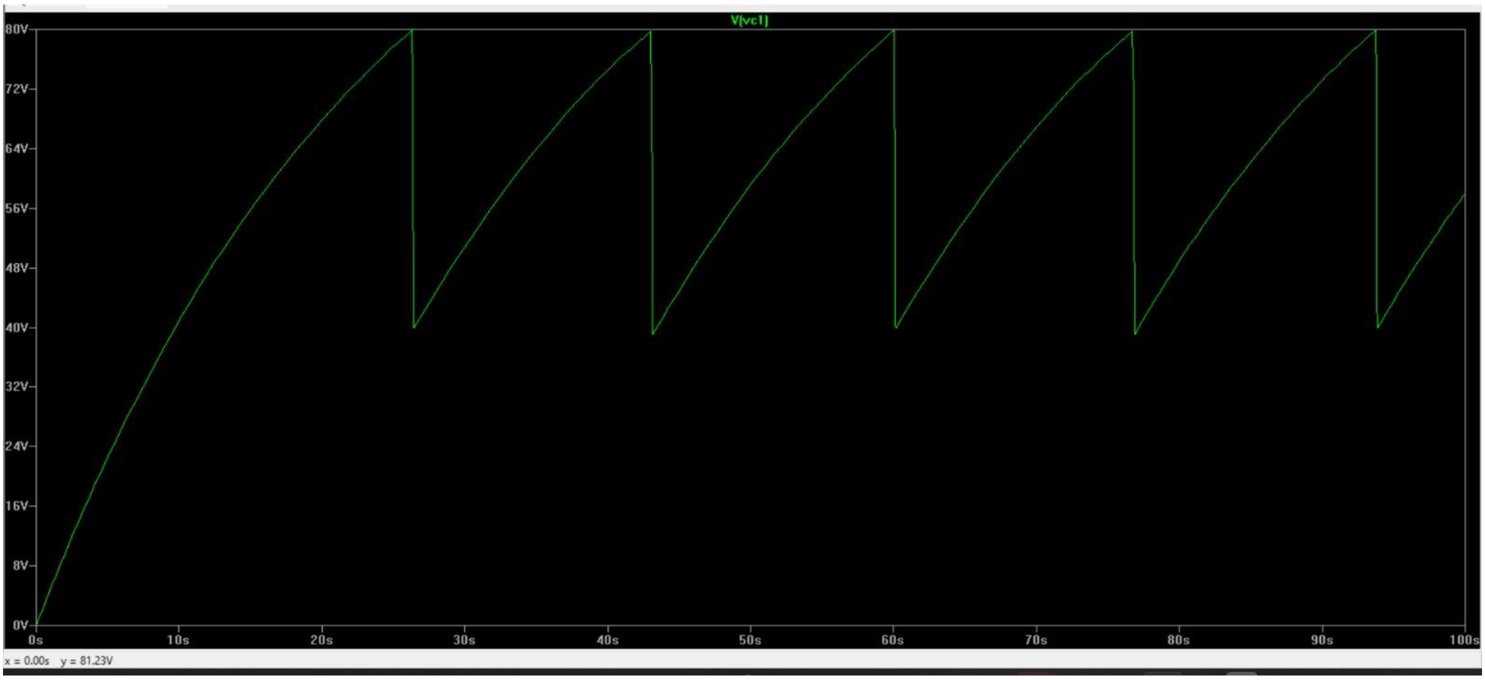


FIGURE 8

Looking at the graph, the following comments can be made:

Neon lamp is a kind of gas discharge lamp containing a glass capsule in which neon and various gases and two electrodes (anode and cathode) are located. When the appropriate voltage is applied and a suitable current is created between the electrodes, the lamp produces an orange glow discharge. Since the capacitor and the lamp are connected in parallel, their voltage values are equal. The initial voltage value of the capacitor is 0 V. As it is known, when it reaches 80 volts after starting to charge, the lamp turns on. The capacitor starts to discharge as the lamp starts to light up. When the capacitor drops to 40 volts, the lamp goes out. The capacitor wants to be recharged from 40 volts. But when it reaches 80 volts, the lamp lights up again and the capacitor starts to drop to 40 volts as a discharge. This cycle continues like this. As can be seen from the graph, the first cycle is completed when the capacitor goes from 0 volts to 80 volts and then drops from 80 volts to 40 volts. The other cycles continue as the capacitor drops from 80 volts to 40 volts and again rises from 40 volts to 80 volts. It is known that these loops are about 16 seconds since the question is solved in the previous question. Looking at the graph, it is observed that this value is correct.

To design a cylindrical capacitor using a dielectric material of our choice such that the capacitance becomes 6 μF.

A cylindrical capacitor consists of a hollow or a solid cylindrical conductor surrounded by another concentric hollow spherical cylinder. The capacitance of a cylindrical capacitor can be derived as: By Gauss law, the charge is enclosed by the Gaussian cylinder of radius r and length L.

$$\int \vec{E} dA = \frac{q}{\varepsilon_0}$$

$$E.2\pi r L = \frac{q}{\varepsilon_0}$$

$$E = \frac{q}{2\pi r L \varepsilon_0}$$

$$V = -\oint \vec{E} dr \qquad V = -\oint \frac{q}{2\pi r L \varepsilon_0} dr$$

$$V = \frac{-q}{2\pi L \varepsilon_0} \oint_{r_0}^{r_1} \frac{dr}{r} \qquad V = \frac{q}{2\pi L \varepsilon_0} \ln \frac{r_0}{r_1}$$

$$C = \frac{q}{V} = \frac{q}{\frac{q}{2\pi L \varepsilon_0} \ln(\frac{r_0}{r_1})} = \frac{2\pi L \varepsilon_0}{\ln(\frac{r_0}{r_1})}$$

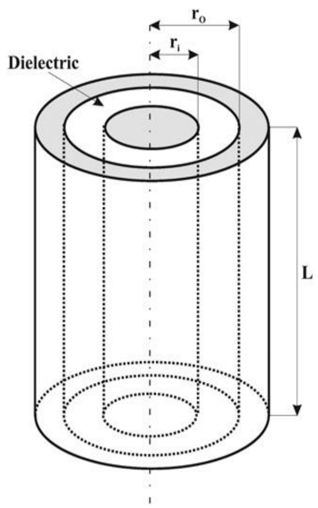


FIGURE 9

Capacitance of cylindrical capacitor is:

$$C = \frac{2\pi L \varepsilon_0 \varepsilon_r}{\ln(\frac{r_0}{r_1})}$$

L= length of the cylinder = 0.1528408 m

r_0= outer radius = 3,01491 mm

r_1=inner radius = 3 mm

ε_r of paper = 3.5

$$C = \frac{2\pi(0.1528408m)(8.85x10^{-12}\frac{F}{m})\,(3.5)}{\ln(1{,}00497)} = 6\ \mu F$$

To design a parallel plate capacitor using a dielectric material of our choice such that the capacitance becomes 6 μF.

This time a cylinder is chosen as the Gaussian surface. Let A be the base area of the cylinder.

$$\int \vec{E} dA = \frac{q}{\varepsilon_0}$$

$$E.A = \frac{q}{\varepsilon_0}$$

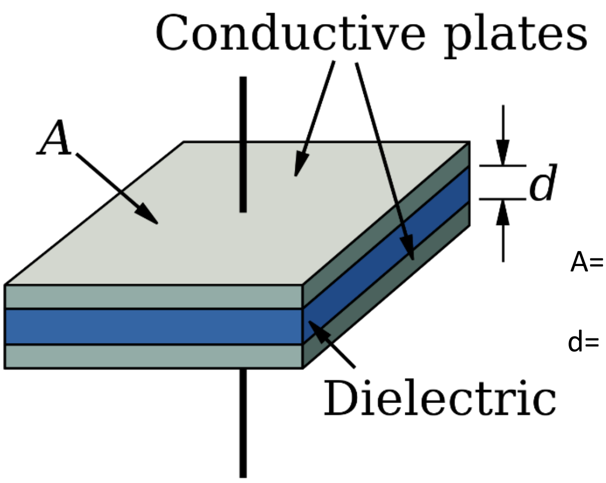
$$q = \lambda . A$$

$$E = \frac{\lambda}{\varepsilon_0}$$

$$V = -\oint \vec{E} dl \quad V = \frac{\lambda . l}{\varepsilon_0}$$

$$(l \text{ is the distance between the two plates.})$$

$$C = \frac{q}{V} = \frac{q\varepsilon_0 A}{\text{q}l} = \frac{\varepsilon_0 A}{l}$$



Capacitance of parallel plate capacitor is:

$$C = \frac{\varepsilon_r \varepsilon_0 A}{d}$$

A= surface area of plate = 10^{-4} m

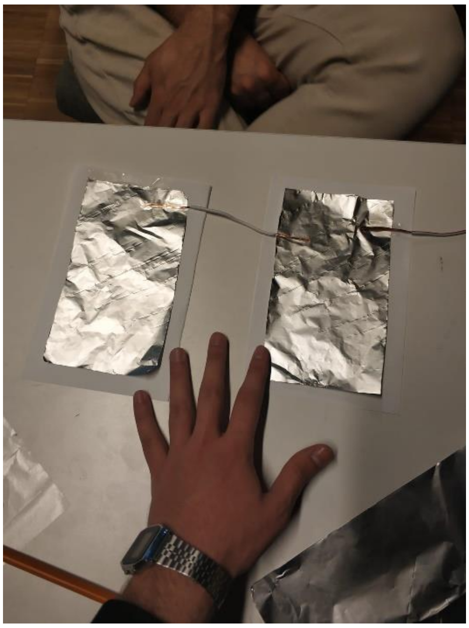
d= distance between the plates = 177×10^{-8} m

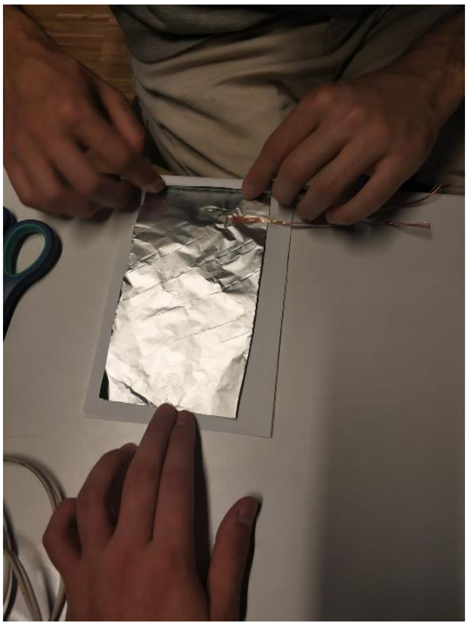
ε_r of silicon = 12

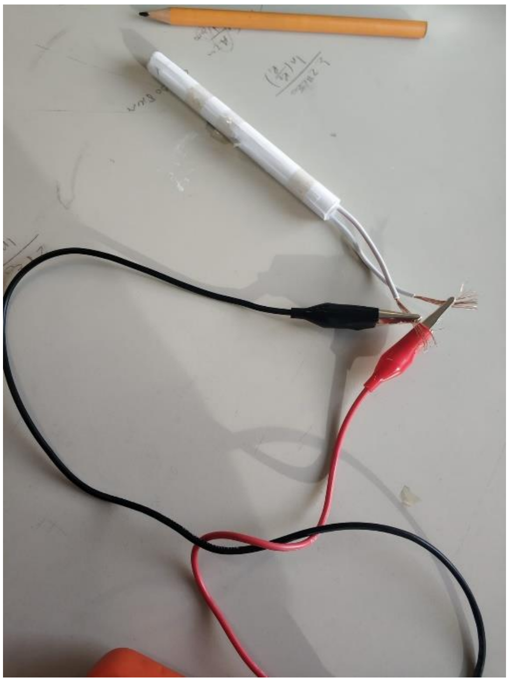
FIGURE 10

$$C = \frac{12(8.85x10^{-12}\frac{F}{m})10^{-4}m}{177x10^{-8}\, m} = 6\mu F$$

To fabricate a parallel plate capacitor using the materials that we can find at home; paper, aluminum foil, electrical cable, glue, multimeter were used to obtain a parallel plate capacitor. Large pieces of paper were cut from aluminum foil. Two pieces of 17x9 aluminum foil were cut. Each aluminum foil was glued on each sheet of paper. An electrical cable was glued onto each aluminum foil. These two structures were stacked on top of each other and wrapped around a pencil. After wrapping it around the pen, the pen was removed and fastened together with tape. The dielectric coefficient of paper is 3.5. The value measured on the multimeter is 5.09 nano-farads. Thus, the experimental part is completed.







To find the theoretical result following steps are done:

The formula for the parallel capacitor known to be obtained in the design part is as follows:

$$\int \vec{E} dA = \frac{q}{\varepsilon_0}$$

$$E.A = \frac{q}{\varepsilon_0}$$

$$q = \lambda . A$$

$$E = \frac{\lambda}{\varepsilon_0}$$

$$V = -\oint \vec{E} dl \quad V = \frac{\lambda.l}{\varepsilon_0}$$

$$(l \text{ is the distance between the two plates.})$$

$$C = \frac{q}{V} = \frac{q\varepsilon_0 A}{\mathrm{q}l} = \frac{\varepsilon_0 A}{l}$$

When the dielectric material is put in between, the capacitance formula becomes:

$$C = \frac{\varepsilon_r \varepsilon_0 A}{d}$$

ε_r = dielectric constant of paper = 3.5

A= area of the plate = 17x9 cm^2 = 17x9x10^{-4} m^2

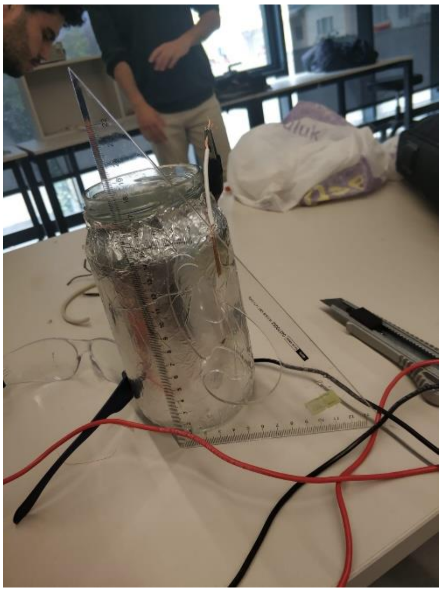
d= distance between to plates = 0.09 mm = 9x10^{-5} m

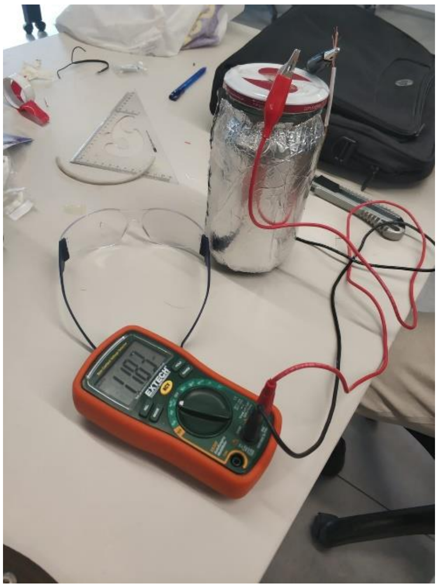
$$C = \frac{(3.5)x\left(8.85x10^{-12}\frac{F}{m}\right)x(17x9x10^{-4}\ m^2)}{9x10^{-5}\ m}$$

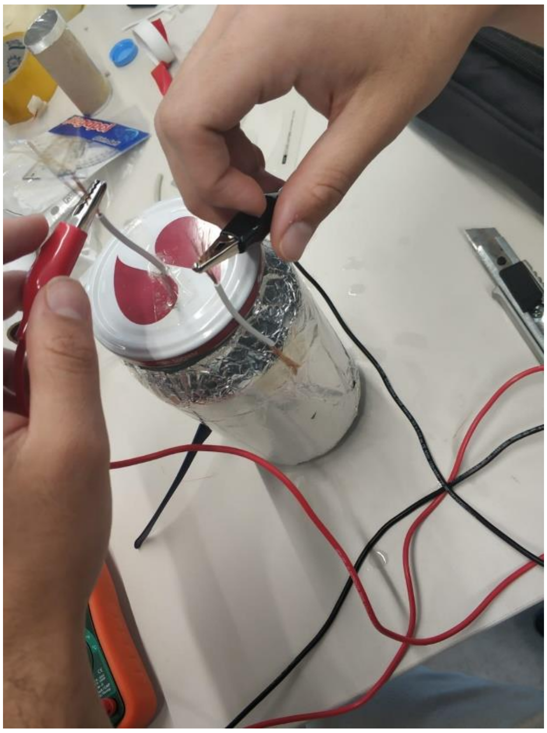
$$C = 526.575x10^{-11}F$$

$$C = 526.575x10^{-11}\ x\ 10^9 = 5.26575\ nF$$

To fabricate a cylindrical capacitor using the materials that we can find at home Glass jar, aluminum foil, glue, electrical cable, salt, and water were used to obtain a cylindrical capacitor. Salt water is placed in a glass jar. Care was taken to ensure that the finish lines of the brine and aluminum foil were equal. The thickness of the jar was measured to find the radii these values are obtained as 3.75 and 3.6 cm. The length of the jar is 16 cm. It is known that the dielectric coefficient of glass is 5. Experimental result is 1.183 nano Farad.







To find the theoretical result following steps are done:

The formula for the cylindrical capacitor known to be obtained in the design part is as follows:

$$\int \vec{E} dA = \frac{q}{\varepsilon_0}$$

$$E.\, 2\pi r L = \frac{q}{\varepsilon_0}$$

$$E = \frac{q}{2\pi r L \varepsilon_0}$$

$$V = -\oint \vec{E} dr \qquad V = -\oint \frac{q}{2\pi r L \varepsilon_0} dr$$

$$V = \frac{-q}{2\pi L \varepsilon_0} \oint_{r_0}^{r_1} \frac{dr}{r} \qquad V = \frac{q}{2\pi L \varepsilon_0} \ln \frac{r_0}{r_1}$$

$$C = \frac{q}{V} = \frac{q}{\frac{q}{2\pi L \varepsilon_0} \ln(\frac{r_0}{r_1})} = \frac{2\pi L \varepsilon_0}{\ln(\frac{r_0}{r_1})}$$

When the dielectric material is put in between, the capacitance formula becomes:

$$C = \frac{2\pi L \varepsilon_0 \varepsilon_r}{\ln(\frac{r_0}{r_1})}$$

L= the length of the glass jar = 16 cm = 0.16 m

ε_r= dielectric constant of glass = 5

r_0= 3.75 cm

r_1= 3.6 cm

$$C = \frac{2\pi (0.16m) \left(8.85x10^{-12} \frac{F}{m}\right) 5}{\ln(1.041)}$$

$$C = 1107.09235\ x\ 10^{-12}\ F$$

$$C = 1107.09235\ x\ 10^{-12}\ x\ 10^{9} = 1.10709235\ nF$$

Write the discrete time series for the capacitor voltage VC(t), taking into account the discrete time step $\Delta t = 0.01\,ms$. Then, the convergence properties of the series are investigated.

$$VC(t) = V_0\ x\ e^{\frac{-t}{RxC}}$$

$$\text{Since } \tau = R\ x\ C = 4M\Omega \text{ x } 6\mu\text{F} = (4 \text{ x } 10^6)\Omega \text{ x } (6 \text{ x } 10^{-6})F = 24\ s$$

$$VC(t) = V_0\ x\ e^{\frac{-t}{24s}}$$

$$\Delta t = 0.01\,ms = 10^{-5}\,s$$

$$VC(t) = V_0\ x\ e^{\frac{-t}{24\ x\ 10^5}}$$

To determine whether a particular series converges or diverges, we will need to use various mathematical tests and techniques, such as the comparison test, limit comparison test, ratio test, root test, integral test, alternating series test, or geometric series test. The choice of test will depend on the specific properties of the series and the information available about the terms in the sequence.

It is seen that this format is in geometric series format. The general formula of geometric series is:

$$\sum_{n=0}^{\infty} ar^n$$

When |r|<1, the series is convergent and the result of the series is $\frac{a}{1-r}$.

When the equation VC(t) is compared with the general formula of the geometric series, V_0 means the same as a and r is equal to $e^{\frac{-t}{24\ x\ 10^5}}$.

$$e^{\frac{-t}{24\ x\ 10^5}} = (e^{\frac{-1}{24\ x\ 10^5}})^t = (\frac{1}{e^{10^5/24}})^t$$

$$r = \frac{1}{e^{10^5/24}} = 0.9999995833$$

That is, it is seen that the r value is less than 1. Which means that the series is convergent.

When we are asked to write a Maclaurin series for Vc(t), the following steps are applied:

As obtained from the previous questions, it is known that the equation Vc(t) is as follows:

$$V(t) = V_\infty + (\,V_0 - V_\infty)\,e^{\frac{-t}{\tau}}$$

It is not known that the value V_∞ is 120 volts and the V_0 value is 80 volts. We stated that the tau value is the product of the resistance value and the capacitance value.

$$\text{Since } \tau = R\ x\ C = 4M\Omega \text{ x } 6\mu\text{F} = (4 \text{ x } 10^6)\Omega \text{ x } (6 \text{ x } 10^{-6})F = 24\ s$$

$$V(t) = 120 - 40e^{-t/24}$$

The Maclaurin series is a mathematical series expansion that represents a function as an infinite sum of simpler functions, each of which is a derivative of the original function evaluated at a specific point (usually zero). The Maclaurin series is a special case of the Taylor series, which is a more general form of series expansion that can be used to approximate a function around any point in its domain. The general formula for the Maclaurin series expansion of a function f(x) is:

$$\sum \frac{f^{(n)}(a).(x-a)^n}{n!}$$

In the Maclaurin series, the number a is considered 0:

$$\sum \frac{f^{(n)}(0).(x)^n}{n!}$$

The equation V(t) is considered as a function f(t).

$$f(t) = 120 - 40e^{-t/24}$$

$$f(0) = 80$$

$$f(t)^{(1)} = \frac{40}{24}e^{-t/24}$$

$$f(0)^{(1)} = \frac{5}{3}$$

$$f(t)^{(2)} = \frac{-5}{72} e^{-t/24}$$

$$f(0)^{(2)} = \frac{-5}{72}$$

$$f(t)^{(3)} = \frac{5}{1728} e^{-t/24}$$

$$f(0)^{(3)} = \frac{5}{1728}$$

…

…

…

The derivative of the f(t) function is taken and 0 is written instead of x and it continuous.

$$\sum f(t) = f(0) + f(0)^{(1)}x + \frac{f(0)^{(2)}x^2}{2!} + \frac{f(0)^{(3)}x^3}{3!} + \cdots$$

$$\sum f(t) = 80 + \frac{5}{3}x - \frac{5}{72}\frac{x^2}{2!} + \frac{5}{1728}\frac{x^3}{3!} - \cdots$$

$$\sum f(t) = 80 + \frac{1}{3}\left(5x - \frac{5}{24}\frac{x^2}{2!} + \frac{5}{576}\frac{x^3}{3!} - \cdots\right)$$

$$\sum f(t) = 80 + \frac{1}{3}\sum_{n=0}^{\infty} \frac{(-1)^n . 5 . x^{n+1}}{24^n . (n+1)!}$$

RESULT AND DISCUSSION

In general, relaxation oscillator circuits are widely used in various electronic applications due to their simple and low-cost design. By examining the behavior and characteristics of such circuits, we can gain insight into their practical applications and limitations. In this experiment, we analyzed a simple relaxation oscillator circuit and observed the behavior of the neon lamp and capacitor. Our theoretical calculations predicted the behavior of the circuit accurately, and the measured values in the laboratory were in good agreement with the predicted values. The results showed that the oscillator circuit can generate periodic waveforms with specific characteristics, making it suitable for various applications, such as in electronic instruments and communication systems. However, the circuit's limitations, such as the need for careful design and optimization for specific applications, should be taken into account when considering its use. Overall, the experiment demonstrated the importance and usefulness of relaxation oscillator circuits in electronics and their practical applications.

The circuit in the project is occurred with a voltage source 120V, a resistor 4M Ω, a capacitor 6μF and a neon bulb 120 Ω . The initial voltage of the capacitor is 0 V. The neon lamp lights up when the capacitor reaches 80 volts and turns off when it drops to 40 volts. Since the capacitor and the neon lamp are connected in parallel, the maximum value that the capacitor can reach is 80 volts. It completes its first cycle by charging from 0 volts to 80 volts, then discharging from 80 volts to 40 volts. Other cycles are completed by charging the capacitor from 40 volts to 80 volts and discharging from 80 volts to 40 volts, and so on.

As requested in the first and second questions, two time values were found. The first of these time values is the duration of the light and this value is 0.49906597 seconds. The other question asks for the charging time from 40 volts to 80 volts after the first charging and discharging of the capacitor, that is, after the first cycle, and this value is 16.6355323 seconds. It has been observed that these time values are affected by the value of the resistance and the value of the resistance of the lamp. The voltage of the lamp is equal to the voltage of the capacitor because they are in parallel. As soon as the voltage value of the capacitor reaches 80 volts, the lamp starts to draw current from the circuit. It is known that when the voltage of the lamp is between 80 and 40 voltage values, it draws current from the circuit. As soon as the capacitor's voltage drops to 40 volts, the lamp has an infinite resistance and no current flows through it. When the capacitor reaches 80 volts again this cycle starts again and so on.

The time constant obtained by multiplying the equivalent resistance and capacitance values is called tau (τ). This value increases with the increase of the equivalent resistance and capacitance. According to the experiments and observations made, as the time constant tau value increases, the charging and discharging speeds of the capacitor decrease and their duration increases.

For parallel plate capacitor, one plate of a parallel plate capacitor is filled with + charge and the other plate - with charge. As the distance ''d'' between them increases, the capacitance decreases, while the capacitance increases as the area of the plates increases. When the coefficient of the dielectric material placed between them increases, the capacitance also increases. A dielectric material is a poor conductor of electricity but an efficient supporter of electrostatic fields. It can store electrical charges, have a high specific resistance and a negative temperature coefficient of resistance. For cylindrical capacitor, as length of the cylinder increases, the capacitance increases. As the ratio of outer radius to inner radius increases, the capacitance decreases.

In this project, two capacitors are designed by hand doing calculation and two capacitors are fabricated by hand at the home with any materials we find. The capacitance of our designed capacitors is wanted to be equal to 6 microfarad and in this way, we find the unknowns such as the area and the distance. On the other hand, it is wanted to be calculated theoretical capacitance of the fabricated capacitors.

Theoretically, after making capacity calculation, we are asked to make an experimental capacity measurement. Measurements were made in the laboratory. Experimentally, after these measurements are made, experimental and theoretical results are compared and interpreted. When the theoretical and experimental results are compared, it is seen that there are minor differences. These differences may be caused by external factors such as heat and very small calculation errors. Nevertheless, experimental and theoretical results are very close. The result obtained by measuring the capacitance of a handmade parallel-plate capacitor made with materials such as aluminum foil, paper, glue, and electrical cable in a laboratory environment with a multimeter result is 5.09 nF. When the necessary formulas are used to find the theoretical result, the theoretical result of the parallel plate capacitor is found as 5.26575 nF. The result obtained by measuring the capacitance of a handmade parallel-plate capacitor made with materials such as aluminum foil, paper, glue, and electrical cable in a laboratory environment with a multimeter result is 1.183 nF. When the necessary formulas are used to find the theoretical result, the theoretical result of the parallel plate capacitor is found as 1.10709235 nF. Firstly, theoretical results are obtained through mathematical or computational models that make assumptions about the system being studied. These assumptions may not always hold true in reality, which can result in a difference between the theoretical and experimental results.

There are several external factors that can affect the process of making capacitors at the laboratory. The dielectric constant of the materials used to create the capacitor might be impacted by the humidity level in the surrounding environment. Inaccurate capacitance measurements may result from the materials absorbing moisture due to high humidity, which might alter their electrical characteristics. The capacitor's capacitance value may also be impacted by the temperature at which it was manufactured. Too much heat can damage or distort the materials, which will reduce the precision of the capacitance measurement. Contaminants such as dust, oils, and other particles can affect the capacitance value of the capacitor by altering the dielectric properties of the materials used. The quality and precision of the equipment and tools used to make the capacitor can also affect its performance. If the equipment or tools are not calibrated correctly or are of poor quality, it can lead to inaccuracies in the capacitance value or a lower overall performance of the capacitor.

Therefore, it is common to observe differences between theoretical and experimental results, and it is important to take into account the limitations and assumptions of both approaches when interpreting and comparing results. However, it is still important to carefully control for these external factors to ensure accurate capacitance values and optimal performance of the capacitor.

When we look at the mathematical questions, it is obtained that the series requested from us is a geometric series. A geometric series is a type of infinite series where each term is obtained by multiplying the previous term by a fixed ratio. Looking at the general formula of the geometric series specified in the solution of the question, 'a' is the first term and 'r' is the common ratio between successive terms. Geometric series can have both positive and negative terms, depending on whether 'r' is greater than or less than 1, respectively. When the absolute value of the common ratio, |r|, is less than 1, the series is convergent. When

$|r|$ is greater than or equal to 1, the series either diverges to infinity or oscillates without settling on a finite value.

Geometric series are important in mathematics and its applications because they can be used to model many phenomena, including compound interest, population growth, and radioactive decay. They are also useful in the analysis of algorithms, signal processing, and many other fields.

In the other question of mathematics, it is asked to obtain a Maclaurin series. A Maclaurin series is a specific type of Taylor series, which is a mathematical tool used to represent a function as an infinite sum of terms involving powers of a variable. The difference between the two is that a Maclaurin series is a Taylor series evaluated at $x=0$, while a Taylor series can be evaluated at any point.

The formula for the Maclaurin series of a function $f(x)$ is given by the sum of an infinite sequence of terms, where each term involves a power of x multiplied by a coefficient that depends on the value of the derivative of the function evaluated at $x=0$. The coefficients are determined by the formula.

The convergence of the Maclaurin series depends on the behavior of the function and its derivatives. If the function and all its derivatives are continuous and well-behaved in some interval around $x=0$, then the Maclaurin series will converge to the function within that interval. The convergence may be uniform, meaning that the error between the function and the Maclaurin series is bounded by a constant, or it may be pointwise, meaning that the error tends to zero as x approaches 0.

Maclaurin series are useful in many areas of mathematics and its applications, such as physics, engineering, and computer science. They can be used to approximate the values of functions, solve differential equations, and analyze the behavior of complex systems. The accuracy of the approximation depends on the number of terms retained in the series, as well as the behavior of the function and its derivatives.

CONCLUSION

In conclusion, the experiment of an RC circuit, designing capacitors, and fabricating capacitors has provided valuable insights into the principles and applications of capacitors in modern electronics. Through the experiment of an RC circuit, we were able to observe the charging and discharging of a capacitor and how it affects the behavior of the circuit. This experiment demonstrated the importance of capacitors in regulating voltage and filtering signals in electronic circuits.

Moreover, designing and fabricating capacitors allowed us to explore the different methods and materials used in the production of capacitors. We were able to gain hands-on experience with constructing capacitors using simple materials such as aluminum foil and paper, as well as understanding the precision techniques used in industrial settings. The process of designing and fabricating capacitors also helped us to understand the various factors that impact the performance of capacitors, such as the thickness and composition of the capacitor layers, the area and spacing of the plates, and the properties of the dielectric material.

Overall, the experiment of an RC circuit, designing capacitors, and fabricating capacitors has enhanced our understanding of the important role that capacitors play in modern electronics. By gaining a deeper understanding of the principles and applications of capacitors, we can better appreciate their importance in electronic circuits and related fields. We hope that this report will serve as a valuable resource for those interested in capacitor design and fabrication and inspire further exploration and innovation in this exciting field.

Additionally, there could have been external factors that could have affected the accuracy of the measurements, such as changes in temperature, humidity, or electromagnetic interference. These factors could have introduced noise or interference in the circuit, leading to inaccuracies in the measurements.

To address these potential sources of error, future experiments could be conducted under controlled environmental conditions, such as in a temperature- and humidity-controlled laboratory. Additionally, the use of shielding or filtering techniques could be employed to minimize the effects of electromagnetic interference on the measurements.

Another factor that could affect the accuracy of the measurements is the skill and experience of the experimenter. Even with high-quality components and accurate instruments, an inexperienced experimenter may make mistakes in the setup or measurement process that could lead to inaccurate results. Therefore, it is important to ensure that the experimenter has the necessary knowledge and experience to conduct the experiment correctly.

Furthermore, the accuracy of the measurements could be affected by the limitations of the measuring instruments themselves. For example, the range and resolution of the instruments could limit their ability to measure small or large values accurately. To address this, a range of measuring instruments with varying sensitivities and ranges could be used to cross-check and validate the results obtained.

Overall, while the current experiment provides useful insights into the behavior of the circuit, further experiments using higher-quality components, more accurate instruments, and under controlled environmental conditions would be necessary to confirm the results obtained and increase the confidence in the conclusions drawn.

REFERENCE LIST

- **https://commons.wikimedia.org/wiki/File:Parallel_plate_capacitor.svg**
- **https://www.researchgate.net/figure/Cylindrical-capacitor_fig4_314304591**
- **https://www.youtube.com/watch?v=WC2sZ5iJ7gQ**
- **https://www.youtube.com/watch?v=GveI9gXIsHw&t=167s**
- **Sears and Zemanskys University Physics with Modern Physics, 13th Edition, Hugh D. Young, Roger A. Freedman**
- **Fundamentals_of_Electric_Circuits_6th_Sadiku**
- **https://en.wikipedia.org/wiki/Neon_lamp**