Department of

Electrical & Electronics Engineering

Abdullah Gül University

Project Report

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EE1200 Electronic System Design (ESD) Capsule

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Grade: / 100

OBJECTIVE

The purpose of this project is to create parallel plate capacitors and cylindrical capacitors using household items, and to make modifications to these capacitors to observe the resulting changes. In the second part of the project, an experiment was designed to measure the capacitance values of the constructed capacitors without using a multimeter. Theoretical and measured values were compared by altering certain parameters to observe changes.

In part three, the capacitor was connected in series with a resistor and fed with a triangular wave of specified frequency and amplitude. Subsequently, the definition of Fourier series and FFT (Fast Fourier Transform) was discussed, and how changes in capacitance affect waveform shapes was investigated.

In part four, calculations were performed while supplying the circuit with a constant voltage value. Part five involved exploring certain series in the mathematical aspect of the project and investigating convergence and divergence properties.

BACKGROUND

An electronic circuit is made up of separate electronic parts connected by conductive wires that allow current to flow, such as resistors, transistors, capacitors, inductors, and diodes.[1]

According to Ohm's law, the voltage across two locations and the electric current flowing through a conductor between them are directly related.

$$v = I \cdot R$$

where V denotes voltage, I denotes current, and R denotes resistance. [2] Also, there is another commonly used law that Kirchhoff's circuit rules. They are a pair of equalities that address the lumped element model of electrical circuits' current and potential difference, or voltage. German physicist Gustav Kirchhoff initially characterized them in 1845.[3]

A capacitor is a tool used in electrical engineering that accumulates electric charges on two closely spaced, isolated surfaces to store electrical energy. [4] The kind of capacitors known as parallel plate capacitors are made up of an electrode and dielectric material configuration. Electrodes are formed by the two conducting plates. Between them, there is a dielectric. This serves to separate the plates. The size of the parallel plate capacitor's two plates are the same. They're wired into the power source. A positive charge is obtained by the plate when it is connected to the battery's positive terminal. Conversely, a negative charge is acquired by the plate that is linked to the battery's negative terminal. Owing to the attraction, charges are somewhat imprisoned within the capacitor's plates. This is the formula for parallel capacitance $C = \frac{\varepsilon_0 \cdot A}{d}$[5]

The hollow or solid cylindrical conductor that surrounds the concentric hollow spherical cylinder is the component of the cylindrical capacitor. A lot of electrical devices, including electric juicers, flour mills, and motors, employ capacitors. Between every capacitor, there is a different potential difference. The proper grouping of capacitors to provide the required capacitance is needed in many electrical circuits.. Capacitance is measured in Farads (F). Also the formula for cylindrical capacitor is $c = \frac{\varepsilon_0 \cdot 2\pi L}{\ln\left[\frac{b}{a}\right]}$[6]

A circuit having a resistor (R) and a capacitor (C) is known as an RC circuit. Electronic equipment frequently use RC circuits. Additionally, they are crucial for the electrical signals that nerve cells transmit.

A resistor connected in series with a capacitor can regulate how quickly it charges or discharges energy. This results in an exponential temporal dependence, which is distinctive. The "time constant" R C is a critical quantity that characterizes the time dependence. [7]

ANALYTICAL AND SIMULATION PROCEDURES

1. First, the necessary materials for making a capacitor at home were identified and purchased.
2. For creating a parallel plate capacitor, pieces were cut from thick cardboard according to the purchased sponge, and aluminum foil was attached to provide conductivity. These cardboard pieces were then glued together.
3. When making a cylindrical capacitor, a suitable jar was first selected along with a chosen nail for conductivity. The exterior of the jar was wrapped with aluminum foil, and the jar lid was pierced to attach the nail.
4. Initially, a resistor was connected to a breadboard, and a circuit was created by connecting an oscilloscope and a signal generator. The resulting circuit was then connected to the capacitors individually.
5. The parameters chosen for modification included adjusting the distance \(d \) for the parallel capacitor and changing the length of the external cylinder for the cylindrical capacitor, which

required altering the length of the aluminum foil accordingly. Additionally, the submerged portion of the nail within the jar's water was adjusted accordingly.

6. First, the signal generator and oscilloscope were set up, and the value of Δx was noted. Then, to eliminate the effect of air, the positive end of the circuit was disconnected, and the Δx values were noted again. By finding the differences, the values of τ were obtained.
7. The found τ values were equated to the product of RC to obtain the capacitance values.
8. These capacitance values were equated using specific formulas for each capacitor, solving equations to find ε_0 values. By taking averages, the average $\varepsilon_0$values of the dielectric materials used were determined, and capacitance values were calculated from the formulas.
9. The requested graphs were plotted.
10. A circuit was set up again, and using the Fourier series summation of a triangular wave, sinusoids were expressed as the sum.
11. By attaching an oscilloscope probe again, only the voltage passing through the resistor was measured, and the changing capacitance values were examined by altering the parameters.
12. Desired outcomes were obtained using FFT (Fast Fourier Transform) analysis tools.
13. When a constant voltage V was applied to the circuit, Kirchhoff's loop rule was applied, and the voltages across the capacitor and resistor were expressed in terms of $q(t)$, yielding the desired results.
14. Finally, the maximum charge qmax value was found for the resistor value considered as an infinite series, and research was conducted.

Aluminum	Thick cardboard	Electrical tape	Glue	Jar	Nail	Water
Ruler	oscilloscope probe	Crocodile clip	Breadboard	Resistor	Signal generator	oscilloscope

Table1: used things

RESULTS

i. Capacitors are devices that are expected to be charged by placing a dielectric material between two conductive materials. In this project, parallel plate and cylindrical capacitors are investigated.[8]

In parallel plate capacitors, the conductor between the two plates is slightly open. A dielectric material, such as air or vacuum, which can polarise the electric field, is placed in this gap. The plates are then connected to a voltage source, such as a battery. And a charge is expected to build up between the plates. In the capacitor designed for this project, two pieces of cardboard of the same dimensions were cut for the plates. Then the cardboards were covered with aluminium foil to provide conductivity. Sponge was used as the dielectric material placed between the plates. Finally, the plates were secured with electrical tape and the parallel plate capacitor was completed. [9]

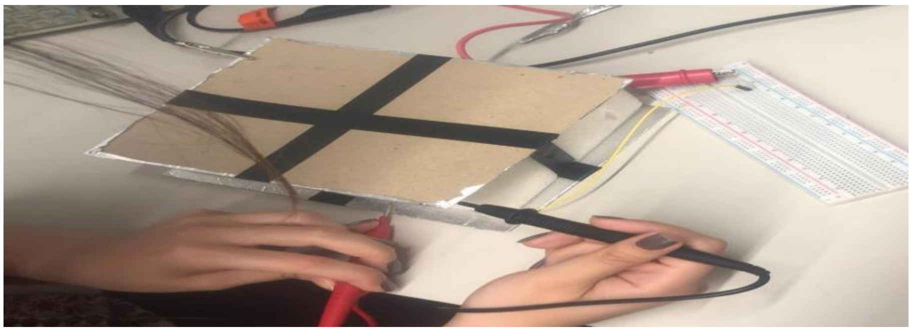


Figure 1: Picture of designed parallel plate capacitor

To make a cylindrical capacitor, a hollow or solid cylindrical conductor is placed inside a concentric hollow spherical cylinder. To design a cylindrical capacitor, aluminium foil was wrapped around the circumference of a jar and the lengths measured .Then the outer cylinder of the capacitor was created. The inside of the glass was then filled with water as the dielectric material. A nail was inserted through the lid of the jar as an inner cylinder. To prevent the nail from being affected by the electric field, the part of the nail that came out of the lid of the jar was wrapped in electrical tape.[10]

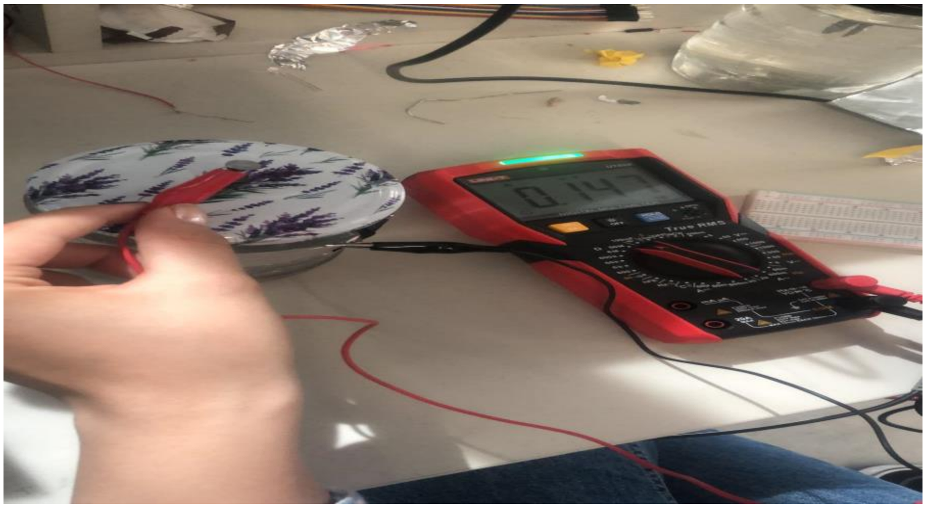


Figure 2:Picture of cylindrical capacitor

ii.

Design an experiment for measuring the capacitance of the capacitors you designed in part i (do not use a multimeter's capacitance measurement setting, we expect to see a circuit design), and compare your results with your theoretical design. You should present:

Since capacitance cannot be measured with a multimeter, a series resistor is connected to the circuit. The aim is to measure the capacitance using τ, the time constant in RC circuits, and the associated formula.

$$\tau = R \times C$$

τ is the charge or discharge time in seconds, R is the resistance in ohms and C is the capacitance in farads.

a) Your circuit diagram and related calculations clearly explaining why and how this circuit measures the capacitance.

Cylindrical Capacitor:

The 10k ohm resistor and capacitor connected to the circuit was given a wave and measurements were taken using an oscilloscope. The Dx value on the oscilloscope expresses the time scale. As an example of how the designed circuit works, a square wave with an amplitude of 5vpp, a frequency of 10k Hz and an offset of 2.5mV was applied to the cylindrical capacitor. The outer circumference of the can was surrounded by a 4cm length of aluminium around the top circumference of the can. When calculating the charge or discharge time (τ) in RC circuits, the time value related to the signal reaching 63% of the initial value or falling is evaluated. The τ value is found by using the value of 3.16V, which is 63% of the dy value, which expresses the vertical distance at which the signal reaches a certain height or falls. Also,to obtain more reliable results, the capacitance of the medium in which the experiment takes place is subtracted from the capacitance of the cylinder capacitor.

When L is equal 3 cm;

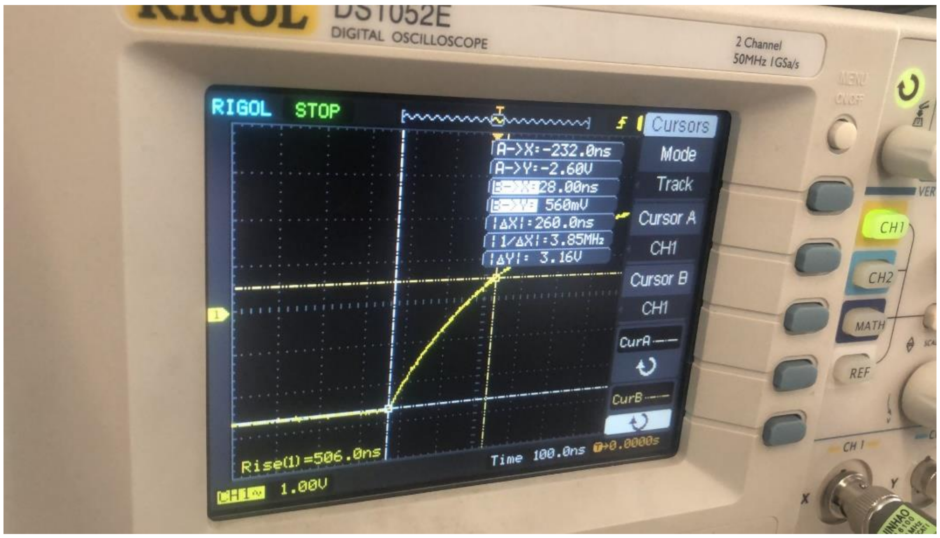


Figure 3: Δx value to be subtracted due to the sensitivity of the oscilloscope

$$\tau = R \times C$$

$$\tau_{air} = 260\text{ns} = 0.260\mu\text{s}$$

$$0.260\mu\text{s} = 10\text{k} \times c_{air}$$

$$0.260\mu\text{s} = 10\text{k} \times c_{air}$$

$$c_{air} = \frac{0.260 \times 10^{-6} s}{10 \times 10^{3}} F$$

$$c_{air} = 26.0\text{pF}$$

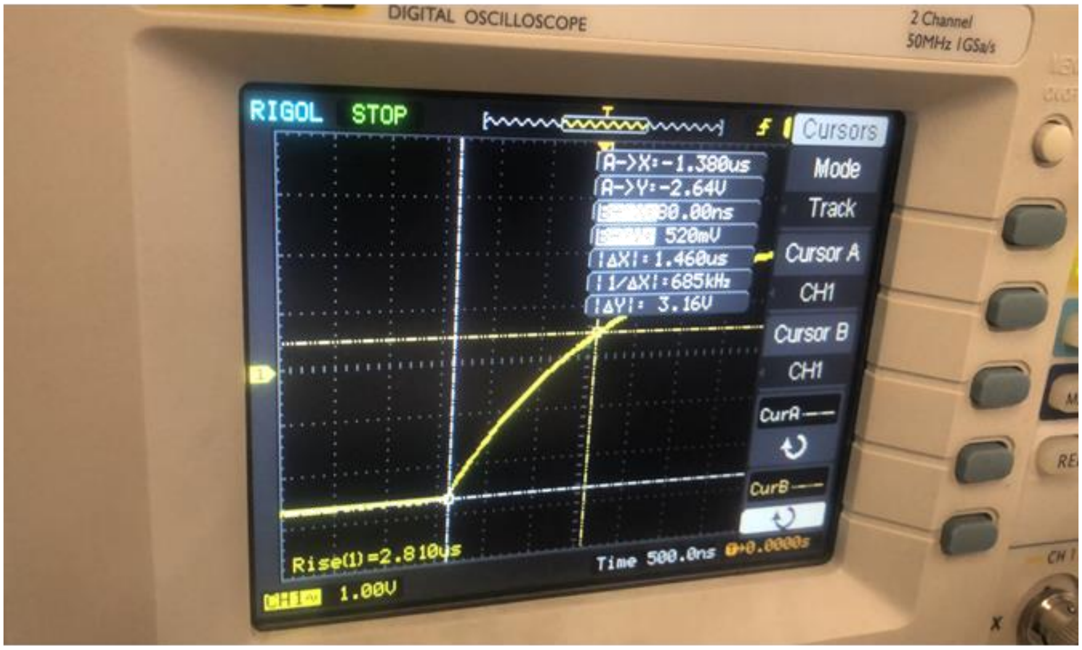


Figure 4: Δx values of capacitance at 3.16V

$$\tau = R \times C$$
$$1.460\text{us} = R \times C$$
$$1.460\text{us} = 1.460 \times 10^{-6} s$$
$$C = \frac{1.460 \times 10^{-6} s}{10 \times 10^{3}} F$$
$$C = 146 \text{ pF}$$

Subtraction is performed only to calculate the capacitance of the cylindrical capacitor.

$$c_{net} = 146 - 26 = 120 \text{ pF}$$

For the ε_0 value in this formula, the dielectric coefficient of air is taken (8.85×10^{-12} F/m). Due to the glass, water and other factors in the jar, the calculation is carried out over 4cm to obtain the ε_r value as one.

$$\text{C} = \frac{2\pi\varepsilon_0\varepsilon_R L}{ln\left(\frac{r_2}{r_1}\right)}$$

$$\varepsilon_0\varepsilon_R = \frac{c \times \ln\left(\frac{r_b}{ra}\right)}{2\pi L}$$

$$\ln\left(\frac{4.5}{0.66}\right) \sim 1.92$$

$$\varepsilon_0\varepsilon_R = \frac{120 \times 10^{-12} \times 192 \times 10^{-2}}{2\pi 4.10^{-2}} = 916.7322472 \times 10^{-12} \text{F/m}$$

The dielectric constant of water varies with temperature. At room temperature (approximately

20°C or 68°F), the dielectric constant of water is around 78.5.

$$\varepsilon_R = \frac{120\times10^{-12}\times192\times10^{-2}}{2\pi4.10^{-2}\times8.85\times10^{-12}}$$ =23,040/222.42476=104.268967

Therefore, the dielectric constant of glass is approximately determined as follows.

104.268967/78.5=1.3282671.

The capacitance value of the cylindrical capacitor calculated according to the capacitance formula is as follows.

$$C = \frac{2\pi\varepsilon_0\varepsilon_R L}{ln\left(\frac{r_2}{r_1}\right)}$$

The circumference of the part of the jar covered with aluminum was calculated as 28 cm.

$C = 2\pi r_2$

$$28 = 2\pi r_2$$

$$r_2 = 4.45633840657307cm$$

$$r_2 \sim 4.5cm$$

The circumference of the nail considered as the inner digest was calculated as 1.5cm.

$C = 2\pi r_1$

$$0.4 = 2\pi r_1$$

$$r_1 = 0.06366198cm$$

$$r_1 \sim 0.066cm$$

The capacitance formula of a cylindrical capacitor is $C = \frac{2\pi\varepsilon_0\varepsilon_R L}{ln\left(\frac{r_2}{r_1}\right)}$.

Accordingly, the inner radius is 0.66cm, the outer radius is 4.5cm and L equals 5cm. When substituted in the formula, the operations are as follows.

$$C = \frac{2\pi\varepsilon_0\varepsilon_R L}{ln\left(\frac{r_2}{r_1}\right)}$$

Parallel Plate Capacitor:

A wave was applied to the 10k ohm resistor and capacitor that were linked to the circuit, and measurements were made with an oscilloscope. The oscilloscope's Dx value indicates the time scale. A square wave with an amplitude of 5 volts per phase, a frequency of 10k hertz, and offset of 2.5 millivolts was applied to the parallel plate capacitor to demonstrate the operation of the intended circuit. A sponge was placed between 2 plates with an area of 260.26 square metres and connected to the oscilloscope. The value of 3.16V, or 63% of the dy value, which indicates the vertical distance at which the signal reaches a particular height or falls, is used to find the τ value. Additionally, the capacitance of the medium used for the experiment is deducted from the capacitance of the cylinder capacitor to get more accurate findings. For example, the length of the sponge is fixed as 5.4cm and a square wave is given.

When d is equal to 5.4 cm;

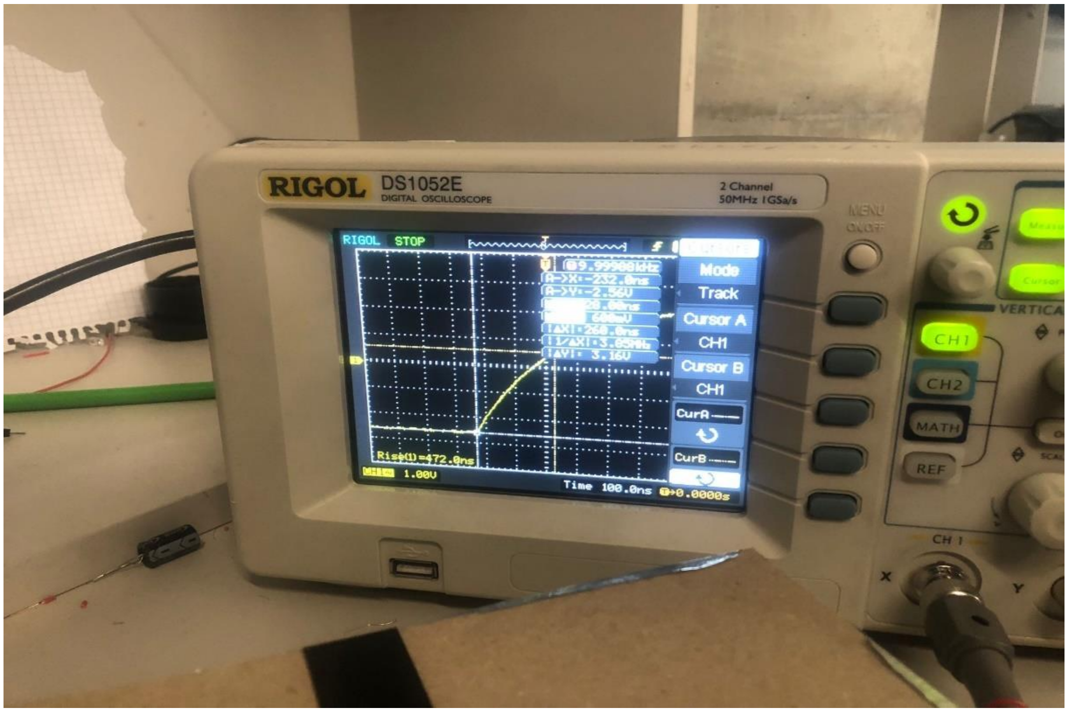


Figure 5:Δx value to be subtracted due to the sensitivity of the oscilloscope

$$\tau = R \times C$$

τ_{air}=260ns=0.260μs

$$0.260\mu s = 10k \times c_{air}$$

$$0.260\mu s = 10k \times c_{air}$$

$$c_{air} = \frac{0.260 \times 10^{-6} s}{10 \times 10^{3}} F$$

$$c_{air} = 26.0\text{pF}$$

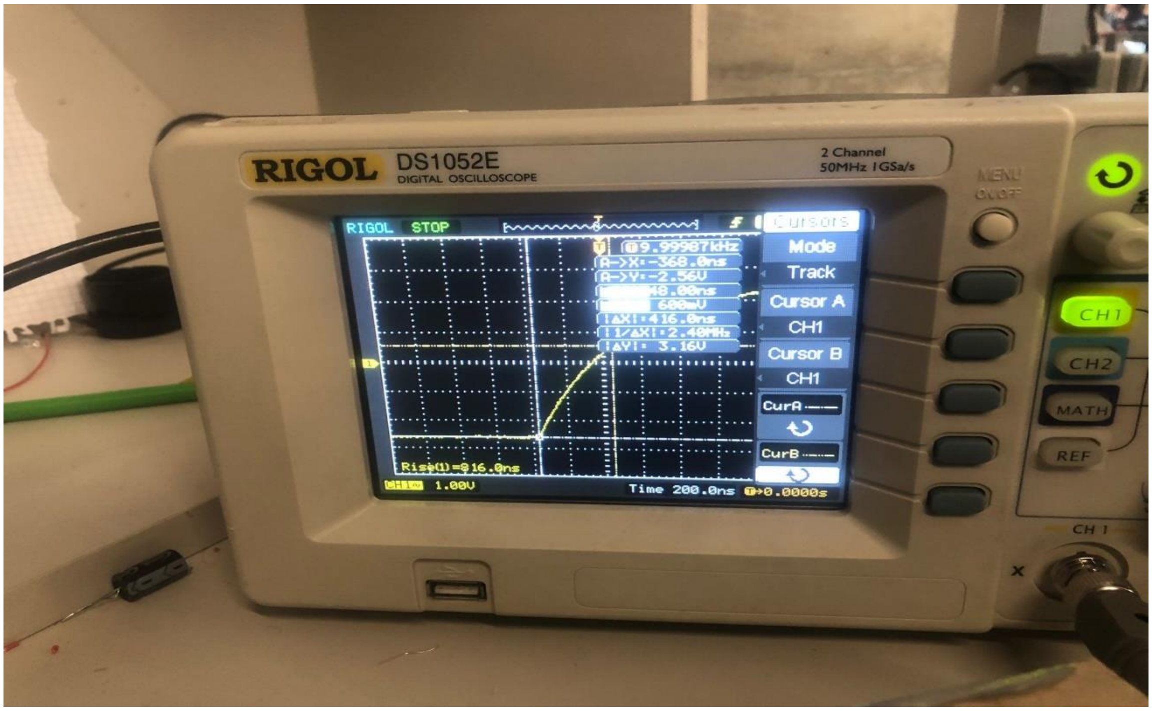


Figure 6: Delta x value at 3.16v

$$\tau = R \times C$$

$$416\text{ns} = R \times C$$

$$416\text{ns} = 416 \times 10^{-9} s$$

$$C = \frac{416 \times 10^{-9} s}{10 \times 10^{3}} F$$

$$C = 41.6\text{ pF}$$

Subtraction is performed only to calculate the capacitance of the parallel plate capacitor.

$$c_{net} = 41.6 - 26 = 15.26\text{ pF}$$

$$\tau = R \times C$$

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

$$188\times 10^{-12}\text{F} = \frac{\varepsilon_0 \varepsilon_r \times 260.26\times 10^{-3}}{5\times 10^{-2}}$$

$$\varepsilon_0 \varepsilon_r = \frac{188\times 10^{-12}\times 5\times 10^{-2}}{260.26\times 10^{-3}}$$

For the ε_0 value in this formula, the dielectric coefficient of air is taken (8.85×10^{-12} F/m). The capacitance values found in the experiment were substituted in the formula and an average value was taken for Er. Er value is taken as 2.67.

b)

LTSpice Simulations

Cylindrical Capacitor

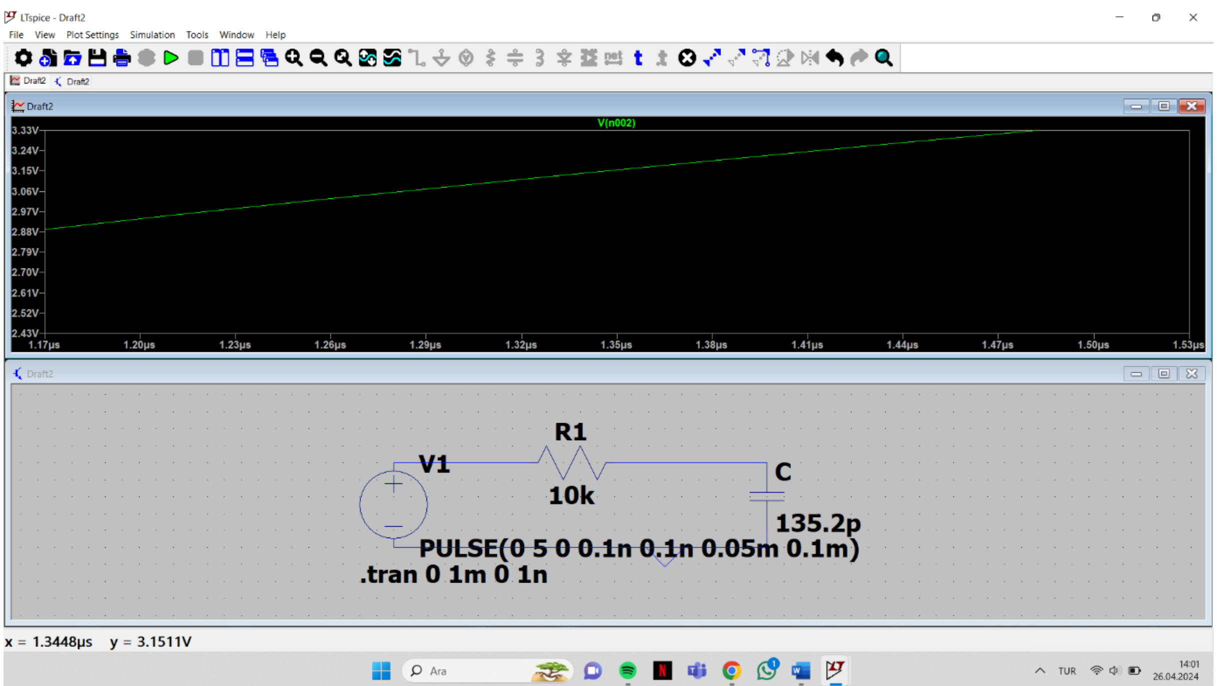


Figure 7: The mechanism in which the jar is covered with 3 cm aluminum foil and a 3 cm nail is dipped into the water

The x value obtained is the tau value in the ideal circuit.

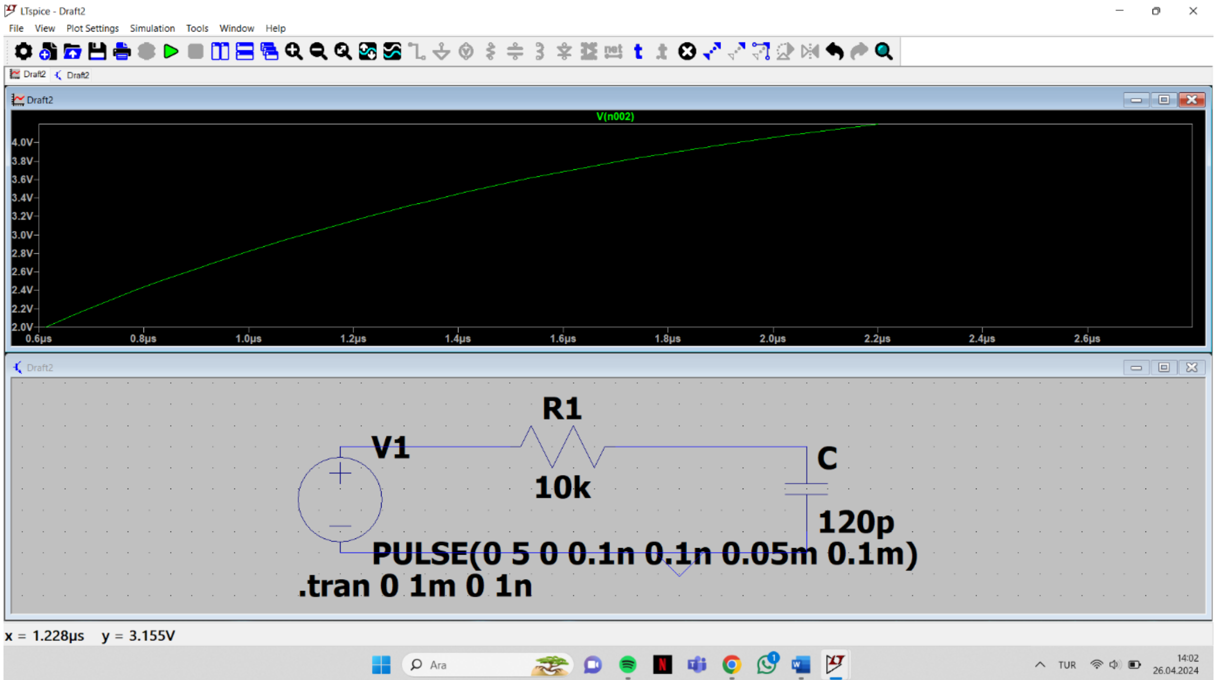


Figure 8:The mechanism in which the jar is covered with 4 cm aluminum foil and a 4 cm nail is dipped into the water

The x value obtained is the tau value in the ideal circuit.

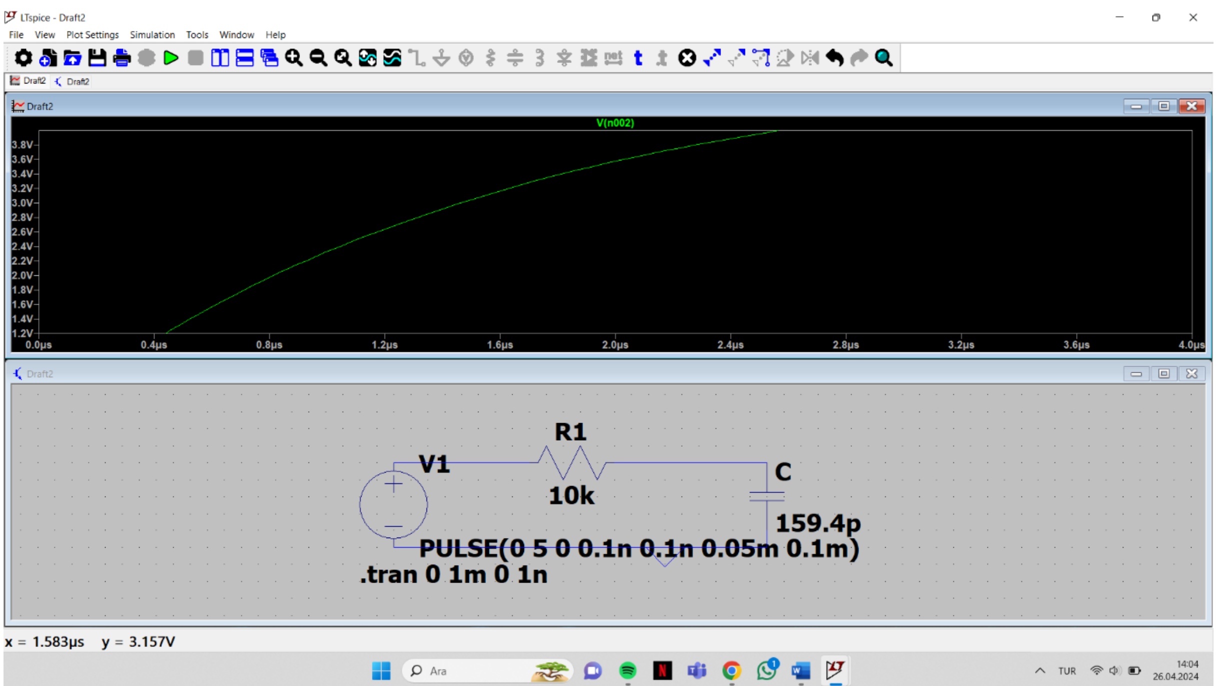


Figure 9: The mechanism in which the jar is covered with 5 cm aluminum foil and a 5 cm nail is dipped into the water

The x value obtained is the tau value in the ideal circuit.

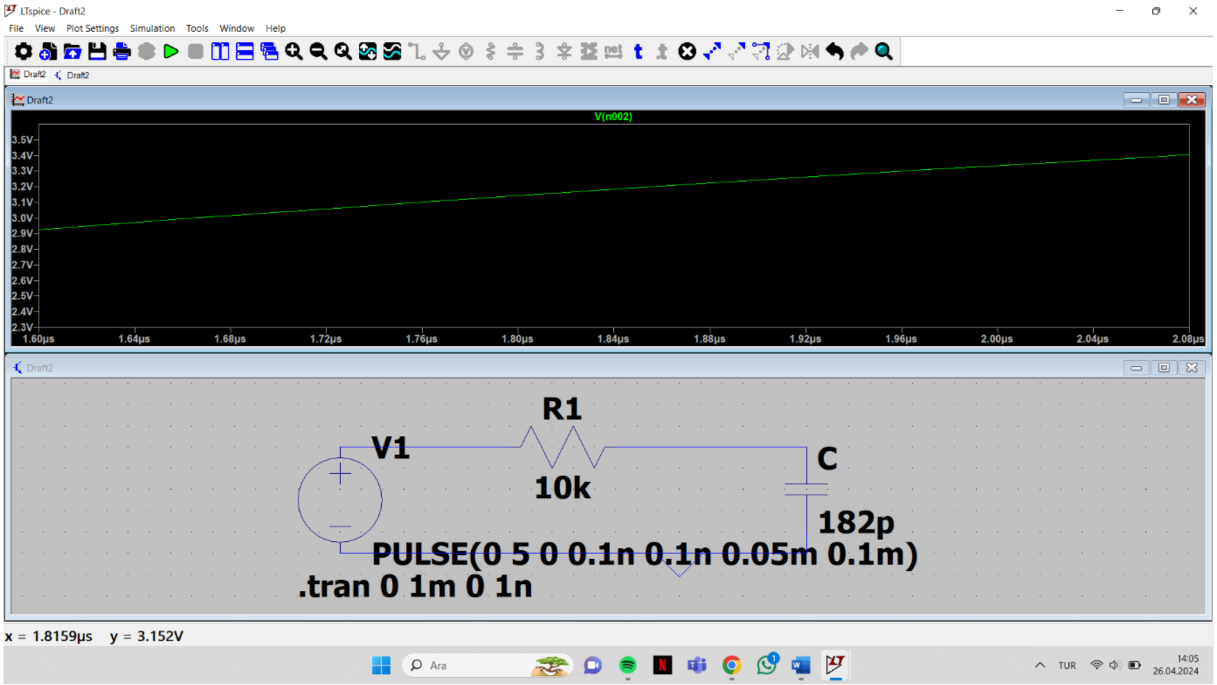


Figure 10: The mechanism in which the jar is covered with 7 cm aluminum foil and a 7 cm nail is dipped into the water

The x value obtained is the tau value in the ideal circuit.

Parallel Capacitor

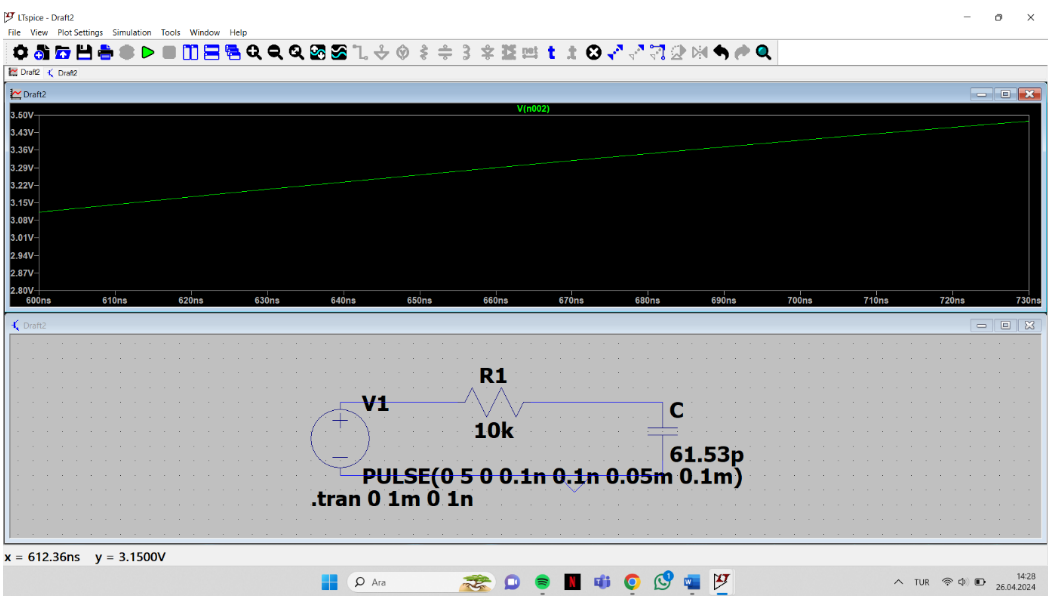


Figure 11:The capacitor and circuit diagram after being pressed 1 cm onto the parallel plates

The x value obtained is the tau value in the ideal circuit.

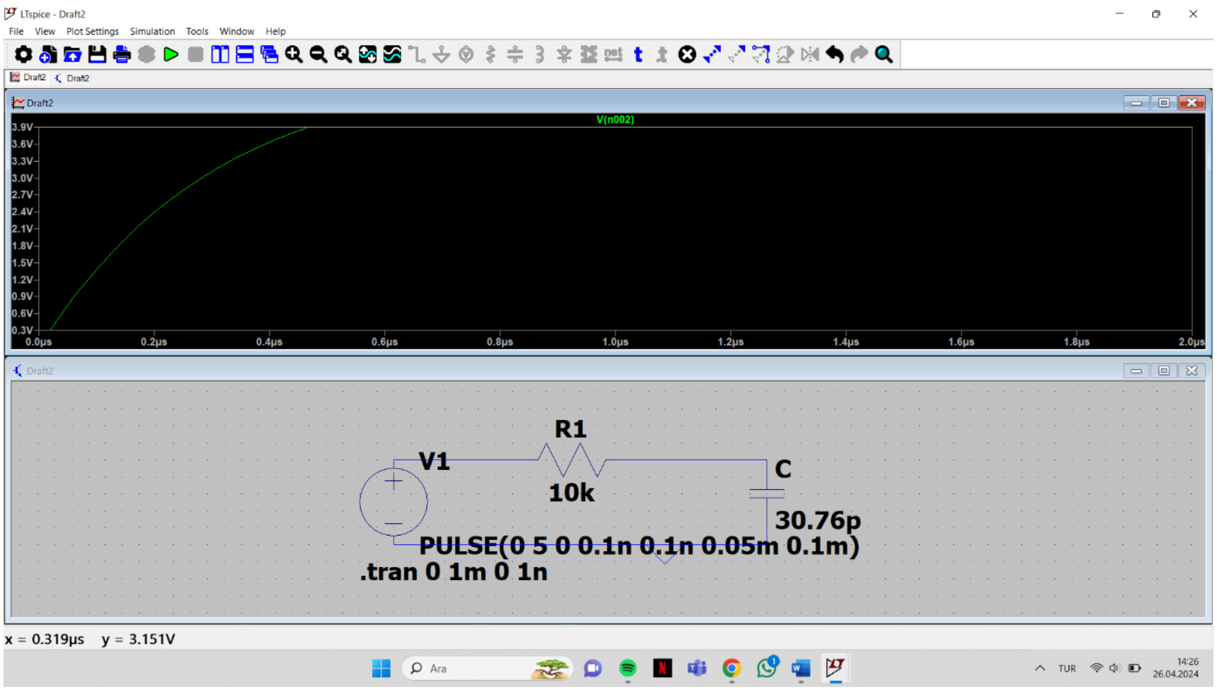


Figure 12: The capacitor and circuit diagram after being pressed 2 cm onto the parallel plates

The x value obtained is the tau value in the ideal circuit.

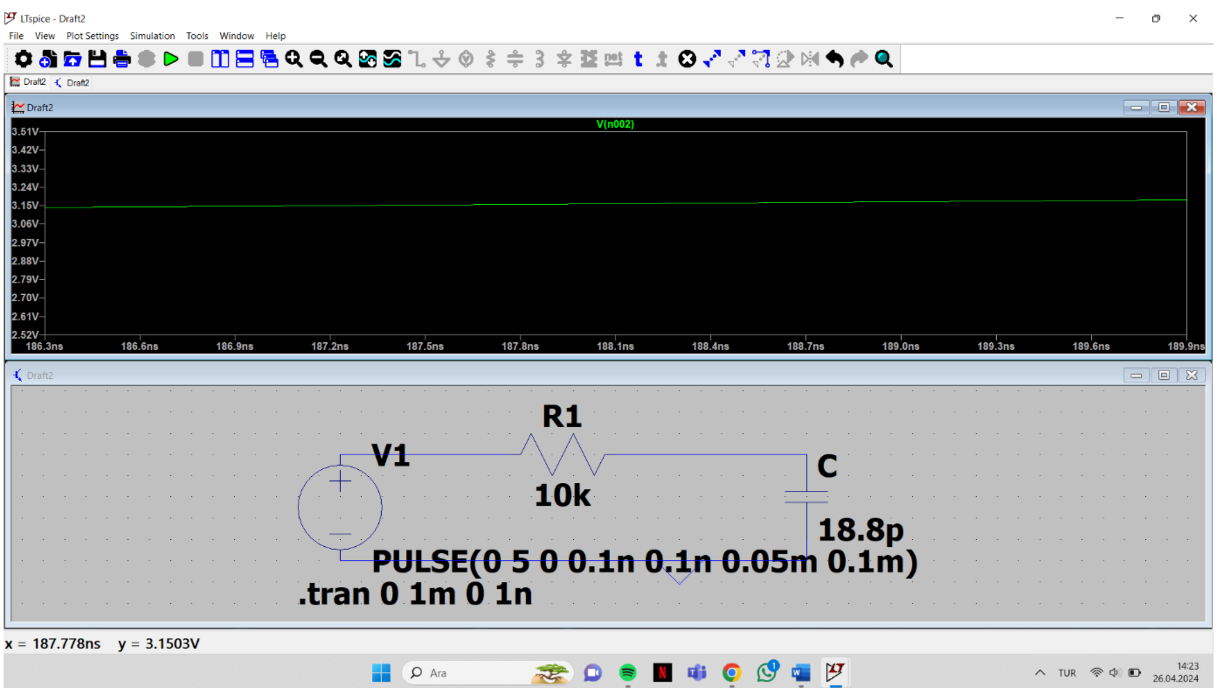


Figure 13: The capacitor and circuit diagram after being pressed 3cm onto the parallel plates

The x value obtained is the tau value in the ideal circuit.

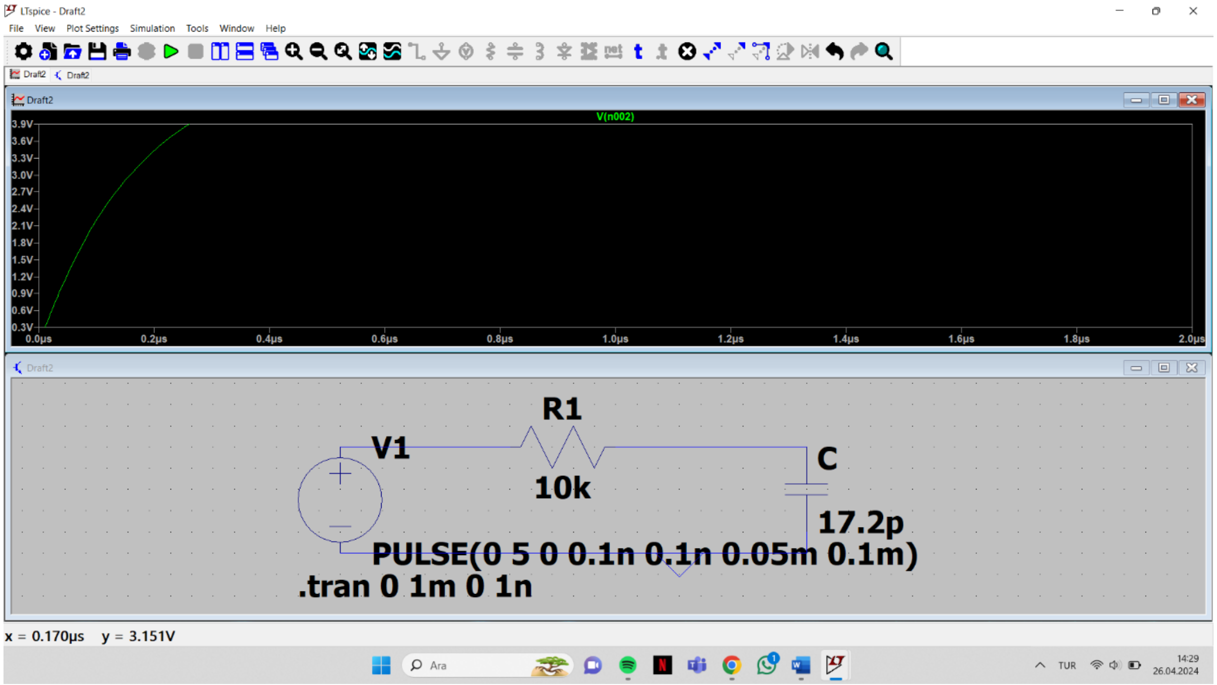


Figure 14: The capacitor and circuit diagram after being pressed 4 cm onto the parallel plates

The x value obtained is the tau value in the ideal circuit.

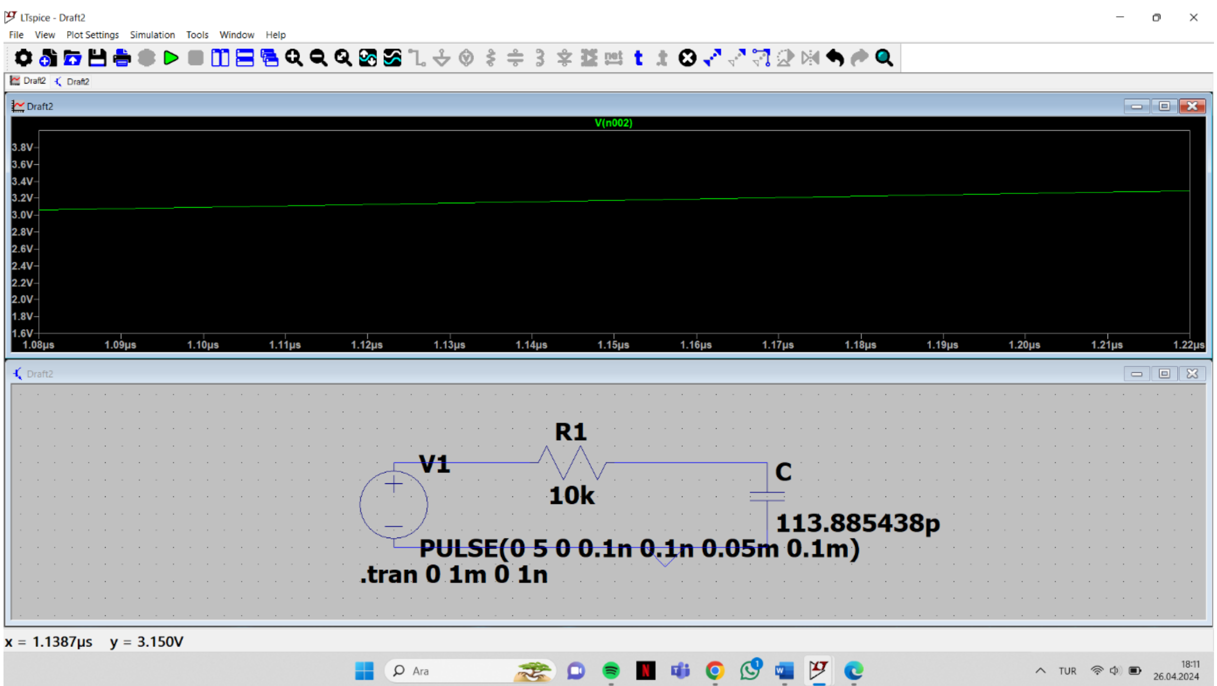


Figure 15: The capacitor and circuit diagram after being pressed 5.4 cm onto the parallel plates

The x value obtained is the tau value in the ideal circuit.

The tau values obtained from Ltspice were close to the tau values obtained from the oscilloscope.

c) Plots of theoretical capacitance vs. the parameter that you use to change the capacitances for parallel-plate and cylindrical capacitors?

The parameter L (length) is used fo

r cylindrical capacitors, while the parameter d (distance) is used for parallel plate capacitors.

Cylindrical capacitor:

$$C = \frac{2\pi\varepsilon_0\varepsilon_R L}{ln\left(\frac{r_2}{r_1}\right)}$$

$$\varepsilon_0\varepsilon_R = \frac{c \times \ln\left(\frac{r_b}{ra}\right)}{2\pi L}$$

$$\ln\left(\frac{4.5}{0.66}\right) \sim 1.92$$

$$\varepsilon_0\varepsilon_R = \frac{120\times10^{-12}\times192\times10^{-2}}{2\pi 4.10^{-2}} = 916.7322472 \times 10^{-12} \text{F/m}$$

When L is equal 3cm;

The formula used to theoretically calculate capacitance is as follows.

$$C = \frac{2\pi\varepsilon_0\varepsilon_R L}{ln\left(\frac{r_2}{r_1}\right)} = \frac{2\pi\times916.73\times10^{-12}\times3\times10^{-2}}{192\times10^{-2}} = 89.9997573\times 10^{-12}\text{F} = 89.9997573\text{pF}$$

When L is equal 4 cm;

The formula used to theoretically calculate capacitance is as follows.

$$C = \frac{2\pi\varepsilon_0\varepsilon_R L}{ln\left(\frac{r_2}{r_1}\right)} = \frac{2\pi\times916.73\times10^{-12}\times4\times10^{-2}}{192\times10^{-2}} = 119.999676\times 10^{-12}\text{F} = 119.999676 \text{ pF}$$

When L is equal 5 cm;

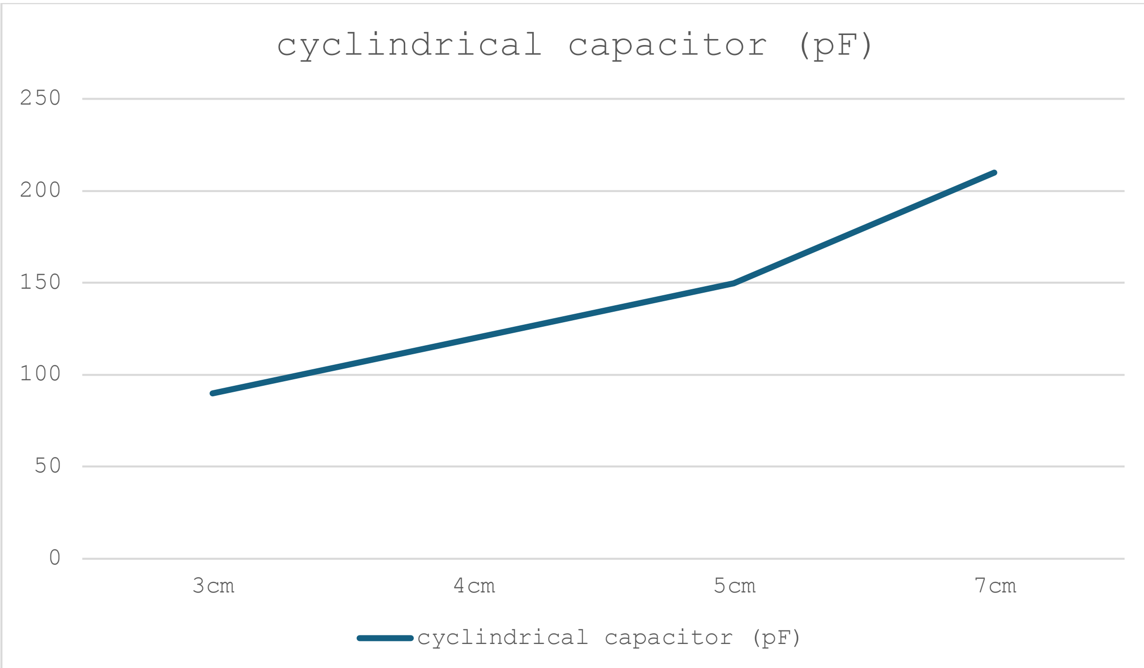
The formula used to theoretically calculate capacitance is as follows.

$$C = \frac{2\pi\varepsilon_0\varepsilon_R L}{ln\left(\frac{r_2}{r_1}\right)} = \frac{2\pi\times916.73\times10^{-12}\times5\times10^{-2}}{192\times10^{-2}} = 149.999595\times 10^{-12}\text{F} = 149.999595\text{pF}$$

When L is equal 7 cm;

The formula used to theoretically calculate capacitance is as follows.

C $=\frac{2\pi\varepsilon_0\varepsilon_R L}{ln\left(\frac{r_2}{r_1}\right)}=\frac{2\pi\times916.73\times10^{-12}\times7\times10^{-2}}{192\times10^{-2}}$ = 209.999434$\times 10^{-12}$F =209.999434pF



Graph 1: theoretically calculated cylindrical capacitor values and they are

The parameter distance (d) is used for parallel plate capacitors, while the parameter d (distance) is used for parallel plate capacitors.

Parallel Plate Capacitor:

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

$$\varepsilon_0\varepsilon_r = 23.6295 \times 10^{-12}\text{F}$$

When d is equal 5.4cm;

The formula used to theoretically calculate capacitance is as follows.

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

$$\varepsilon_0\varepsilon_r = 23.6295 \times 10^{-12}\text{F}$$

$$C = \frac{23.6295 \times 10^{-12} \times\ 260.26 \times 10^{-3}}{5.4 \times 10^{-2}}$$

C=113.885438$\times\ 10^{-12}$F =11.3885438pF

When d is equal 4cm;

The formula used to theoretically calculate capacitance is as follows.

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

$$\varepsilon_0 \varepsilon_r = 23.6295 \times 10^{-12}\text{F}$$

$$C = \frac{23.6295 \times 10^{-12} \times\ 260.26 \times 10^{-4}}{4 \times 10^{-2}}$$

C=$153.745342 \times 10^{-12}$F = 15.3745342pF

When d is equal 3cm;

The formula used to theoretically calculate capacitance is as follows.

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

$$\varepsilon_0 \varepsilon_r = 23.6295 \times 10^{-12}\text{F}$$

$$C = \frac{23.6295 \times 10^{-12} \times\ 260.26 \times 10^{-4}}{3 \times 10^{-2}}$$

C=$204.993759 \times 10^{-12}$F = 20.4993759pF

When d is equal 2cm

The formula used to theoretically calculate capacitance is as follows.

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

$$\varepsilon_0 \varepsilon_r = 23.6295 \times 10^{-12}\text{F}$$

$$C = \frac{23.6295 \times 10^{-12} \times\ 260.26 \times 10^{-4}}{2 \times 10^{-2}}$$

C=$307.490684 \times 10^{-12}$F = $30.7490684pF$

When d is equal 1cm

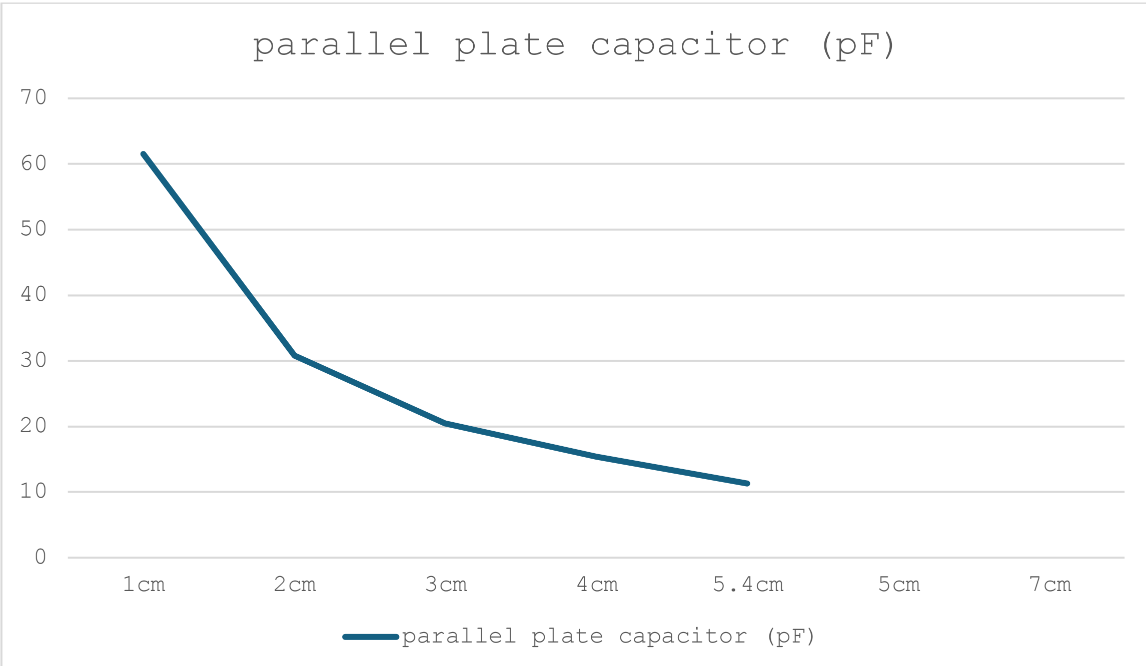
The formula used to theoretically calculate capacitance is as follows.

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

$$\varepsilon_0 \varepsilon_r = 23.6295 \times 10^{-12}\,\mathrm{F}$$

$$C = \frac{23.6295 \times 10^{-12} \times 260.26 \times 10^{-4}}{1 \times 10^{-2}}$$

C=61.49$\times 10^{-12}$F =61.49pF



Graph 2:theoritically calculated parallel plate values

d)

Plots of measured capacitance vs. your parameter that you use to change the capacitances for parallel-plate and cylindrical capacitor.

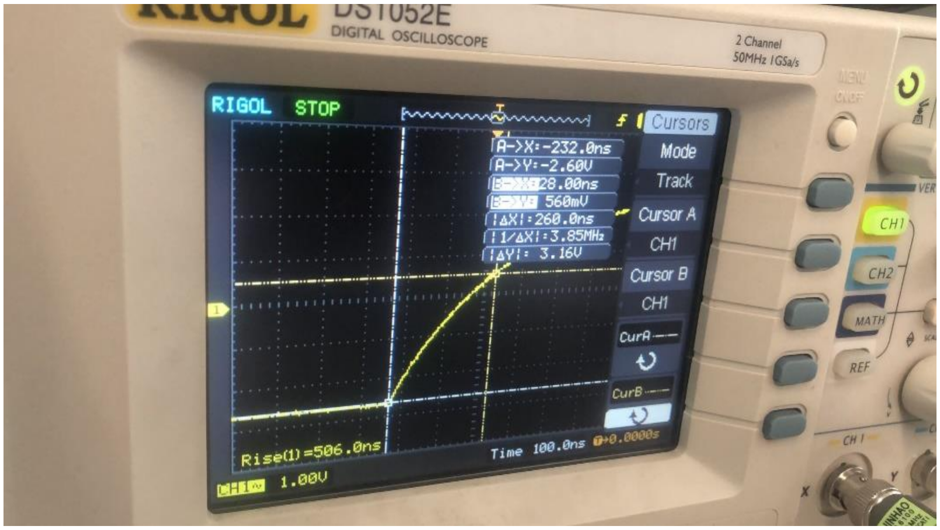


Figure 16: dx values in oscilloscope at 3cm

When L equals to 3cm;

$$\tau = R \times C$$

$$\tau_{air} = 260\text{ns} = 0.260\mu\text{s}$$

$$0.260\mu\text{s} = 10\text{k} \times c_{air}$$

$$0.260\mu\text{s} = 10\text{k} \times c_{air}$$

$$c_{air} = \frac{0.260 \times 10^{-6} s}{10 \times 10^{3}} F$$

$$c_{air} = 26.0\text{pF}$$

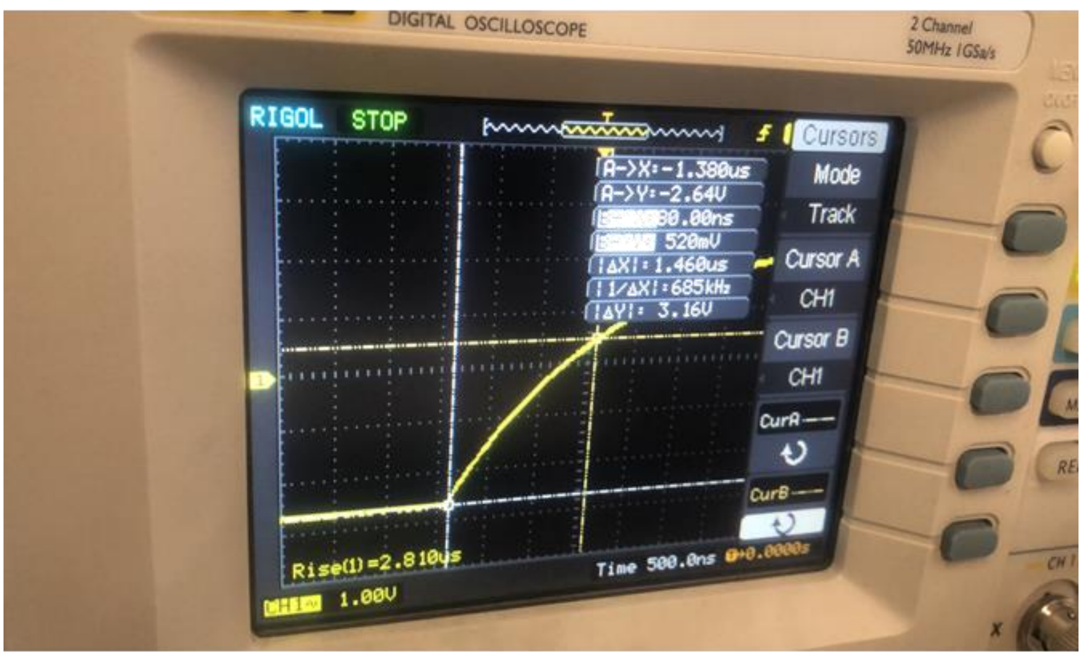


Figure 17: the value of measured air at 3cm

$$\tau = R \times C$$

$$1.460\text{us} = R \times C$$

$$1.460\text{us} = 1.460 \times 10^{-6} s$$

$$C = \frac{1.460 \times 10^{-6} s}{10 \times 10^{3}} F$$

$$C = 146 \text{ pF}$$

Subtraction is performed only to calculate the capacitance of the cylindrical capacitor.

$$c_{net} = 146 - 26 = 120 \text{ pF}$$

When L is equal 4 cm;

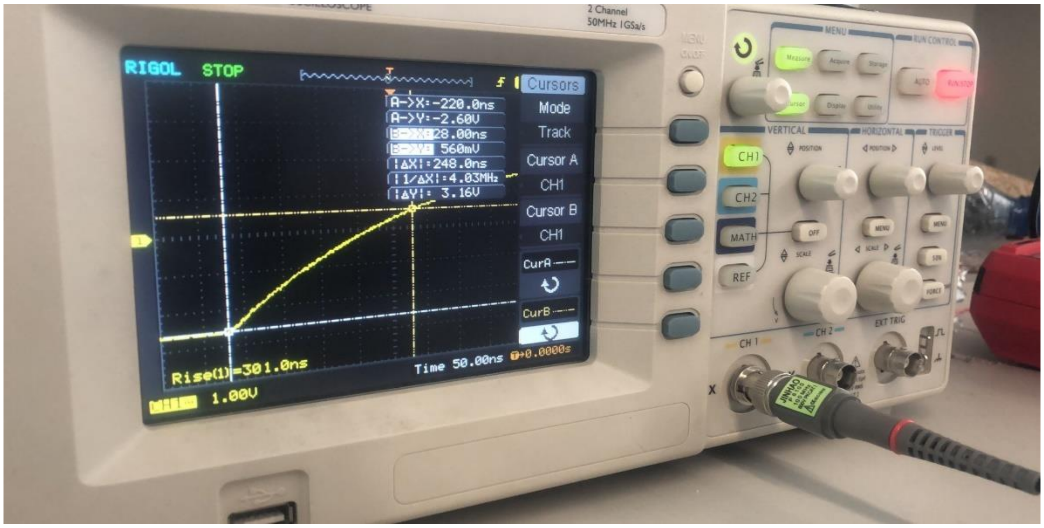


Figure 18: the value of measured air at 4cm

$$\tau = R \times C$$

$$\tau_{air} = 248\text{ns} = 0.248\mu\text{s}$$

$$0.248\mu\text{s} = 10\text{k} \times c_{air}$$

$$0.248\mu\text{s} = 10\text{k} \times c_{air}$$

$$c_{air} = \frac{0.248 \times 10^{-6} s}{10 \times 10^{3}} F$$

$$c_{air} = 24.8\text{pF}$$

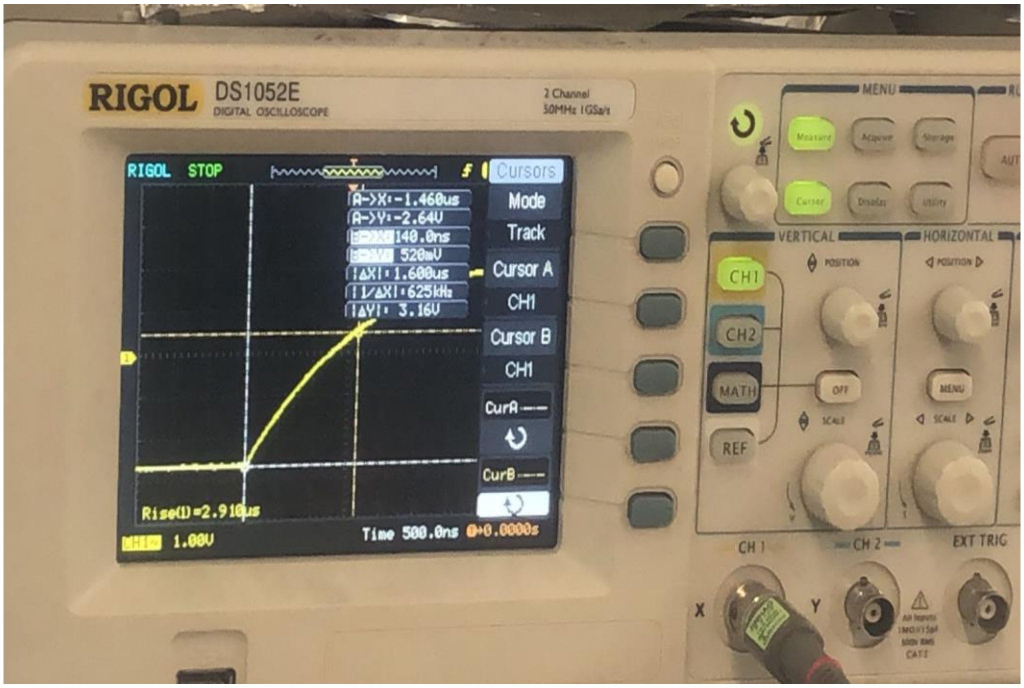


Figure 19: dx value at 4cm

$$\tau = R \times C$$

1.600us= $R \times C$

1.600us=1.600$\times 10^{-6}s$

$$C = \frac{1.600\times 10^{-6}s}{10\times 10^{3}}F$$

C=*160* pF

Subtraction is performed only to calculate the capacitance of the cylindrical capacitor.

c_{net} =*160-24.8=135.2* pF

When L is equal 5cm;

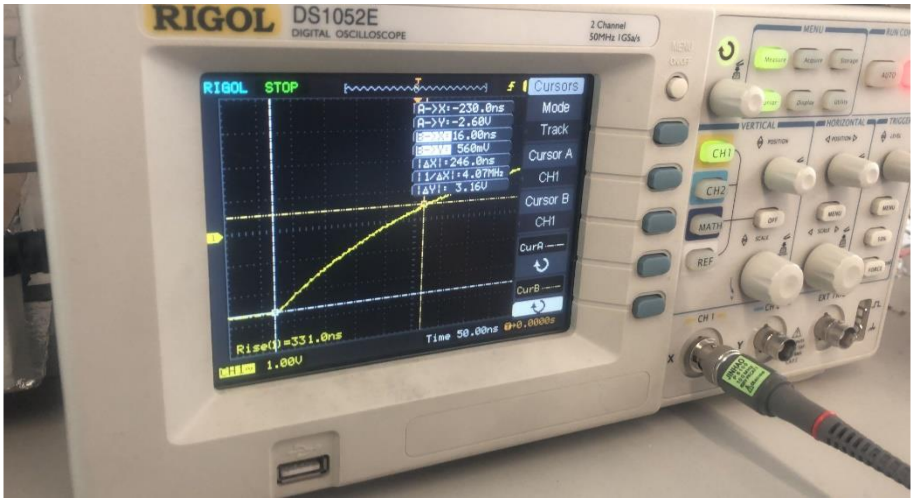


Figure 20:The values of the measured air

$$\tau_{air}\text{=256ns=0.246μs}$$

$$\tau_{air}\ \text{=0.256μs=}\ R \times C$$

$$\text{0.256μs=10k} \times c_{air}$$

$$c_{air} = \frac{0.256 \times 10^{-6} s}{10 \times 10^{3}} F$$

$$c_{air} = 25.6\text{pF}$$

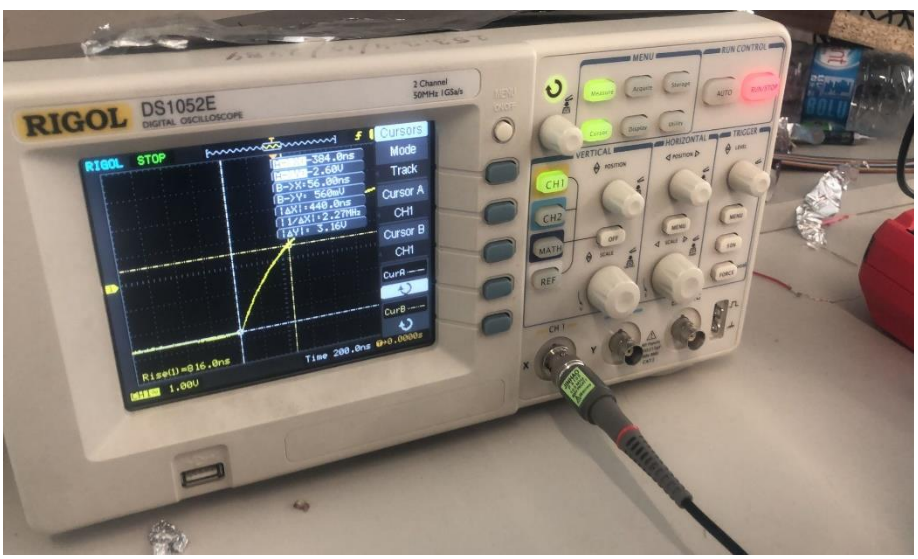


Figure 21: The values of measued in capacitor at 5cm

$$\tau = 1.840us = 1.840 \times 10^{-6}\text{sn}$$

$$\tau = R \times C = 1.840 \times 10^{-6}$$

$$C\text{=}\ \frac{1.840 \times 10^{-6} s}{10 \times 10^{3}} F$$

$$C = 184\text{pF}$$

Subtraction is performed only to calculate the capacitance of the cylindrical capacitor

$$c_{net} = 184 - 24.6 = 159.4 \text{ pF}$$

When L is equal 7cm;

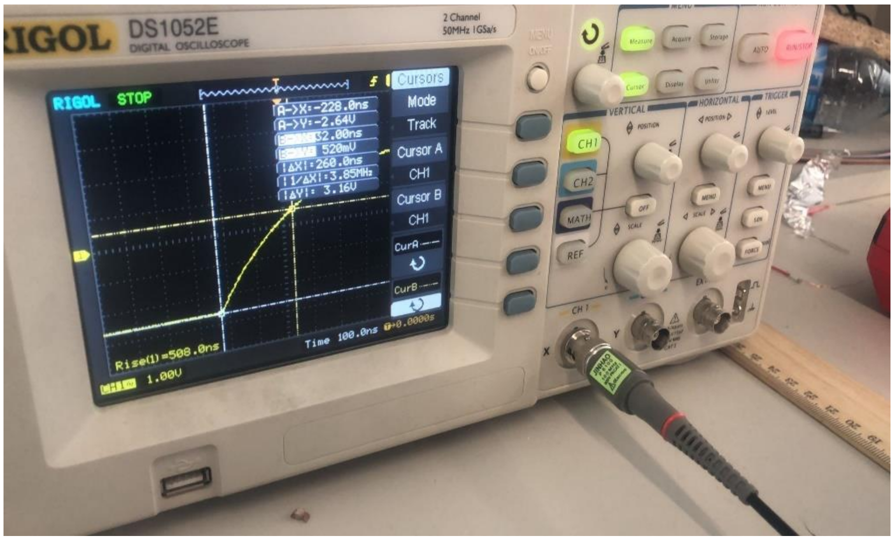


Figure 22: measured air value at 7cm

$$\tau = R \times C$$

$$\tau_{air} = 260\text{ns} = 0.260\mu\text{s}$$

$$0.260\mu\text{s} = 10\text{k} \times c_{air}$$

$$0.260\mu\text{s} = 10\text{k} \times c_{air}$$

$$c_{air} = \frac{0.260 \times 10^{-6} s}{10 \times 10^{3}} F$$

$$c_{air} = 26.0\text{pF}$$

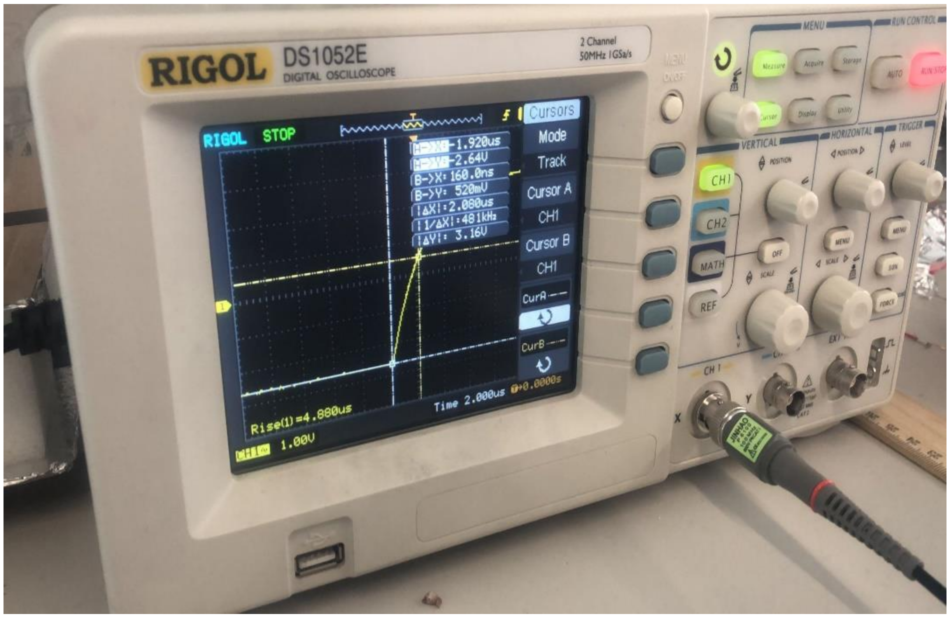


Figure 23: delta x value at 7cm

$$\tau = R \times C$$

2.080us= $R \times C$

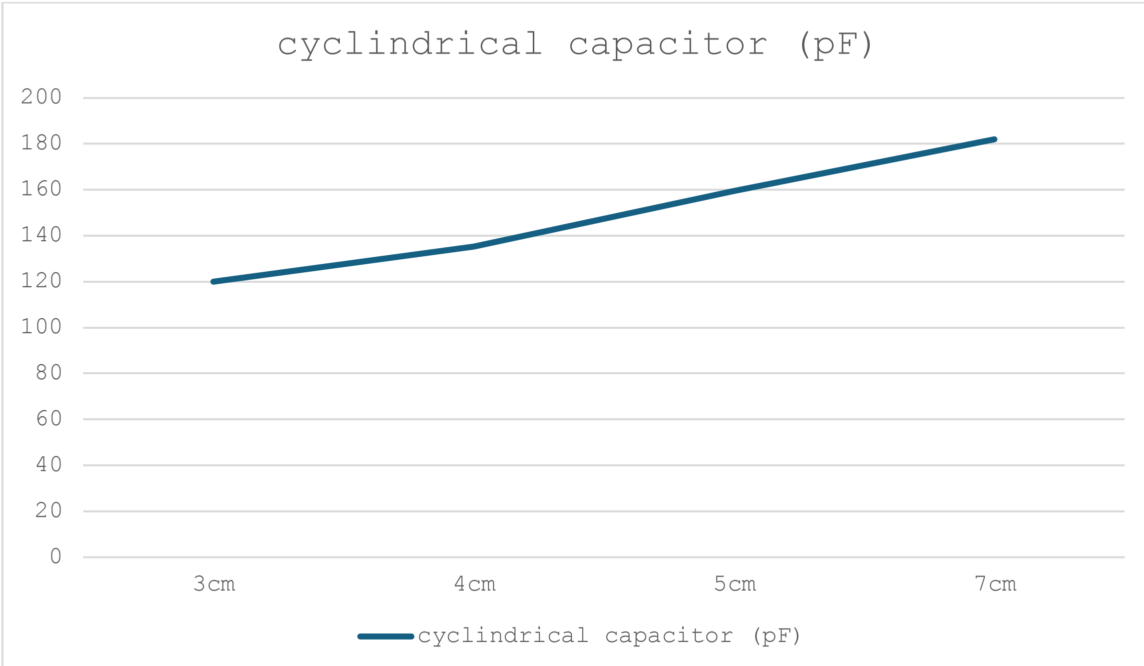
2.080us=2.080$\times 10^{-6} s$

$$C = \frac{2.080\times10^{-6}s}{10\times10^{3}} F$$

C=208 pF

Subtraction is performed only to calculate the capacitance of the cylindrical capacitor.

c_{net} *=208-26=182* pF



Graph 3: measured cylindrical capacitance values

Parallel Plate Capacitor

When d is equal 5.4 cm;

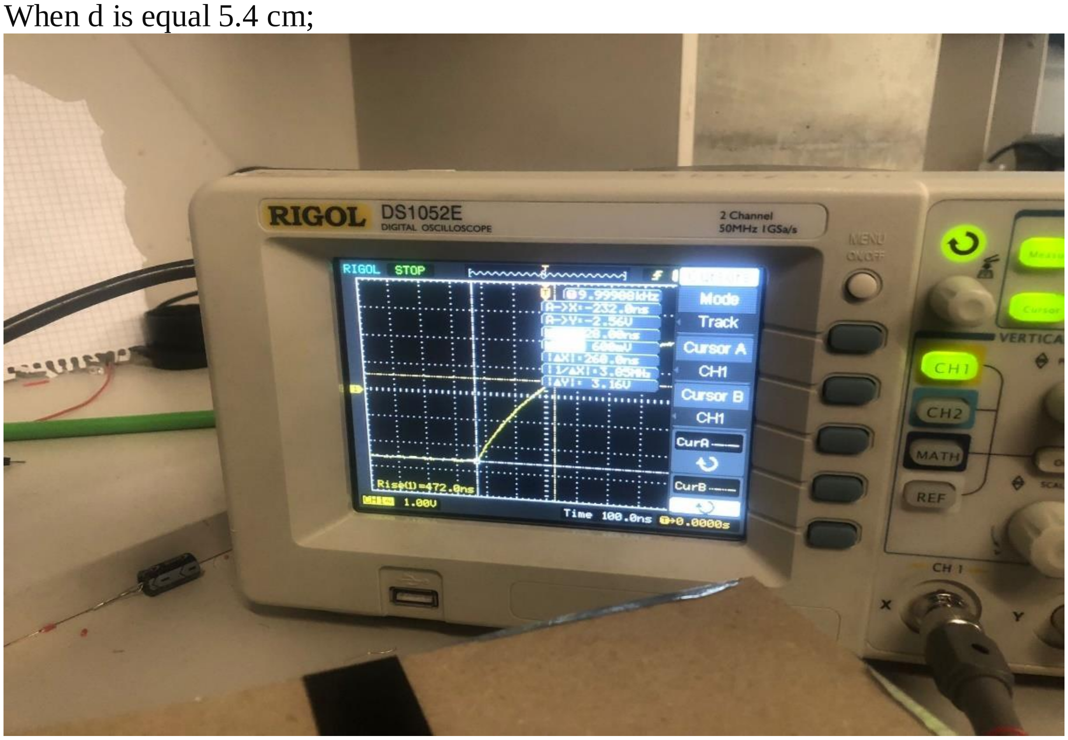


Figure 24: measured air at 5.4 cm

$$\tau = R \times C$$

τ_{air}=260ns=0.260µs

0.260µs=10k $\times$ c_{air}

0.260µs=10k $\times$ c_{air}

$$c_{air} = \frac{0.260 \times 10^{-6} s}{10 \times 10^{3}} F$$

c_{air} = 26.0pF

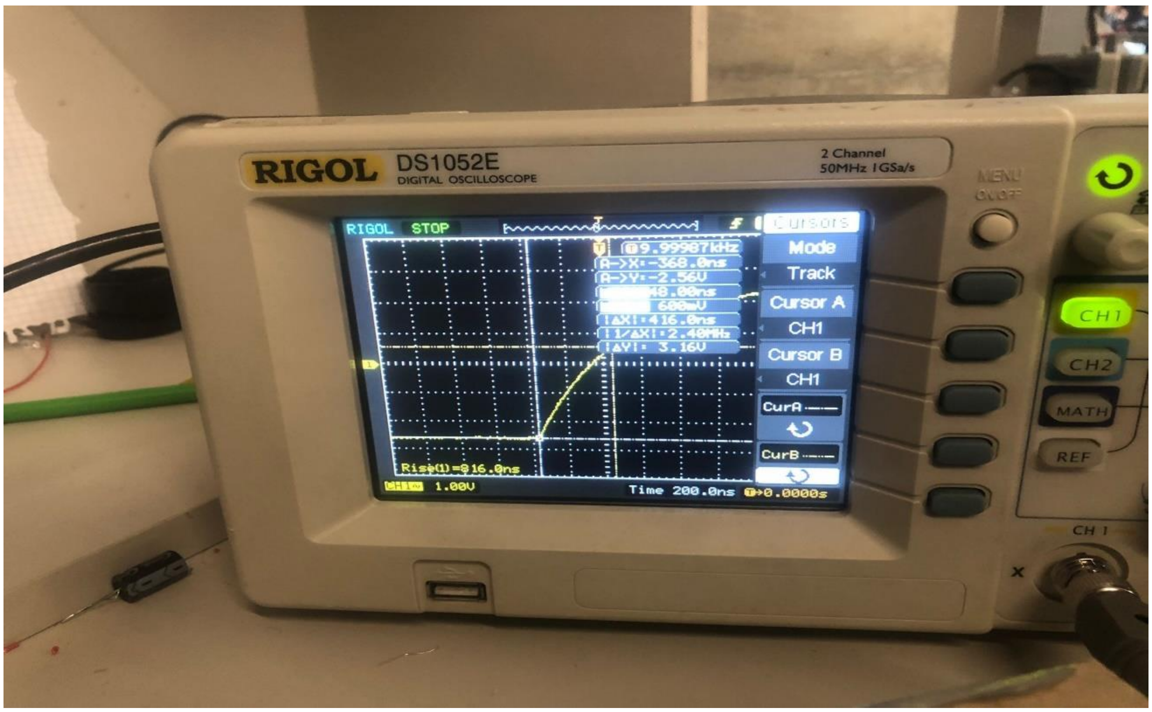


Figure 25: delta x value at 5.4 cm

$$\tau = R \times C$$

416ns= $R \times C$

416ns=416$\times$ $10^{-9} s$

C= $\frac{416 \times 10^{-9} s}{10 \times 10^{3}} F$

C=41.6 pF

Subtraction is performed only to calculate the capacitance of the parallel plate capacitor.

c_{net} =*41.6-26=15.26* pF

When d is equal 4 cm;

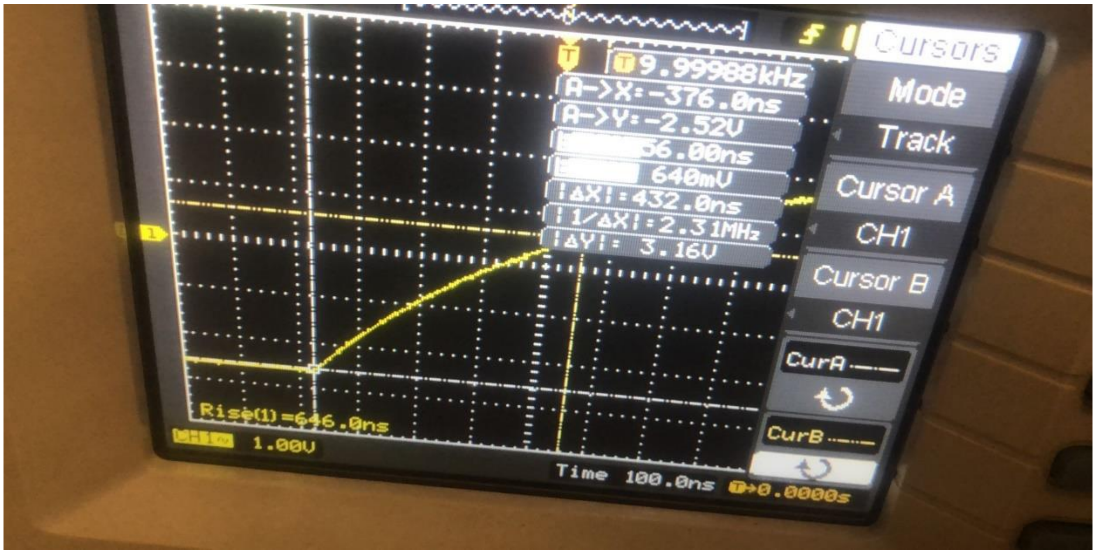


Figure 26: delta x value at 4cm

$$\tau = R \times C$$

$$432\text{ns} = R \times C$$

$$432\text{ns} = 432 \times 10^{-9} s$$

$$C = \frac{432 \times 10^{-9} s}{10 \times 10^{3}} F$$

$$C = 43.2 \text{ pF}$$

Subtraction is performed only to calculate the capacitance of the parallel plate capacitor.

$$c_{net} = 43.2 - 26 = 17.2 \text{ pF}$$

When d is equal 3 cm;

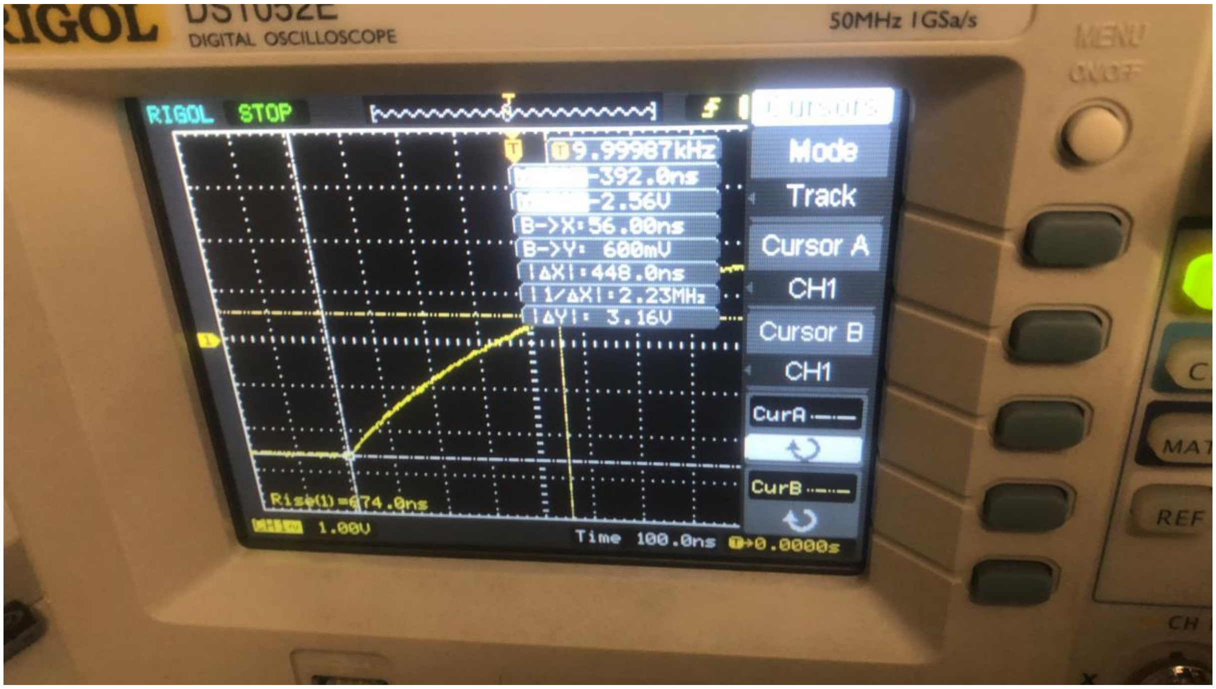


Figure 27:delta x value at 3cm

$$\tau = R \times C$$

448ns= $R \times C$

448ns=448$\times$ $10^{-9}s$

$$C= \frac{448\times10^{-9}s}{10\times10^{3}} F$$

C=44.8 pF

Subtraction is performed only to calculate the capacitance of the parallel plate capacitor.

c_{net} *=44.8-26=18.8* pF

When d is equal 2 cm;

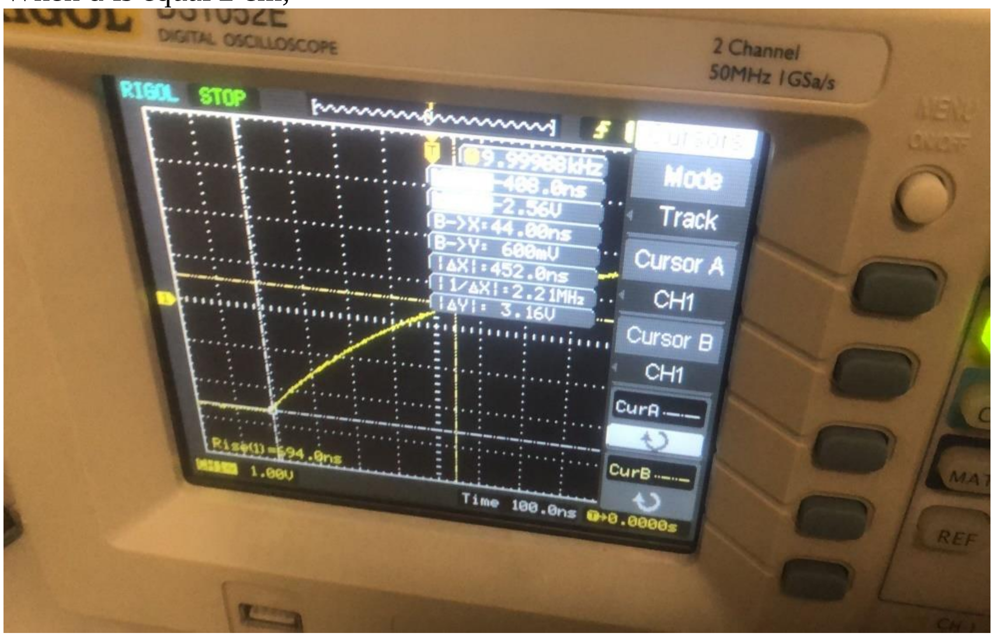


Figure 28: delta x value at 2cm

$$\tau = R \times C$$

$$452\text{ns} = R \times C$$

$$452\text{ns} = 452 \times 10^{-9} s$$

$$C = \frac{452 \times 10^{-9} s}{10 \times 10^{3}} F$$

$$C = 45.2 \text{ pF}$$

Subtraction is performed only to calculate the capacitance of the parallel plate capacitor.

$$c_{net} = 45.2 - 26 = 19.2 \text{pF}$$

When d is equal 1 cm;

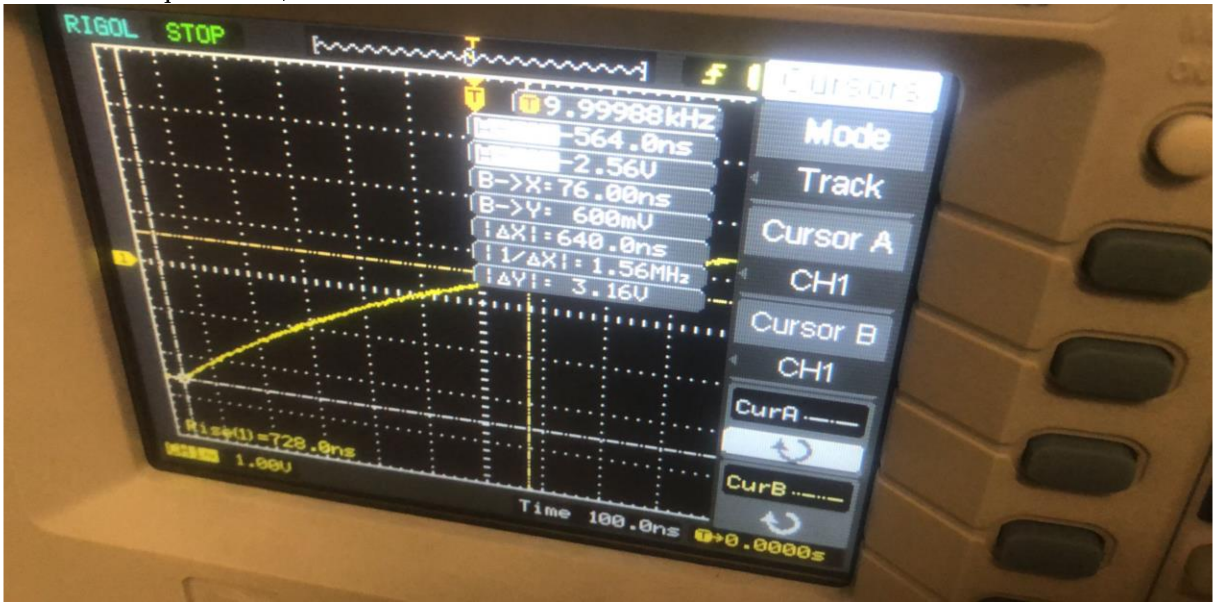


Figure 29:delta x value at 1cm

$$\tau = R \times C$$

$$640\text{ns} = R \times C$$

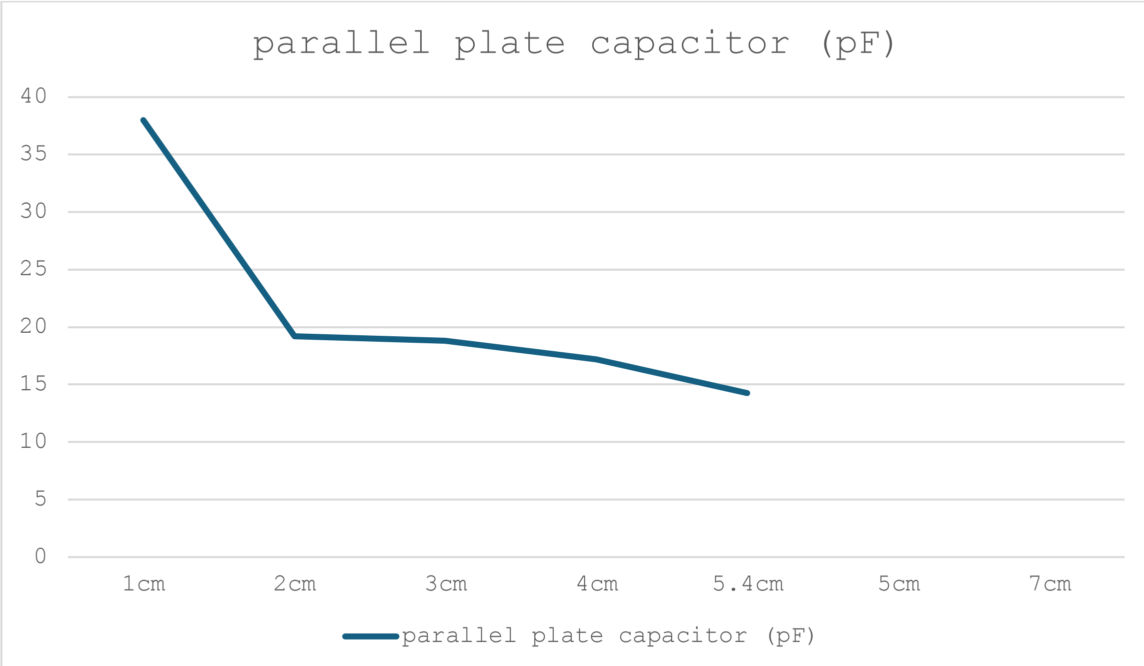
$$640\text{ns} = 640 \times 10^{-9} s$$

$$C = \frac{640 \times 10^{-9} s}{10 \times 10^{3}} F$$

$$C = 64 \text{ pF}$$

Subtraction is performed only to calculate the capacitance of the parallel plate capacitor.

$$c_{net} = 64 - 26 = 38 \text{pF}$$



Graph 4: measured parallel plate capacitance values

e)

Plots of charge (theoretically calculated) vs. your parameter that you use to change the capacitances for parallel-plate and cylindrical capacitor at a fixed voltage.

The ability of a capacitor to hold energy in an electric field is known as its capacitance. It is represented by 'C' and is based on the voltage differential V applied across the capacitor as well as the capacitance C. The capacitor is made up of two plates, one of which has a +Q charge and the other a -Q charge. Capacitance is measured in farads (F), which is one coulomb per volt in SI units. The capacitance has a direct correlation with the area of its plates and an inverse relationship with their distance from one another.[11]

$Q = c \times v$

The voltage value was taken as 5V throughout the process. The capacitance change parameter in a cylindrical capacitor is length. Accordingly, the theoretical capacitance values are as follows.

$Q = c \times v$

$$Q1 = 89.9 \times 10^{-12} F \times 5V = 449.5 \times 10^{-12} C$$

$$Q2 = 119.9 \times 10^{-12} F \times 5V = 599.5 \times 10^{-12} C$$

$$Q3 = 148.9 \times 10^{-12} F \times 5V = 749.5 \times 10^{-12} C$$

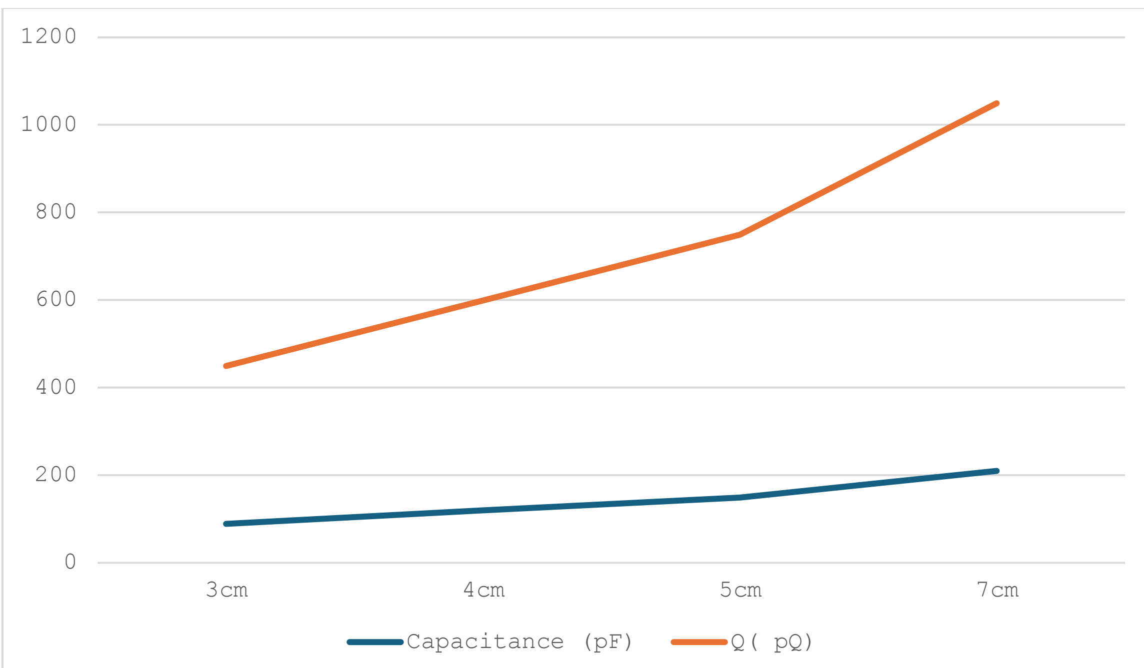
$$Q4 = 209.9 \times 10^{-12} F \times 5V = 1049.5 \times 10^{-12}$$

Length	3cm	4cm	5cm	7cm
Capacitance	$89.9\times 10^{-12}F$	$119.9\times 10^{-12}F$	$148.9\times 10^{-12}F$	$209.9\times 10^{-12}F$
Q	$449.5\times 10^{-12}C$	$599.5\times 10^{-12}C$	$749.5\times 10^{-12}C$	$1049.5 \times 10^{-12}C$

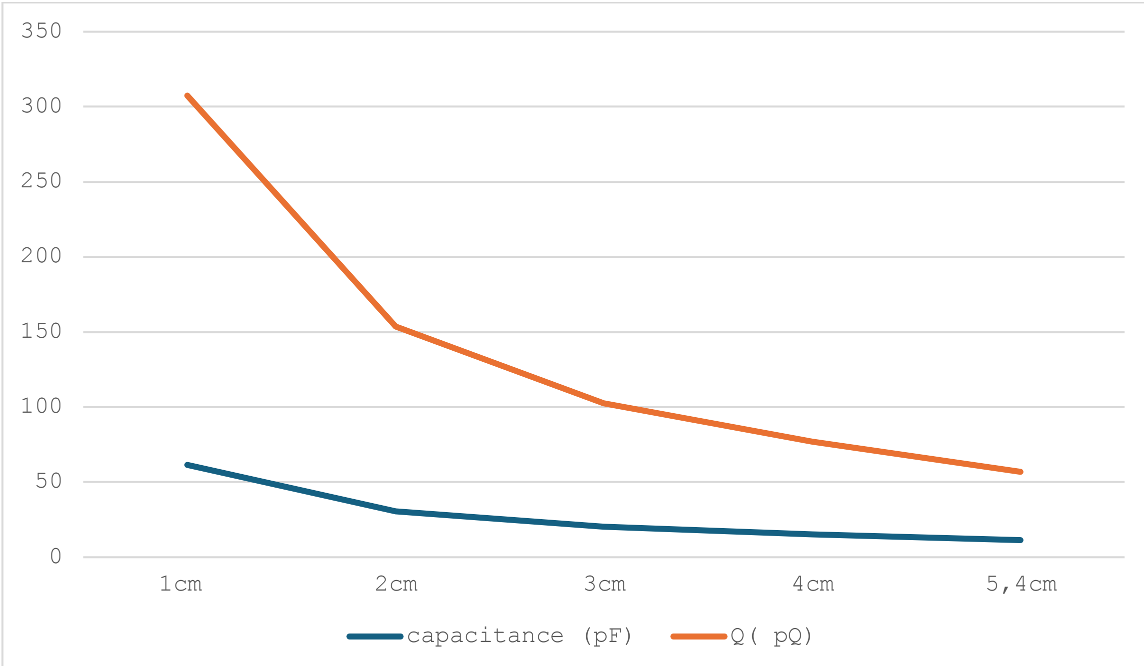
Table 2: theoric capacitance and load table of cylindrical capacitor

Distance	5.4cm	4cm	3cm	2cm	1cm
Capacitance	$11.38 \times 10^{-12}F$	$15.37 \times 10^{-12}F$	$20.49 \times 10^{-12}F$	$30.7 \times 10^{-12}F$	$61.49 \times 10^{-12}F$
Q	$56.9 \times 10^{-12}C$	$76.85 \times 10^{-12}C$	$102.45 \times 10^{-12}C$	$153.5 \times 10^{-12}C$	$307.455 \times 10^{-12}C$

Table 3: theoric capacitance and load table of parallel plate capacitor



Graph 5: theoric capacitance and load table of a cylindrical capacitor



Graph 6: theoric capacitance and load graph of parallel plane capacitor

f)

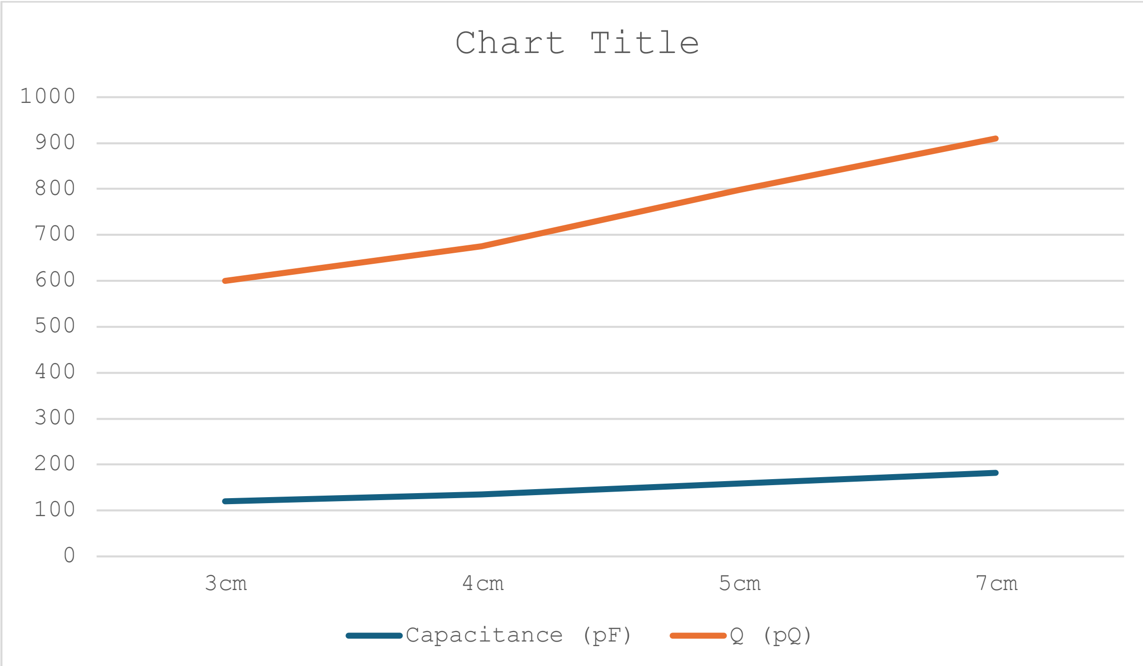
Plots of charge (calculated based on your measured capacitance) vs. your parameter that you use to change the capacitances for parallel-plate and cylindrical capacitor at a fixed voltage.

Length	3cm	4cm	5cm	7cm
Capacitance	$120\times 10^{-12}F$	$135.2\times 10^{-12}F$	$159.4\times 10^{-12}F$	$182\times 10^{-12}F$
Q	$600\times 10^{-12}C$	$676\times 10^{-12}C$	$797.5\times 10^{-12}C$	$910\times 10^{-12}C$

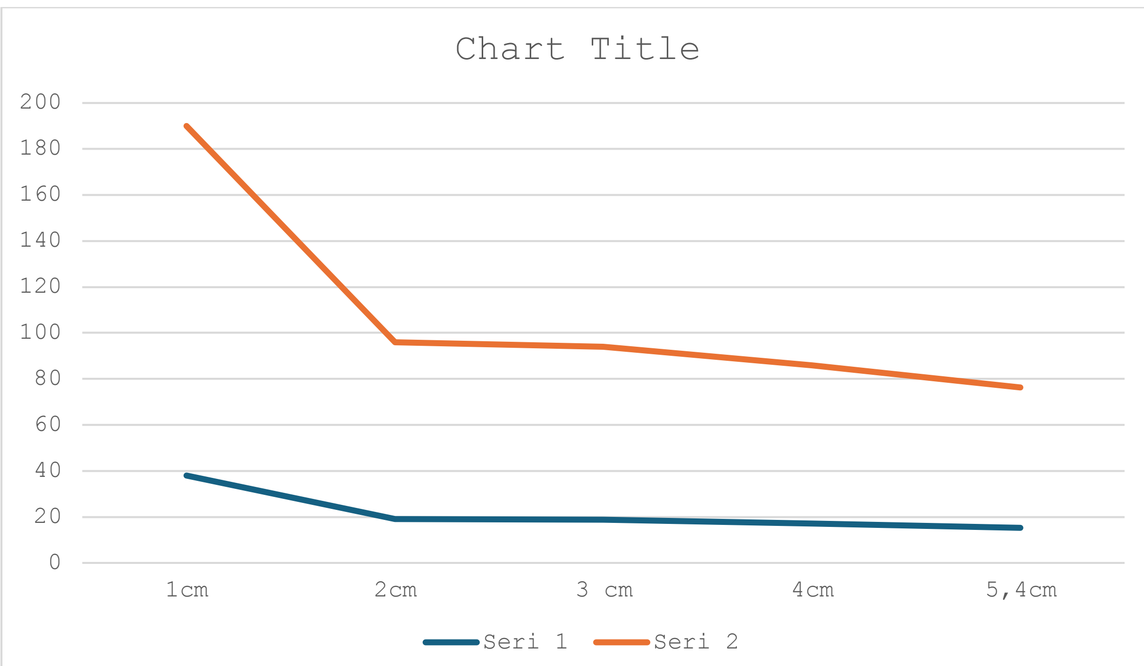
Table 4: Measured capacitance and load table of cylindrical capacitor

Length	1cm	2cm	3cm	4cm	5.4cm
Capacitance	$38\times 10^{-12}F$	$19.2 \times 10^{-12}F$	$18.8 \times 10^{-12}F$	$17.2 \times 10^{-12}F$	$15.26 \times 10^{-12}F$
Q	$190 \times 10^{-12}C$	$96\times 10^{-12}C$	$94\times 10^{-12}C$	$86\times 10^{-12}C$	$76.3 \times 10^{-12}C$

Table 5: Measured capacitance and load table of parallel plate capacitor



Graph 7:measured capacitance and load graph of cyclindrical capacitor



Graph 8: measured capacitance and load of parallel plate capacitor

g)

Discussion of the differences between theoretical results and experimental results.

There are many reasons why the results are close but not exactly the same. Some of these are the lack of an ideal laboratory environment. The oscilloscope and other laboratory equipment used have their own internal resistances and some errors which are tried to be minimised in the measurement.

For example 3cm in cylindrical capacitance	*Theoretical*	*Experimental*
Capacitance	$89.9 \times 10^{-12} F$	$120 \times 10^{-12} F$
Q	449.5×10^{-12}	449.5×10^{-12}

Table 6: example

For example 3cm in parallel plate capacitance	*Theoretical*	*Experimental*
Capacitance	$20.49 \times 10^{-12} F$	18.8×10^{-12}
Q	$102.45 \times 10^{-12} C$	$94 \times 10^{-12} C$

Table 7: example 2

iii. Construct a circuit containing one of your capacitors and a resistor that are connected in series. Then feed this circuit with a voltage in the form of a periodic triangular wave of a frequency and amplitude of your choice.

a) Express the triangular wave as sums of sinusoidals.

Triangular signals are an important part of devices used in everyday life. Periodic non-sinusoidal waveforms having a triangle shape are known as triangular waves. In these waveforms, voltage levels rise and fall linearly at the same rate on each ramp. A triangle wave exhibits abrupt transitions between positive and negative peaks, a linear rise and fall, and a consistent amplitude throughout each half-cycle. It is a piecewise linear function, where frequency denotes the number of cycles per unit of time and period is the length of a cycle.[1] Any wave may be produced by summing sine waves, where the wavelength is the length of the repeating component. Fourier series must be mastered in order to express triangular waves as the sum of sine waves. The triangle wave contains two discontinuous changes in slope every cycle, but no discontinuous leaps. There will also be an endless variety of sinusoidal components if the slope changes discontinuously.

$$a + \sum_{n=1}^{\infty} b_n \, cos(n\omega x) + \sum_{n=1}^{\infty} C_n \sin(n\omega x)$$

$$\Lambda(x) = \cos x + \frac{\cos 3x}{3^2} + \frac{\cos 5x}{5^2} + \frac{\cos 7x}{7^2}\frac{+ \cos 9x}{9^2} + \ldots$$

To express the triangle waves as a sum of sinusoids, the cos expressions in the formula are converted to sinusoidal expressions. According to the this equation '$\cos(x)=\sin(x+\pi/2)$' , This equation can be written.

$\Lambda(x)=\sin(x+\pi/2)+\sin(3x+\pi/2)/9+\sin(5x+\pi/2)/25+\sin(7x+\pi/2)49+\sin(9x+\pi/2)/81+\cdots$

$\Lambda(x)=sin\left(x+\frac{\pi}{2}\right)+\frac{1}{9}\cdot\frac{sin\left(3x+\frac{\pi}{2}\right)}{3}+\frac{1}{25}\cdot\frac{\sin\left(5x+\frac{\pi}{2}\right)}{5}+\frac{1}{49}\cdot\frac{\sin\left(7x+\frac{\pi}{2}\right)}{7}+\frac{1}{81}\cdot\frac{\sin\left(9x+\frac{\pi}{2}\right)}{9}\ldots$

The triangular wave function can be expressed as a Fourier series by breaking it down into sinusoidal components, using fundamental frequency harmonics to approximate wave shape, and adjusting amplitudes to accurately describe its behavior.

$\Lambda(x) =\frac{A}{\pi}(sin(2\pi fx)) - \frac{1}{9^2}\sin(2\pi 3fx) + \frac{1}{25^2}\sin(2\pi 5fx) - \frac{1}{49^2}\sin(2\pi 7fx) + \cdots)$

t is used instead of x for typical notation

$\Lambda(t) =\frac{A}{\pi}(sin(2\pi ft)) - \frac{1}{9^2}\sin(2\pi 3ft) + \frac{1}{25^2}\sin(2\pi 5ft) - \frac{1}{49^2}\sin(2\pi 7ft) + \cdots)$

As a last step, instead of A and f, the values used are written in the formula. In the circuit experiment, the amplitude is 5Vpp and the frequency is 10k Hz.

$\Lambda(t) =\frac{5}{\pi}(sin(2\pi\ 10{,}000t)) - \frac{1}{9^2}\sin(2\pi 3\ 10{,}000t) + \frac{1}{25^2}\sin(2\pi 510{,}000t) -$

$\frac{1}{49^2}\sin(2\pi 7\ 10{,}000t) + \cdots)$

$\Lambda(t) =\frac{5}{\pi}(sin(20{,}000\pi t) - \frac{1}{81}sin(60{,}000\pi t) + \frac{1}{625}sin(100{,}000\pi t) - \frac{1}{2401\ \sin(140{,}000\pi t)+\cdots)} + \cdots$

b) How do the waveforms appear when you measure the voltages on the capacitor and resistor? How do they change when you change the capacitance?

For Triangle Waveforms, the rise has the same time duration as the negative going decay, giving the triangle waveform a 50% duty cycle. As the amplitude increases, the peaks and troughs on the triangular wave are higher. A larger amplitude means that the top and bottom points of the waveform are higher. To observe the change of waves for resistance in a cylindrical circuit;

To observe the change of waves for resistor and capacitor in a cylindrical connected circuit;

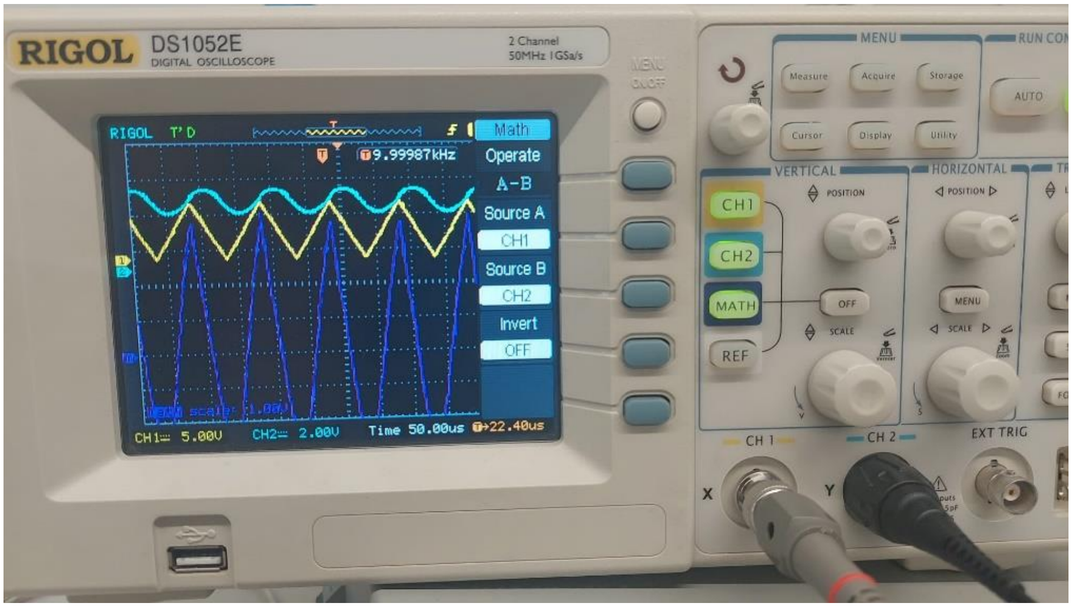


Figure 30: When offset=3.75V Amplitude=7.5V

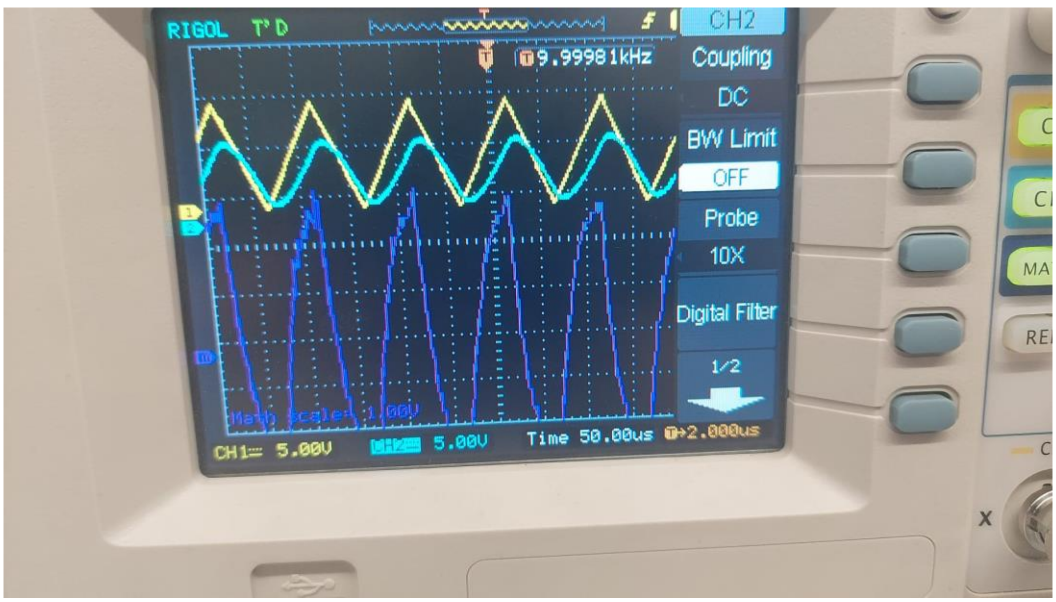


Figure 31: When offset=5 Amplitude=10

Vmax increased as the offset was given higher. Vmax was measured at 15 volts. When the triangular waveform is applied to the circuit, it is observed that the waveform of the voltage on the capacitor is as in the photograph. it is observed that there is a softening in the peaks of the wave in the triangular form. it is observed that there is no change in the frequency of the capacitor voltage. Since the resistor is not a reactive circuit element, it is observed that only the value of the voltage decreases according to ohm's law.

c) For the signals you measured in part iii.b, take the “Fast Fourier Transform” of your signals using the FFT analysis tool of your oscilloscope. What do you see when you change the capacitance?

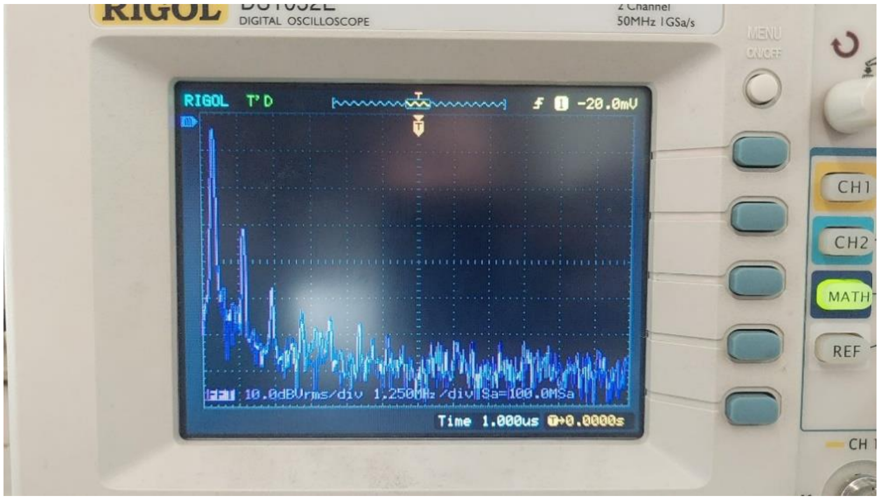
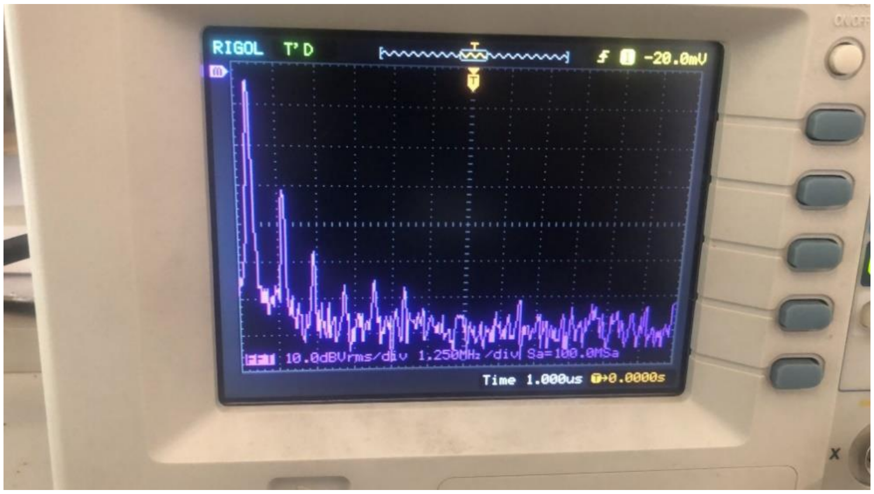


Figure 32: FFT image of the resulting signal before changing the capacitance



Picture : FFT image of the signal obtained after capacitance increase

It is observed that the capacitance increases when the distance between the two parallel plates is decreased. As can be seen from the FFT waveforms, a decrease in the corner frequency is observed as a result of the increase in capacitance, and it is observed that the fluctuations at high frequencies are reduced. It was observed that as the capacitance increased, the signal became lower frequency and had a wider frequency spectrum. As a result of the change in capacitance, the corner frequency of the circuit decreases. Therefore, the waves at high frequencies decreased and the waves at low frequencies increased. The name of this system is low pass filter.

$F_c = \frac{1}{2\pi FRC}$ comes from this formula.

d)

1)Increasing the capacitance causes the time constant to rise. A larger capacitance value necessitates more time for the capacitor to charge or discharge.

$\tau = R \times C$

if C increases, τ increases.

In this case, as can be seen from the photographs, the triangle wave signal changed more slowly on the capacitor.

2) As the circuit's capacitance increased, distinct reactions were detected in voltage or current transients depending on the frequency. While a bigger capacitance could improve permeability at low frequencies, it resulted in greater permeability loss at higher frequencies.

$$F_c = \frac{1}{2\pi FRC}$$

As can be seen in the formula, increasing C causes the mentioned changes. The triangle wave signal shows a low-pass filter-like behavior with the voltage drop across the capacitor.

3) Increasing capacitance results in a lower voltage across the capacitor for the same amount of charge.

$Q = V \cdot C$

A decrease in the voltage across the capacitor, i.e. a slowdown, indicates that the triangle wave signals continue more smoothly and slowly.

iv. Consider that you feed the circuit studied in iii with a constant voltage V. Initially the capacitor has not been charged. Apply the Kirchhoff loop rule to the circuit, and express the capacitor and resistor voltages in the terms of the electrical charge q(t) of the capacitor and its first derivative dq(t)/dt. Find explicitly the capacitor charge q(t) as a function of the time t, and the constants: the feeding voltage V, the capacitance C and the resistance R. Plot the graph q(t) for certain numerical values of E, C and R. Explain how the resistance R contributes to the shape of the plot

$$v = i \cdot R + v_c$$
$$v = i(t) \cdot R + v_c(t)$$
$$v_c = \frac{q(t)}{c}$$
$$i(t) \cdot R = v - v_c(t)$$
$$i(t) = \frac{v}{R} - \frac{v_c(t)}{Rc}$$
$$\frac{dq}{d_t} = i(t)$$
$$\frac{dq}{dt} = \frac{v}{R} - \frac{q(t)}{RC}$$
$$\frac{dq}{9 - vC} = -\frac{d_t}{RC}$$
$$\int_0^q \frac{dV}{4 - VC} = \int_0^t \frac{dt}{RC}$$
$$\ln\left(\frac{q - vc}{-vc}\right) = \frac{-t}{RC}$$
$$\frac{q - vc}{-vc} = e^{-t/RC}$$
$$q(t) = v \cdot C\left(1 - e^{-t/RC}\right)$$

And,

$$q(t) = VC\left(1 - \left(\frac{1}{e}\right)^{t/RC}\right)$$
$$q(t) = VC\left(1 - (0{,}367)^{t/R.C}\right)$$

1) For T $=182x10^{-8}$;

$$t/R\,C = 1$$
$$(1 - (0.367)^1) = 0.633$$
$$R.C = 182x10^{-12}\ x\ 10^4 = 182x10^{-8}$$
$$V.C = 182x10^{-12}x5 = 91x10^{-11}$$

$$q(182x10^{-8}) = 91x10^{-11}\ x\ 633x10^{-3} = 57.603\ x\ 10^{-11}$$

2) T for=$364x10^{-8}$

$$t/R\,C = 2$$

$$R.C = 182x10^{-12}\ x\ 10^4 = 182x10^{-8}$$

$$V.C = 182x10^{-12}x5 = 91x10^{-11}$$

$$(1-(0.367)^2) = 0.865311$$

$$q(364x10^{-8}) = 91x10^{-11}\ x\ 865.311x10^{-3} = 78.743301\ x\ 10^{-11}$$

3) T for $= 10^{-7}$

$$t/R\,C = 0.0549450549\ \cong 0.05$$

$$R.C = 182x10^{-12}\ x\ 10^4 = 182x10^{-8}$$

$$V.C = 182x10^{-12}x5 = 91x10^{-11}$$

$$(1-(0.367)^{0.05}) = 0.0488844038$$

$$q(10^{-7}) = 91x10^{-11}\ x\ 0.0488844038 = 4.4484807458\ x\ 10^{-11}$$

4) T for=$546x10^{-8}$

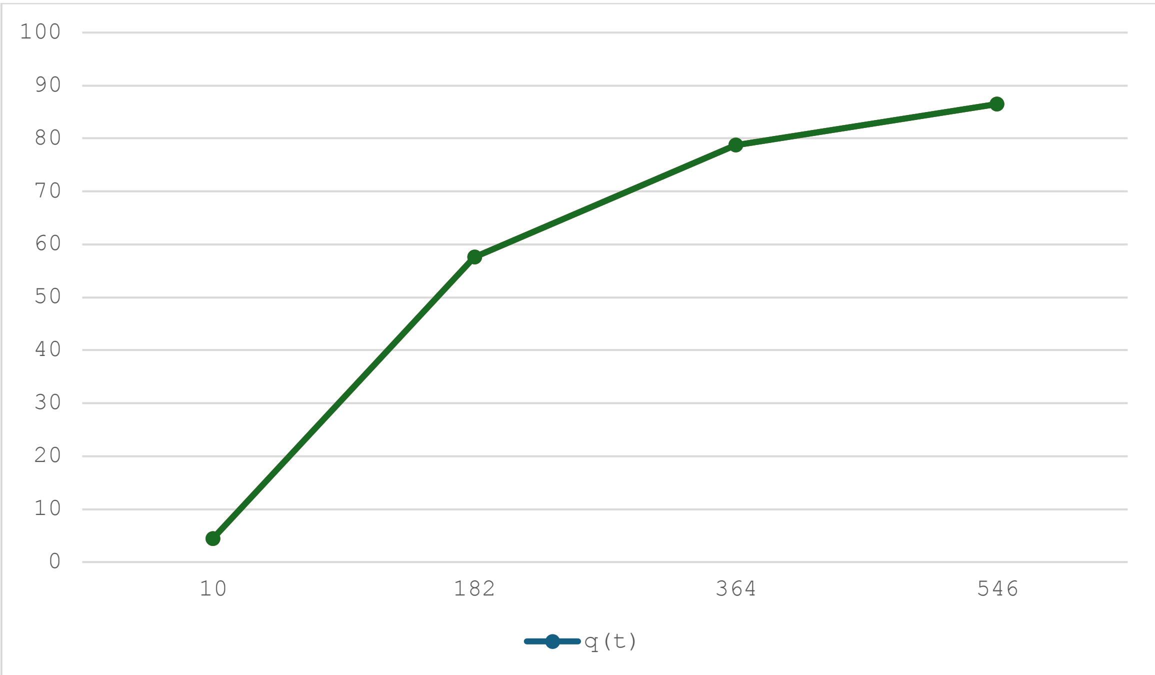
$$t/R\,C = 3$$

$$R.C = 182x10^{-12}\ x\ 10^4 = 182x10^{-8}$$

$$V.C = 182x10^{-12}x5 = 91x10^{-11}$$

$$(1-(0.367)^3) = 0.950569137$$

$$q(546x10^{-8}) = 91x10^{-11}\ x\ 0.950569137 = 86.501791467x10^{-11}$$



Graph 9: q(t) graph

10^{-11} multiples of the values calculated with the formulas entered on the y-axis.

10^{-8} multiples of the values calculated with the formulas entered on the x-axis.

$$q(t) = VC\left(1 - \left(\frac{1}{e}\right)^{t/RC}\right)$$

$$q(t) = VC\left(1 - (0{,}367)^{t/R.C}\right)$$

An increase in r causes qt values to increase. in short, the y-axis values in the graph result in higher points. a decrease in r causes qt values to decrease. in short, the y-axis values in the graph result in lower points. but since the change of this function also depends on an exponential function, the change is not the same for every t value.

v.

Imagine that you have an infinite sequence for R in the form: R1 = R, R2 = 2R, …, and Rn = nR, and so on. Find the corresponding sequence qmax for the maximum charge of the capacitor as a function of R: qmax,n = qmax(Rn). Investigate the converge properties of the sequence qmax,n. Investigate the convergence of the infinite series qmax,n.

$$q = VC$$

$$V(t) = V_0 \cdot e^{-t/RC}$$

$$q_{max} = CV_0 e^{-t/RC}$$

$$V(n) = V_0 \cdot e^{-n/RC}$$

The sequence qmax,n diminishes exponentially as n grows. The exponential term $e^{-t/RC}$ approaches 0 as n approaches infinity, hence the series converges to 0.

To determine the convergence of the infinite series q_{max},n, we can add the terms of the sequence:

$$(qmax)_n = CV_0 e^{-n/RC}$$

$$\lim_{n\to\infty} CV_0 e^{-n/Rc}$$

$$CV_0 \lim_{n\to\infty} (e^{-1/RC})^n = 0 \text{ so it is convergent.}$$

For infinite series;

$\sum_{n=1}^{\infty} (qmax)_n = \sum_{n=L}^{\infty} CV_0 e^{-n/RC}$ we should geometric series test to solve this.

$|e^{-1/RC}| < 1$ so it is convergent.

DISCUSSION

Methods from both theory and experimentation were used, and thorough and organized processes were followed to gather pertinent data. One potential cause of error in the fabrication of a cylindrical capacitor is the difficulty in precisely not knowing the dielectric values of water and glass also being not capable of doing perfect cylinders during the manufacturing process. The challenge of accurately measuring the dimensions of the materials used in the construction of the capacitor is the second element responsible for the observed disparity. The fact that the signal generator and oscilloscope data were not compatible with each other caused the desired value to not be given to the circuit in the voltage etc. values given to the circuit. One possible reason for the discrepancies between theory and experimental results is that the aluminum foil used is too delicate, and the tears that occur affect the capacitance value of the capacitor. Especially in the cylindrical capacitor construction, there were difficulties in covering the jar with aluminum foil, and the cables used caused damage to the aluminum foil. The capacitor was also measured with a multimeter to use in the LTspice simulation after measuring the desired circuit in the project. The fact that the multimeter was not accurate enough may have caused the error rate to increase. Another reason is that the materials used cannot be measured precisely due to their imperfect shape. The inability to precisely measure the dimensions of the materials caused the differences in the results. After all, all processes were repeated and checked more than once to minimize errors.

CONCLUSION

In this project, cylindrical and parallel plate capacitors were designed and the characteristics of the waves were observed by giving different waves in the laboratory environment. The values obtained from the oscilloscope were used to find the capacitance values in the experimental environment. Simulations were performed in Ltspice for the results of the circuits in ideal environment. The theoretical values were calculated using the formula and the deviations of the values were compared. It was found that the experimental results in the laboratory environment were due to various reasons such as the internal resistance of the resistors and instruments used, and distance from ideal conditions. The FFT analysis of the given signals was carried out and the characteristics and changes of the waves were recorded. For some calculations related to the capacitor, the formula of circuit theories and series were utilized.

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