Lab-06:
March 3rd

Objectives: Measure the capacitance of a capacitor without using the digital multimeter

Clarifying this Objective:
Capacitance measures the amount of electrical charge that can be held by a conductor relative to the voltage across it. In essence, it's the conductor's capability to retain charge. Capacitance describes how much electrical charge a capacitor can store, with the capacitor comprising two plates divided by an insulating material. It is calculated as the quotient of the electric charge on one of the capacitor's plates to the voltage difference between the plates.

$$C = \frac{q}{V}$$

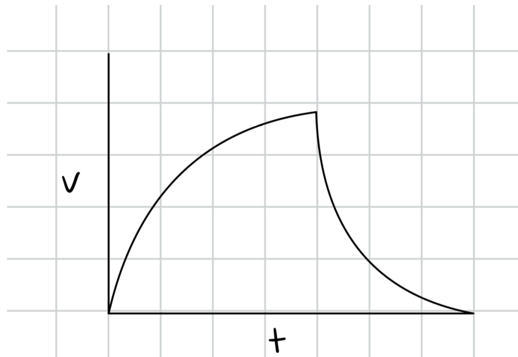
Capacitance (C) is determined by the charge (q) and the voltage (V) across the capacitor's plates. Factors influencing a capacitor's capacitance include the plates' dimensions and configuration, the gap between the plates, and the nature of the dielectric substance between them. A greater surface area of the plates, a reduced spacing between them, and the use of a material with a higher dielectric constant all contribute to an increased capacitance. Additionally, capacitance increases with the dielectric constant of the intervening material and decreases as the distance between the plates increases.

In an RC (resistor-capacitor) circuit, the presence of a capacitor causes the current to vary over time. This is a direct consequence of the capacitor's ability to store charge, which leads to the creation of a potential difference that opposes the voltage supplied by the battery. This characteristic underlines the time-dependent behavior of current in circuits involving capacitors.

For the first method, we'll assemble a basic RC circuit and determine its time constant. Following that, we can connect the time constant with the voltage decay function.

In the second method, we'll plot the voltage over time v(t) using an oscilloscope, transfer this data to a USB drive, then graph the data in MATLAB. By analyzing the slope of this graph, we will calculate the capacitance.

Figure 1. Capacitor charge graph that we are looking for



Explore Tools:

Table 1: Tools to be used in this lab

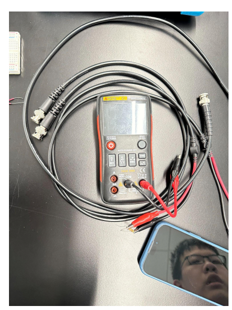
Tool	Physical Parameter	Resolution and Range	Image	Usage
Oscilloscope	Measuring voltage, amps, time	N/A (depends on how it is set up)		Measures the wave length, height of a wave, frequency, and voltage
Digital Multimeter	Voltage and Resistance	Resolution: 0.001 V Range: 0-999.99 V		Measuring the resistance and the voltage.
Function generator	Measure frequency	N/A (depends on how it is set up)		Generate waves to be read by oscilloscope

Figure 2. Set up of RC circuit used

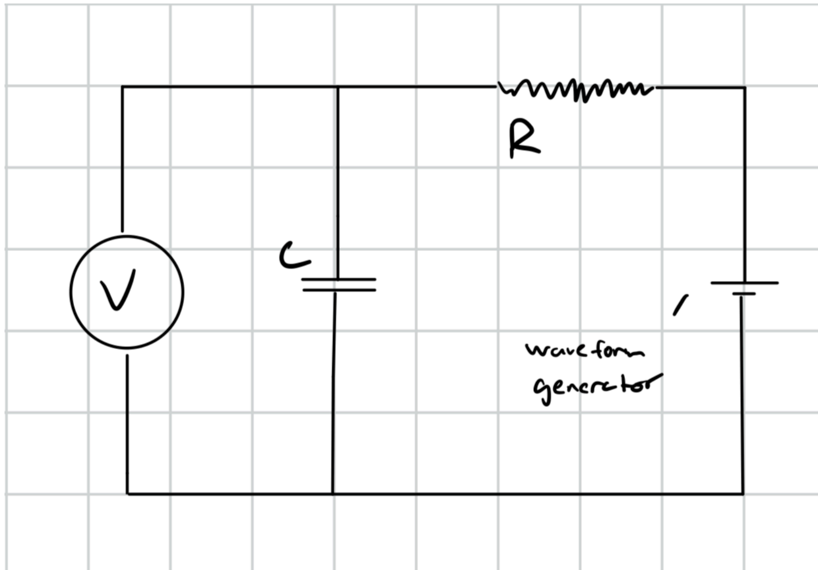
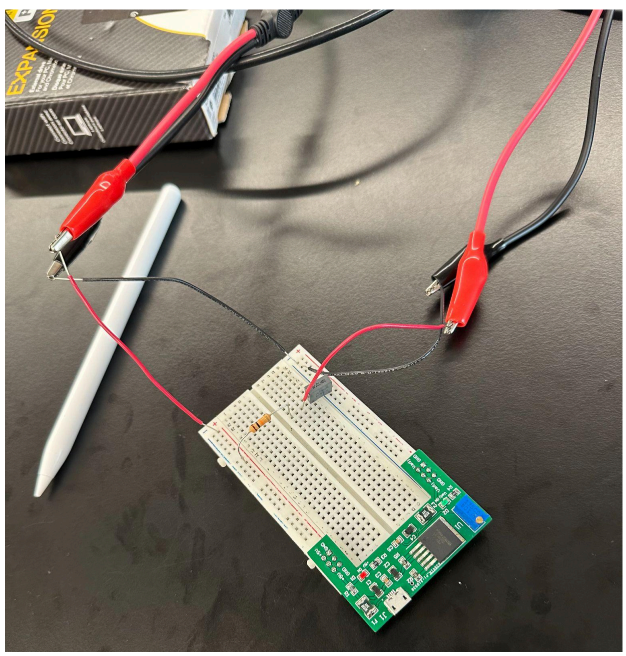


Figure 3. RC circuit created on breadboard



Relate Quantities:

$\tau = RC$

$v(t) = V_0 e^{\frac{-t}{\tau}}$

Rewriting and combining equations we get:

$C = \frac{-t}{Rln(\frac{v(t)}{V_0})}$

The actual capacitance of a $10.05nF$ measured through the digital multimeter. We are also going to be using a $10k\Omega$ resistor also measured using the digital multimeter.

The time constant, denoted as tau ($\boldsymbol{\tau}$), is a crucial parameter in RC circuits that dictates the rate at which voltage or current changes within the circuit. It is calculated by multiplying the circuit's resistance (R) by its capacitance (C), expressed as τ = RC.

With this understanding, our goal is to determine the voltage as a function of time when a capacitor is either being charged or discharged. By comparing ratios, we can deduce the RC value, which will, in turn, enable us to ascertain the capacitance value.

Test and Try

Method 1:
Using method 1 we are able to calculate capacitance by just taking the value of voltage and value for time at any point in time. This means we are able to calculate time constant and therefore calculate capacitance.

Table 2.

$V(t)$	Time (s)	Voltage V_0 (v)
$26.8 \cdot 10^{-3}$	$204 \cdot 10^{-6}$	$352 \cdot 10^{-3}$

Using the values from table 2 and the equations provided earlier we can calculate capacitance using method 1.

$$C = \frac{-t}{Rln(\frac{v(t)}{V_0})}$$

$$C = \frac{-200*10^{-6}}{10*10^{3}ln(\frac{29.1*10^{-3}}{352*10^{-3}})}$$

$$C = 8.183 \cdot 10^{-9} f$$

Uncertainty calculation:

Using the following formula we calculate for uncertainty

Figure 5. Formula for uncertainty

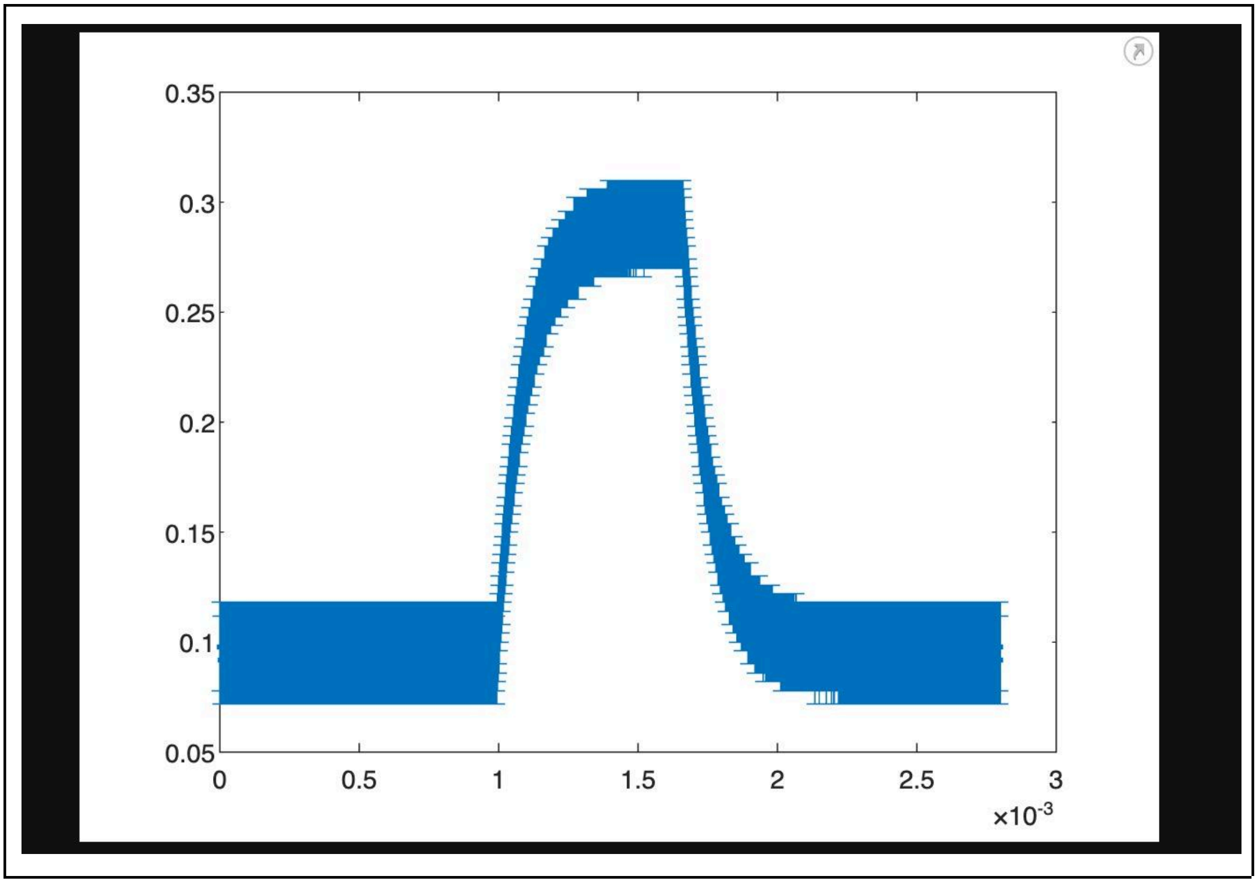
$$\frac{\delta C}{C} = \sqrt{\left(\frac{\delta v(t)}{v(t)}\right)^2 + \left(\frac{\delta v_0}{v_0}\right)^2 + \left(\frac{\delta R}{R}\right)^2 + \left(\frac{\delta t}{t}\right)^2}$$

We get uncertainty of capacitance to be $\pm\ 3 \cdot 10^{-10} f$

Method 2:

In the second approach, we will chart the voltage as a function of time (v(t)) by employing an oscilloscope, then export this information to a USB drive, and subsequently plot the data in MATLAB. By examining the graph's slope, we can deduce the value of the capacitance.

Figure 6. Voltage across capacitor over time



Next we must perform a linear fit by first linearizing the formula

$$ln(v(t)) = -\frac{t}{\tau} + ln(V_0)$$

Next, we need to determine the linear fit. Our research outlines the procedure for achieving a linear fit. Unfortunately, due to time constraints, we were unable to complete this task during our class session. However, since this step involves only computations with data we already possess, we plan to carry out this analysis in our own time before the next lab session.

Procedure:

1. Construct the circuit as depicted in Figures 2 and 3 to enable the charging of the capacitor. Ensure that the capacitor, resistor, and voltage source are connected in series.

2. Activate the function generator and adjust its parameters to align with the details provided in Table 4.

3. To ascertain the ideal frequency for our measurements, observe the oscilloscope's display for a plateau in voltage levels, which indicates a steady state. Refer to Figure 4 for a graphical representation.

4. Proceed to transfer the gathered data into MATLAB for analysis.

5. For the data transfer, initiate the process by pressing the 'trigger' followed by 'save' on the oscilloscope. Save the results as a CSV file onto a USB drive. Then, on a computer, open the CSV file and import the data into MATLAB.

6. Within MATLAB, select three distinct points that adhere to the natural logarithm relationship of $ln(v(t)) = -\frac{t}{\tau} + ln(V_0)$.

7. Create a linear fit of these points to visually and analytically represent their relationship.

8. From the linear fit, determine the slope and use this value to calculate the capacitance (C).

Edit 1: During this lab session, we did not incorporate uncertainty calculations into our process. We will address this in Experiment 2.2, where we will refine this method and include a larger set of data points to improve accuracy.

Reflection:

As we reflect on the completion of our recent lab session, it's crucial to evaluate both the challenges we faced and the insights we gained. Our initial strategy involved linearizing the data acquired from the oscilloscope (Voltage vs Time) to then calculate capacitance using the slope of this linear relationship. This approach aimed to mitigate the uncertainty associated with time measurements, thus primarily leaving us with the uncertainties in Voltage and Resistance. By reducing the number of variables with significant uncertainty, we anticipated a decrease in the overall uncertainty propagation within our results. Our plan was to utilize Excel and MATLAB scripts to accurately determine the uncertainty in the slope value.

Unfortunately, we encountered technical difficulties with Excel and MATLAB on Mac, preventing us from linearizing the data as intended. Consequently, we adapted our method to use individual data points from the oscilloscope's graph to calculate capacitance. Theoretically, this alternative approach should introduce greater uncertainty due to errors in time measurement. Surprisingly, our results were remarkably accurate, exhibiting low uncertainty even without the linearization process. This outcome suggests that our methodological foundation and the circuit layout we employed are robust, yielding reliable results.

Moreover, our calculated value using this adapted method was 8.18 nanofarads, closely aligning with the expected value of 10 nanofarads. This precision underscores the effectiveness of our approach, despite the unforeseen obstacles. Looking forward, we anticipate that linearizing the data to solve for capacitance will enhance accuracy, as it allows for a comprehensive analysis that incorporates all data points. We expect this refined method to produce superior results by offering a more detailed understanding of the relationship between variables.

Due to the technical issues we faced this session, we plan to delve deeper into the linearization method in our next lab. We are optimistic that this technique will form the basis of our final test and results. To prepare, we intend to practice with the data obtained from this lab throughout the upcoming week, utilizing MATLAB to refine our analysis skills. This proactive approach will not only help us overcome the technical challenges encountered but also ensure that we are well-equipped to execute more sophisticated analyses in future experiments.