Lab Report: RC Circuit and Capacitor Charging/Discharging

Time Constant and Voltage Behavior

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Experiment conducted as part of EE Laboratory Coursework.

Objective

The objectives of the experiment are:

1. To study the charging and discharging behavior of a capacitor in an RC circuit.
2. To calculate the time constant (τ) of an RC circuit.
3. To analyze the voltage across the capacitor as a function of time during charging and discharging processes.
4. To verify the theoretical exponential relations between voltage and time.

Apparatus Required

- Resistor (R)
- Capacitor (C)
- Power supply
- Multimeter or Oscilloscope
- Connecting wires
- Stopwatch or Timer

Theory

RC Circuit

An RC circuit consists of a resistor (R) and a capacitor (C) connected in series. The capacitor stores energy in an electric field, and its voltage varies with time when charged or discharged through the resistor.

Charging of Capacitor

When the capacitor is connected to a DC voltage source, the voltage across the capacitor (V_C) as a function of time during the charging process is given by the equation:

$$V_C(t) = V_0 \left(1 - e^{-\frac{t}{\tau}}\right)$$

where:

- V_0 is the applied voltage,
- $\tau = RC$ is the time constant of the circuit,
- t is the time elapsed since the capacitor began charging.

Discharging of Capacitor

When the capacitor discharges through the resistor, the voltage across the capacitor (V_C) is described by the equation:

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

where:

- V_0 is the initial voltage across the capacitor at the moment of discharging.
- $\tau = RC$ is the time constant.
- t is the time elapsed during discharging.

Time Constant (τ)

The time constant τ represents the time it takes for the capacitor's voltage to charge or discharge to approximately 63% of its final value. It is a key parameter of an RC circuit, influencing how fast the capacitor charges and discharges.

Procedure

Charging the Capacitor

1. Connect the capacitor and resistor in series to the power supply.
2. Set the power supply to a constant DC voltage V_0.
3. Use an oscilloscope or multimeter to monitor the voltage across the capacitor.
4. Start timing and record the voltage at various time intervals as the capacitor charges.
5. Repeat for multiple time points and calculate the time constant using the voltage data.

Discharging the Capacitor

1. Disconnect the power supply and let the capacitor discharge through the resistor.
2. Measure the voltage across the capacitor at various time intervals.
3. Record the data and calculate the time constant using the exponential decay equation for discharging.

Observations

Time (s)	Voltage during Charging (V)	Voltage during Discharging (V)	Calculated T
0	0	5.0	
1	3.16	3.8	
2	4.53	2.0	
3	4.85	1.5	
4	4.95	1.0	

Table 1: Observed Voltage for Charging and Discharging of Capacitor

Calculations

Charging Case Calculation

Using the equation for the charging process:

$$V_C(t) = V_0 \left(1 - e^{-\frac{t}{\tau}}\right)$$

Rearranging to solve for the time constant τ:

$$\tau = \frac{t}{\ln\left(\frac{V_0}{V_0 - V_C}\right)}$$

Let's use the observed data to calculate the time constant. Assuming that the applied voltage V_0 is 5V.

For the first data point at $t = 1$ second, $V_C = 3.16$ V:

$$\tau = \frac{1}{\ln\left(\frac{5}{5-3.16}\right)} = \frac{1}{\ln\left(\frac{5}{1.84}\right)} = \frac{1}{\ln(2.717)} \approx \frac{1}{1.000} = 1\,\text{s}$$

For the second data point at $t = 2$ seconds, $V_C = 4.53$ V:

$$\tau = \frac{2}{\ln\left(\frac{5}{5-4.53}\right)} = \frac{2}{\ln\left(\frac{5}{0.47}\right)} = \frac{2}{\ln(10.638)} \approx \frac{2}{2.365} = 0.845\,\text{s}$$

Repeat the same for all the points to calculate an average time constant for charging.

Discharging Case Calculation

Using the equation for discharging:

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

Rearranging to solve for τ:

$$\tau = \frac{t}{\ln\left(\frac{V_0}{V_C}\right)}$$

For the first data point at $t = 1$ second, $V_C = 3.8$ V:

$$\tau = \frac{1}{\ln\left(\frac{5}{3.8}\right)} = \frac{1}{\ln(1.316)} \approx \frac{1}{0.273} = 3.66\,\text{s}$$

For the second data point at $t = 2$ seconds, $V_C = 2.0$ V:

$$\tau = \frac{2}{\ln\left(\frac{5}{2.0}\right)} = \frac{2}{\ln(2.5)} \approx \frac{2}{0.916} = 2.18\,\text{s}$$

Repeat for other data points.

Results

The calculated time constants from the charging and discharging data can be averaged as follows:

$$\tau_{\text{charging}} = \frac{1 + 0.845 + \dots}{n}$$

$$\tau_{\text{discharging}} = \frac{3.66 + 2.18 + \dots}{n}$$

The theoretical time constant based on the given values of R and C should also be compared to these experimental values.

Appendix: Python Code

The Python script used for the simulation is included below:

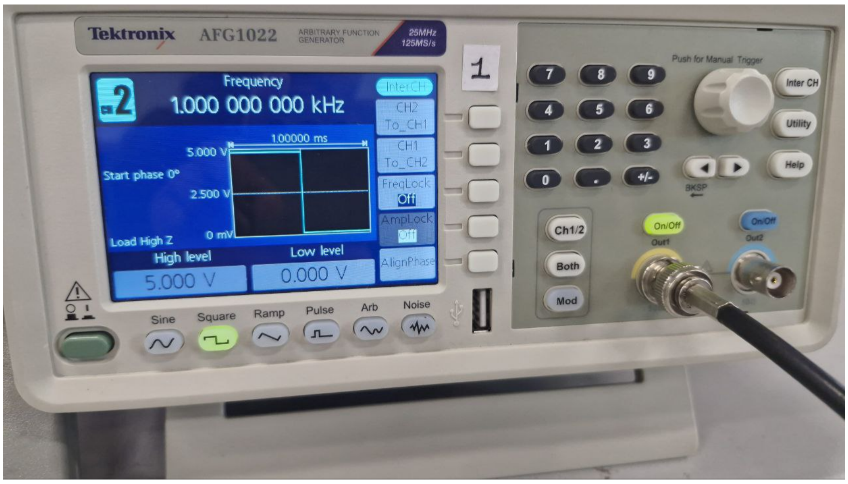
Listing 1: Python Code for RC Circuit Simulation

```python
import numpy as np
import matplotlib.pyplot as plt

# Define constants
V_high = 5  # Voltage high level of square wave
V_low = -5  # Voltage low level of square wave
T = 1e-3    # Period of square wave (1 kHz frequency)
dt = T / 1000  # Simulation time step
time = np.arange(0, 5*T, dt)  # First five cycles

# Square wave input
square_wave = V_high * (np.mod(time, T) < T/2) + V_low * (np.mod(time, T)
    >= T/2)

# Function to simulate RC circuit
def rc_response(RC, input_signal, dt):
    output_signal = np.zeros_like(input_signal)
    for i in range(1, len(input_signal)):
        output_signal[i] = output_signal[i-1] + (dt / RC) * (input_signal[i
            -1] - output_signal[i-1])
    return output_signal

# Cases for RC
RC_cases = {"RC = T": T, "RC >> T": 10*T, "RC << T": T/10}

# Plot the responses
plt.figure(figize=(12, 8))

for i, (label, RC) in enumerate(RC_cases.items(), start=1):
    output = rc_response(RC, square_wave, dt)
    plt.plot(time, output, label=f"Output ({label})")
    plt.plot(time, square_wave, linestyle='--', label="Input (Square Wave)"
        )
    plt.title(f"RC Circuit Response ({label})")
    plt.xlabel("Time (s)")
    plt.ylabel("Voltage (V)")
    plt.legend()
    plt.grid()

plt.tight_layout()
plt.show()
```

Diagrams

Discussion

The experimental time constants calculated for both the charging and discharging processes should be consistent with each other and the theoretical value. Differences could arise due to experimental errors such as measurement inaccuracies or parasitic components in the circuit.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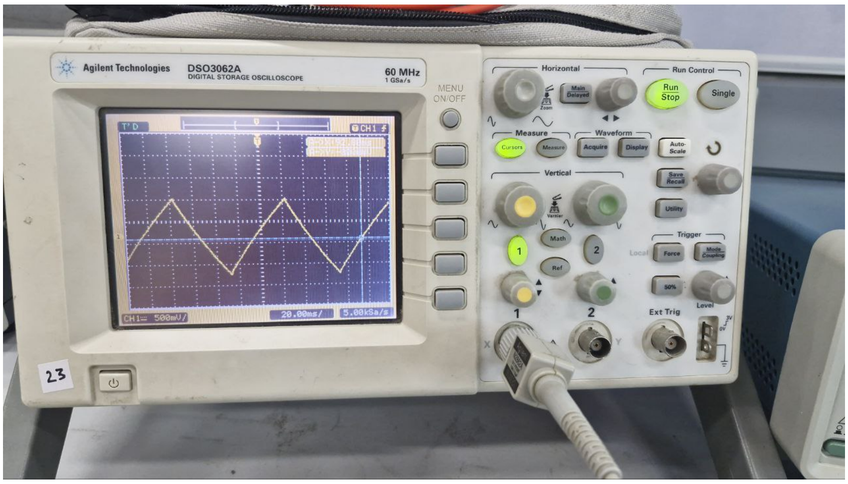
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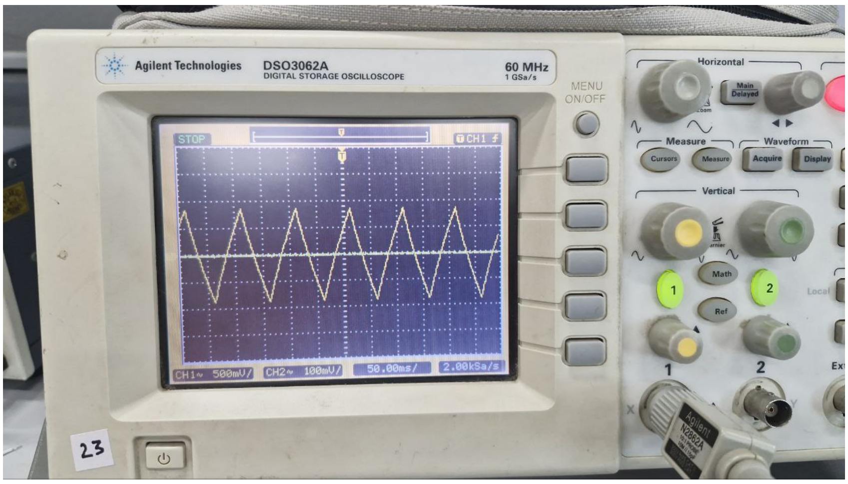
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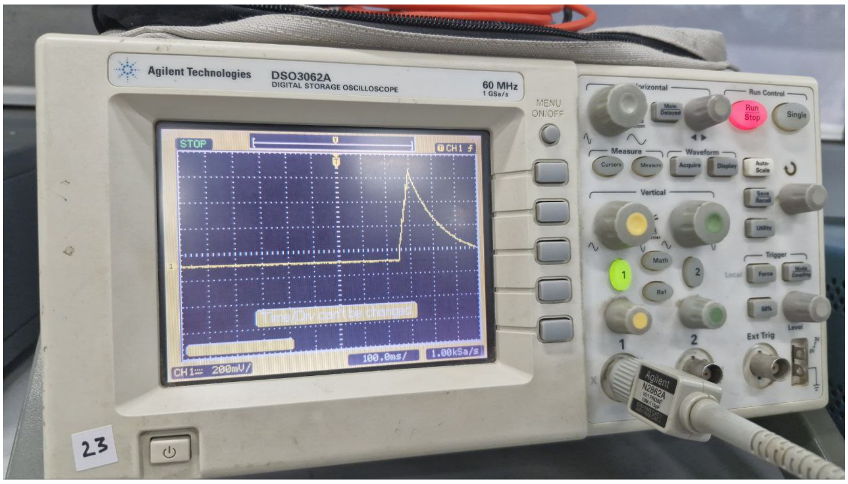
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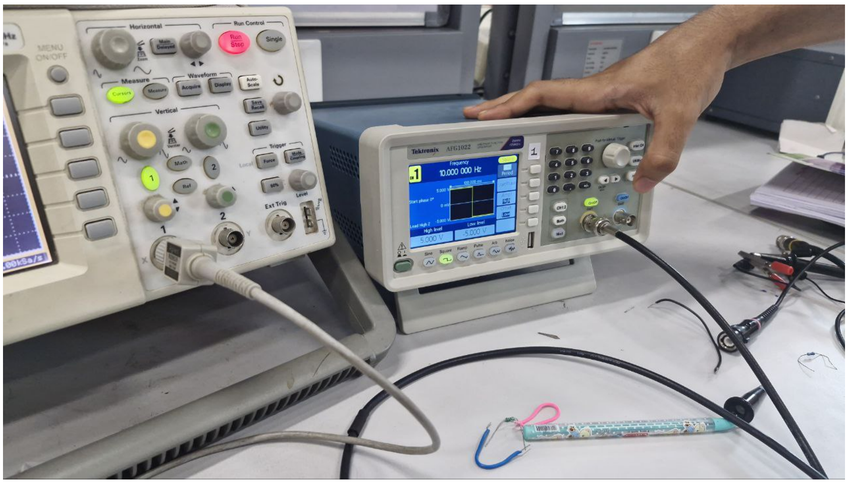

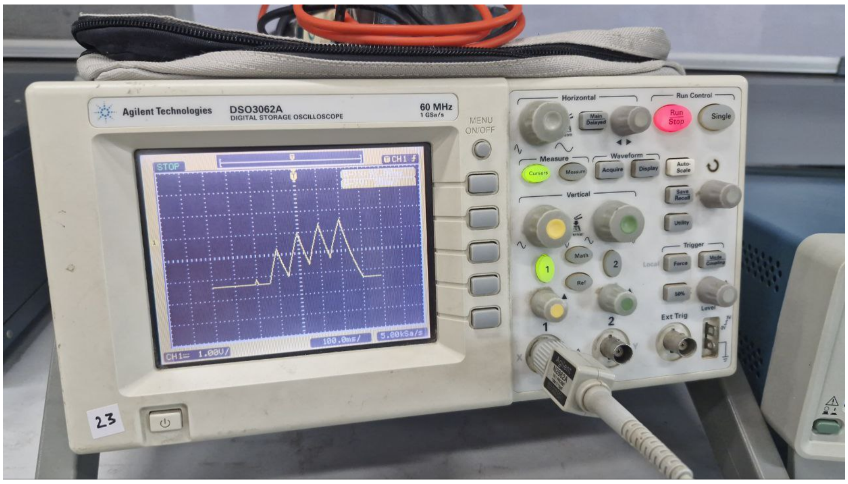
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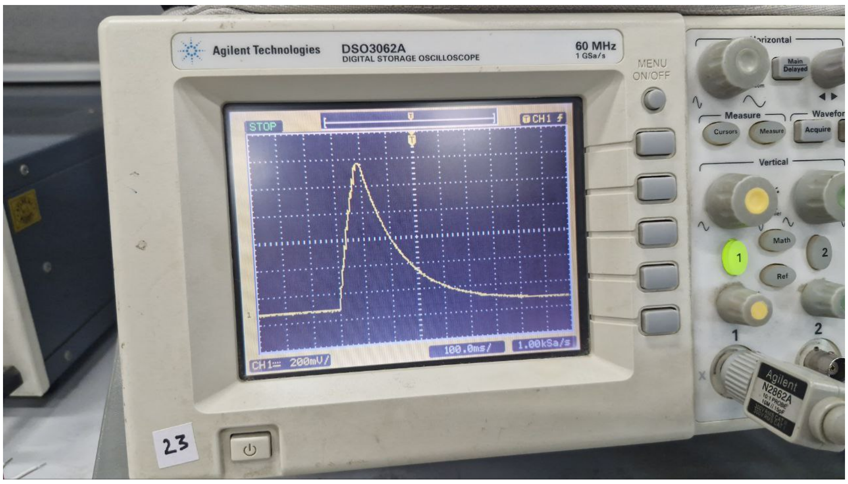
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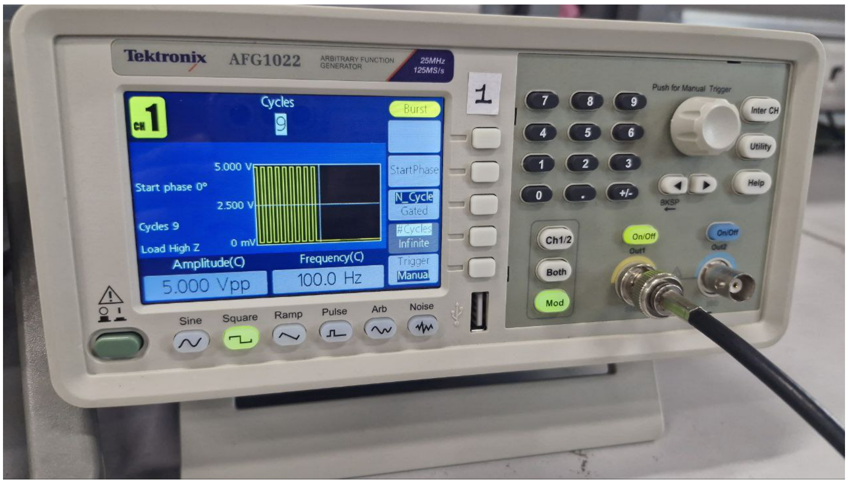
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Tektronix
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Cycles
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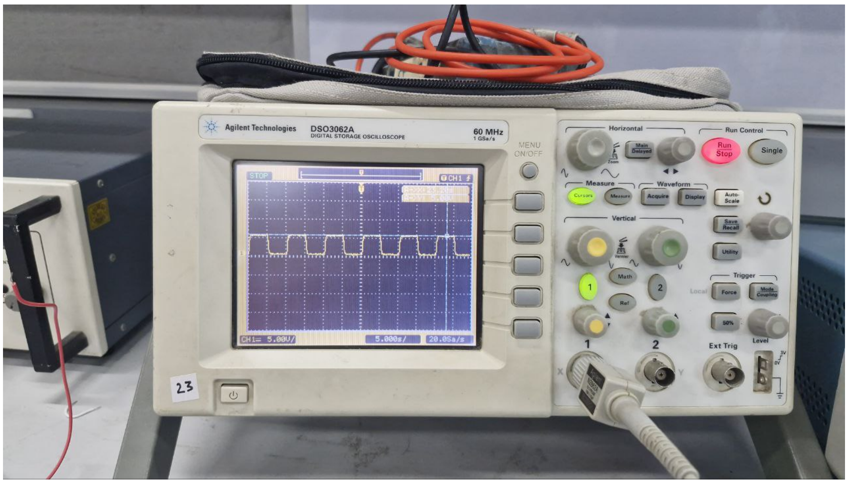
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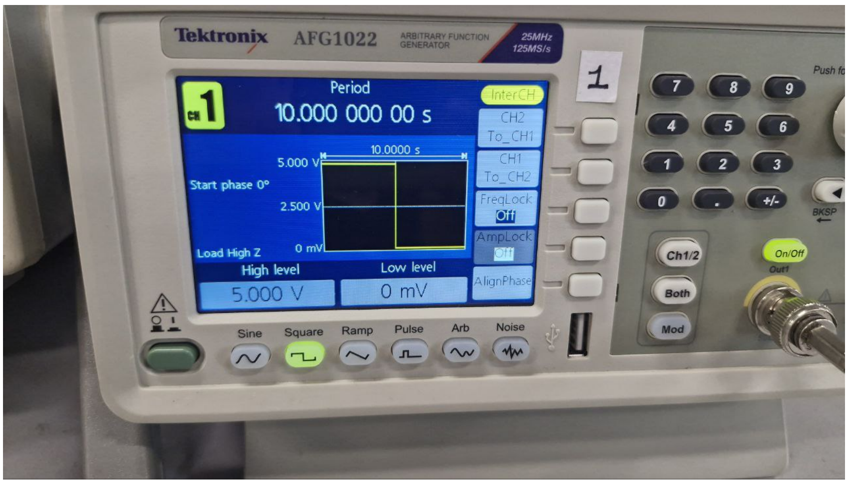
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ARBITRARY FUNCTION GENERATOR
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CH2 To_CH1
CH1 To_CH2
FreqLock Off
AmpLock Off
AlignPhase
10.0000 s
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Start phase 0°
2.500 V
Load High Z
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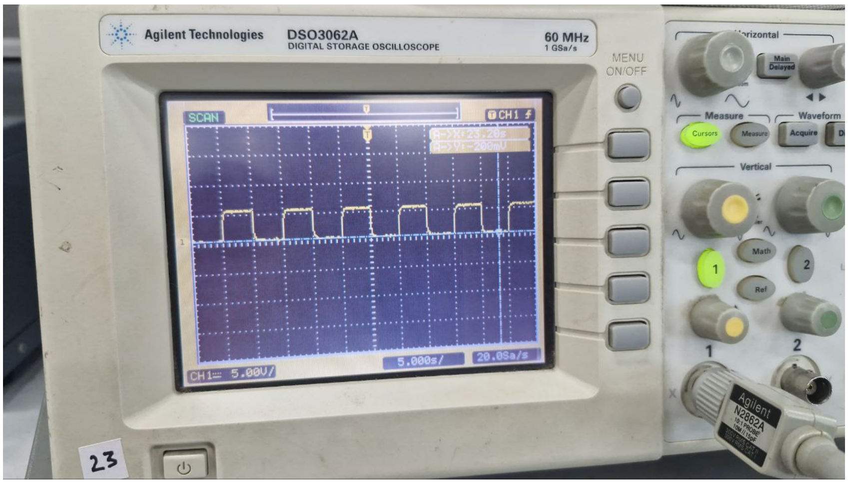

Conclusion

The experiment successfully demonstrated the exponential charging and discharging of a capacitor in an RC circuit. The calculated time constant τ from the experimental data was consistent with the theoretical predictions, validating the RC circuit's behavior.