Lab Report 2

Sai Akhila Reddy Turpu - EE24BTECH11055
Suguru Sai Akshita - EE24BTECH11054

January 29, 2025

Contents

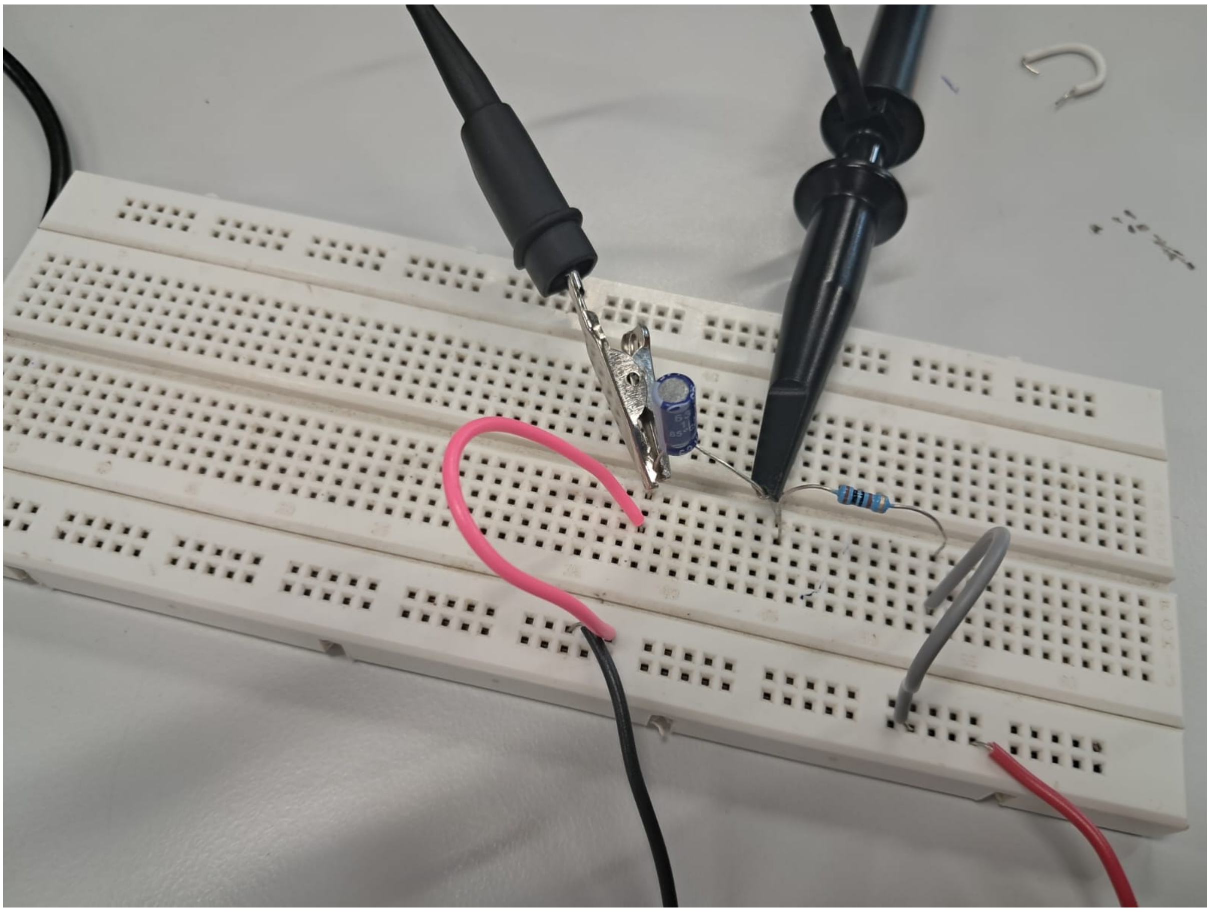
1 Objective

1. Analyzing the RC circuit response for square wave input

2 Apparatus and procedure

2.1 Materials

- Cathode ray Oscilloscope
- Function Generator (2 channels)
- Probes
- Connecting wires
- Breadboard
- Capacitor 1μF
- Resistor (1kΩ)



2.2 Procedure

1. Place the Components on the Breadboard:

   Insert the electrolytic capacitor into the breadboard. Ensure the longer leg (positive) and shorter leg (negative) are correctly oriented.

   Insert the resistor into the breadboard, ensuring one end connects to the capacitor.

2. Connect Power Supply:

   Use red and black wires to provide power to the circuit.

   The red wire is connected to the positive rail.

   The black wire is connected to the negative rail (ground).

3. Connect one end of the resistor to the capacitor.

   Connect the other end of the resistor to the designated node (gray wire area).

4. Attach the black probe to the ground of the circuit.

   Attach the second probe to the capacitor-resistor junction to monitor the signal.

5. Observe the circuit operation and monitor signals using the oscilloscope. Adjust the frequency accordingly for observations.

6. Press Mode/Coupling button and then change sweep mode from auto to normal. In the Trigger menu, press Mode until "Edge" is selected. Then select Single mode. Wait until mode will initiate.

7. Set the number of cycles to 5 and push the trigger to generate the transient response.

8. Now, change the mode to continuous and wait for 1 second to obtain the steady state response.

9. Keep changing the frequency to get different responses.

3 Observation

$RC = 10^{-3}$
We have 3 cases:

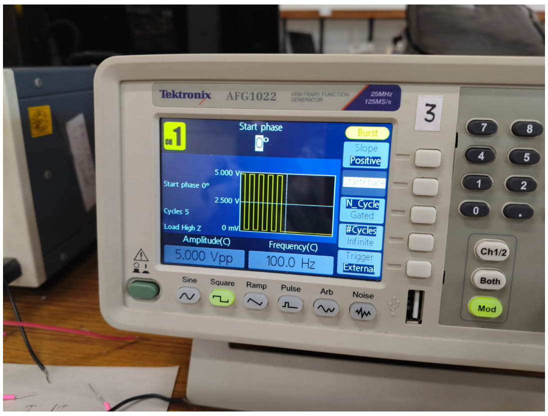
1. $T >> RC$

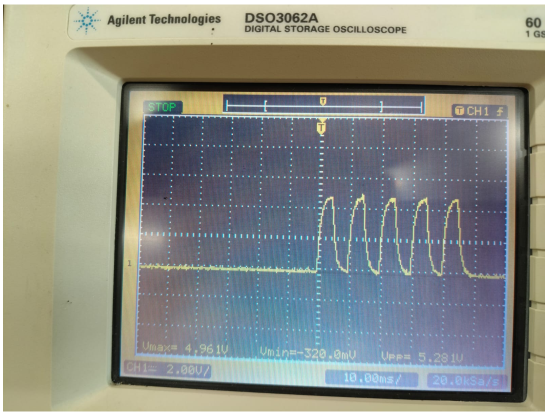
2. $T = RC$

3. $T << RC$

3.1 T>>RC ($T = 10$ ms)

For the input shown in the figure below, the output signal recorded on the oscilloscope is as follows:





Explanation: The equation for charging of a capacitor is given by:

$$V_1 = V_0(1 - e^{-\frac{t}{\tau}})$$

$$V_1 = 5(1 - e^{-\frac{10^{-2}}{2\times10^{-3}}})$$

$$V_1 = 5(1 - e^{-5})$$

$$V_1 = 4.966$$

Now the maximum value of the first peak is 4.96V. Now, as the value of the signal from the function generator is zero, the capacitor starts discharging, with the peak value as 1.96V. The equation for discharging of a capacitor is:

$$V = V_0 e^{-\frac{(t-(T/2))}{\tau}}$$

$$V_2 = 4.966 \times e^{-\frac{t-10^{-2}/2}{10^{-}}}$$

$$V_2 = 4.966 \times e^{-\frac{10^{-2}-10^{-2}/2}{10^{-3}}}$$

$$V_2 = 0.0334606$$

Now, we again send a signal of 5V. On solving the differential equation corresponding to a series RC circuit with initial conditions, we get:

$$v = V(1 - e^{-\frac{t-t_0}{RC}}) + v_0 e^{-\frac{(t-t_0)}{RC}}$$

Here, $v_0 = 0.0334606$
Hence, $V_3 = 5(1 - e^{-5}) + 0.0335(e^{-5})$

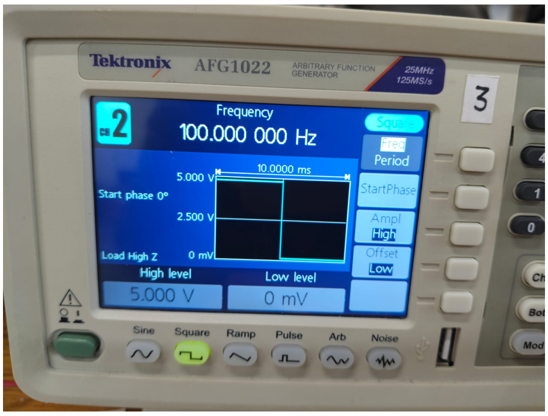
$$V_3 = 4.966225$$

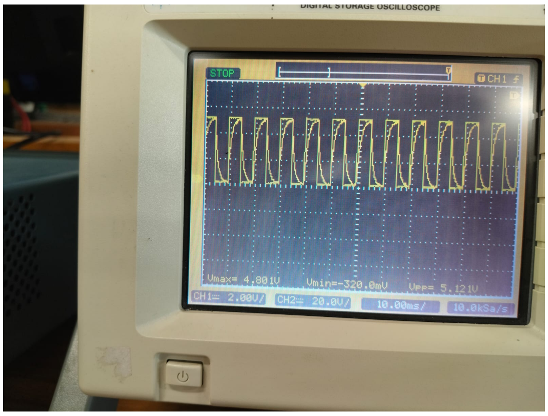
We notice that $V_3 > V_1$. Again, now when the capacitor starts discharging, we get,

$$V_4 = V_3 e^{-\frac{t-(3T/2)}{\tau}}$$

$$V_4 = 0.03346216$$

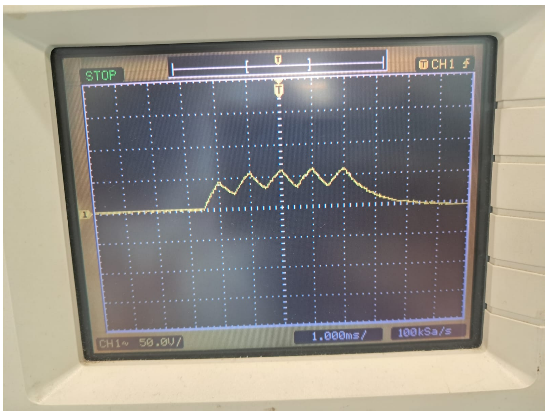
In the same way, we calculate the values of V_5, V_6 and so on.
As the number of cycles increases, the circuit is most likely going to reach steady state. Given below is the steady state response of the circuit:





3.2 T=RC ($T = 1$ms)

For the input shown in the figure below, the output signal recorded on the oscilloscope is as follows:



Explanation: The equation for charging of a capacitor is given by:

$$V_1 = V_0(1 - e^{-\frac{t}{\tau}})$$

$$V_1 = 5(1 - e^{-\frac{10^{-3}}{2\times10^{-3}}})$$

$$V_1 = 5(1 - e^{-\frac{1}{2}})$$

$$V_1 = 1.96$$

Now the maximum value of the first peak is 1.96V. Now, as the value of the signal from the function generator is zero, the capacitor starts discharging, with the peak value as 1.96V. The equation for discharging of a capacitor is:

$$V = V_0 e^{-\frac{(t-(T/2))}{\tau}}$$

$$V_2 = 1.96 \times e^{-\frac{t-10^{-3}/2}{10^{-3}}}$$

$$V_2 = 1.96 \times e^{-\frac{10^{-3}-10^{-3}/2}{10^{-3}}}$$

$$V_2 = 1.193$$

Now, we again send a signal of 5V. On solving the differential equation corresponding to a series RC circuit with initial conditions, we get:

$$v = V(1 - e^{-\frac{t-t_0}{RC}}) + v_0 e^{-\frac{(t-t_0)}{RC}}$$

Here, $v_0 = 1.193$
Hence, $V_3 = 5(1 - \frac{1}{\sqrt{e}}) + 1.193(\frac{1}{\sqrt{e}})$

$$V_3 = 2.691$$

We notice that $V_3 > V_1$. Again, now when the capacitor starts discharging, we get,

$$V_4 = V_3 e^{-\frac{t-(3T/2)}{\tau}}$$

$$V_4 = 1.632$$

In the same way, we calculate the values of V_5, V_6 and so on.

As the number of cycles increases, the circuit is most likely going to reach steady state.

$$V_5 = 2.957 \tag{1}$$

$$V_6 = 1.794 \tag{2}$$

$$V_7 = 3.055 \tag{3}$$

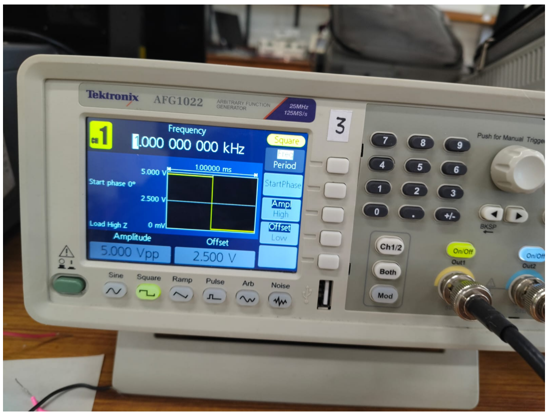
$$V_8 = 1.8532 \tag{4}$$

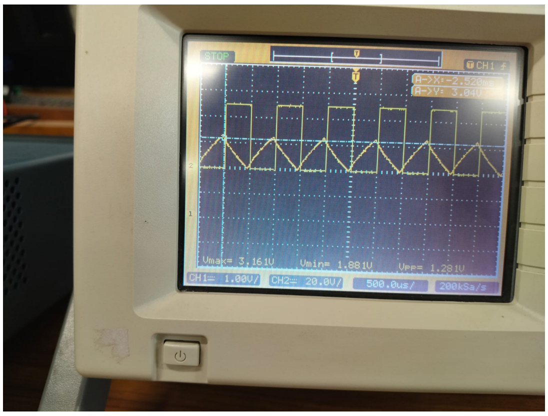
$$V_9 = 3.091 \tag{5}$$

$$V_{10} = 1.875 \tag{6}$$

$$V_{11} = 3.1042 \tag{7}$$

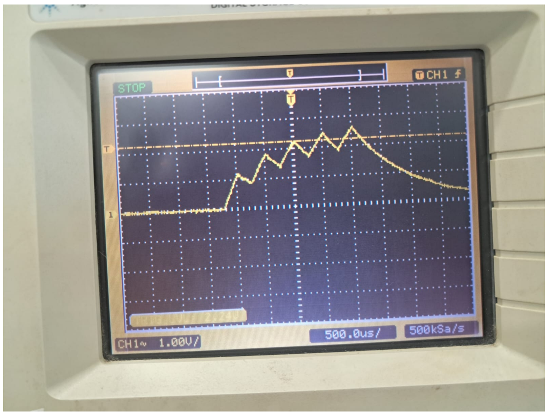
Given below is the steady state response of the circuit:





3.3 T<<RC ($T = 0.5$ ms)

For the input shown in the figure below, the output signal recorded on the oscilloscope is as follows:



Explanation: The equation for charging of a capacitor is given by:

$$V_1 = V_0(1 - e^{-\frac{t}{\tau}})$$

$$V_1 = 5(1 - e^{-\frac{10^{-4}}{2\times10^{-3}}})$$

$$V_1 = 5(1 - e^{-\frac{1}{20}})$$

$$V_1 = 1.776$$

Now the maximum value of the first peak is 1.776V. Now, as the value of the signal from the function generator is zero, the capacitor starts discharging, with the peak value as 1.776V. The equation for discharging of a capacitor is:

$$V = V_0 e^{-\frac{(t-(T/2))}{\tau}}$$

$$V_2 = 1.776 \times e^{-\frac{t-10^{-4}/2}{10^{-3}}}$$

$$V_2 = 1.776 \times e^{-\frac{10^{-4}-10^{-4}/2}{10^{-3}}}$$

$$V_2 = 1.3837$$

Now, we again send a signal of 5V. On solving the differential equation corresponding to a series RC circuit with initial conditions, we get:

$$v = V(1 - e^{-\frac{t-t_0}{RC}}) + v_0 e^{-\frac{(t-t_0)}{RC}}$$

Here, $v_0 = 1.3837$
Hence, $V_3 = 5(1 - \frac{1}{e^{\frac{1}{20}}}) + 1.3837(\frac{1}{e^{\frac{1}{20}}})$

$$V_3 = 2.1837$$

We notice that $V_3 > V_1$. Again, now when the capacitor starts discharging, we get,

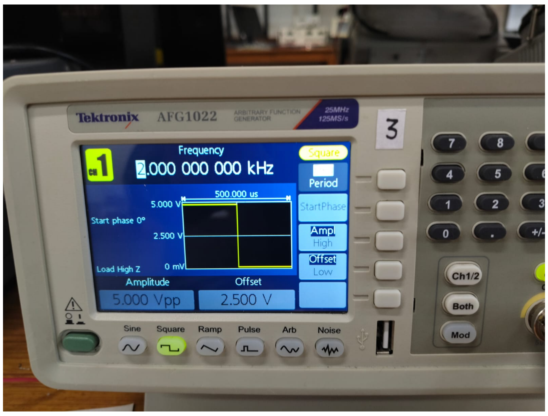
$$V_4 = V_3 e^{-\frac{t-(3T/2)}{\tau}}$$

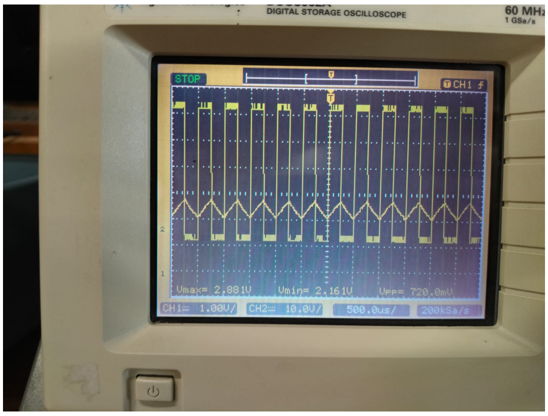
$$V_4 = 1.7007$$

In the same way, we calculate the values of V_5, V_6 and so on.
As the number of cycles increases, the circuit is most likely going to reach steady state.

$$V_5 = 2.4305 \tag{8}$$
$$V_6 = 1.89 \tag{9}$$
$$V_7 = 2.5801 \tag{10}$$
$$V_8 = 2.0094 \tag{11}$$
$$V_9 = 2.6709 \tag{12}$$
$$V_{10} = 2.0801 \tag{13}$$
$$v_{11} = 2.7260 \tag{14}$$
$$\tag{15}$$

We used lab.c code to iterate through these values. We notice that the steady state $V_{max} = 2.810755$ and $V_{min} = 2.189018$(after 38 iterations). Given below is the steady state response of the circuit:





4 Conclusion

In this experiment, we analyzed the response of an RC circuit to a square wave input by varying the time period relative to the circuit's time constant RC. The observations demonstrate how the capacitor charges and discharges depending on the input signal frequency.

- **For $T >> RC$ (Low Frequency):**
  - The capacitor has enough time to fully charge and discharge during each cycle.
  - The circuit behaves almost like a DC system with minimal voltage drop across the capacitor after charging.
- **For $T = RC$ (Intermediate Frequency):**

  - The capacitor does not fully charge or discharge within one cycle, resulting in a gradual buildup of voltage.
  - The system reaches a steady-state oscillation with increasing peak voltages over multiple cycles.

- **For $T << RC$ (High Frequency):**
  - The capacitor does not get enough time to charge significantly, causing small voltage fluctuations.
  - The circuit behaves more like a resistive element, with minimal capacitive effects.

These results align with the theoretical predictions for RC circuits and demonstrate the fundamental principles of transient and steady-state responses. Understanding such behavior is crucial in designing circuits for filtering, signal processing, and timing applications.