भारतीय प्रौद्योगिकी संस्थान हैदराबाद
Indian Institute of Technology Hyderabad

EXPERIMENT-2

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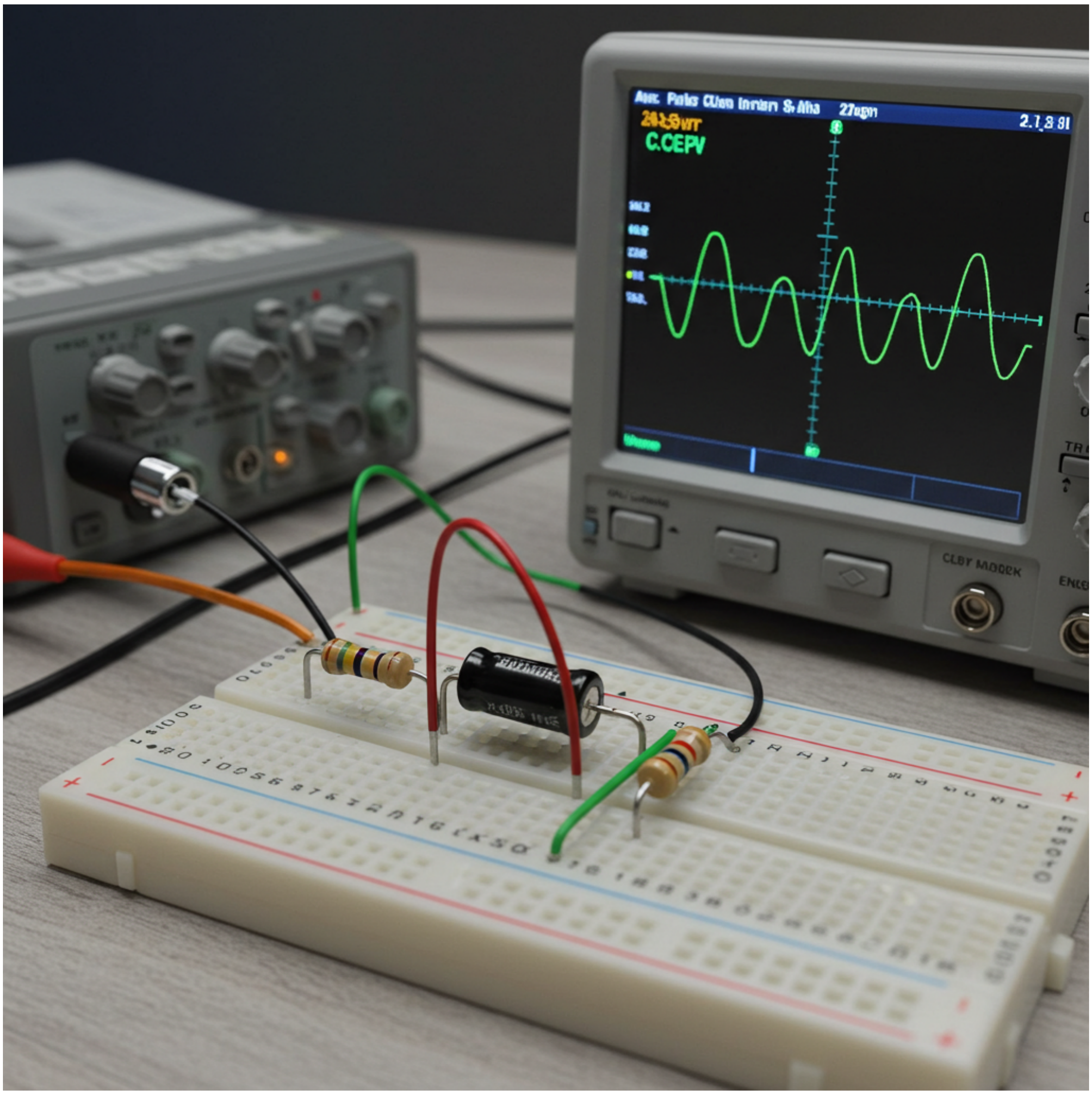
Date Last Edited: February 17, 2025

Abstract

The transient and steady-state behavior of RC circuits plays a pivotal role in understanding signal processing and circuit dynamics. This project investigates the response of an RC circuit to a $5V$ square wave input, with particular focus on three cases: $RC = T$, $RC \gg T$, and $RC \ll T$, where T is the time period of the input signal.

By applying theoretical equations for charging and discharging phases of the capacitor, the transient and steady-state responses are analyzed. Simulations and experimental measurements using a Cathode Ray Oscilloscope (CRO) are employed to validate the theoretical results. Markers on the CRO are used to measure key parameters such as voltage levels and time constants, ensuring an accurate comparison between calculated and observed values.

The results reveal how the RC time constant influences the circuit's behavior, with significant differences observed between transient and steady-state responses across the three cases. This study not only reinforces the theoretical understanding of RC circuits but also demonstrates the practical utility of oscilloscopes in analyzing dynamic circuit responses.



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Chapter 1

RC- Circuit

1.1 Set Up

Introduction

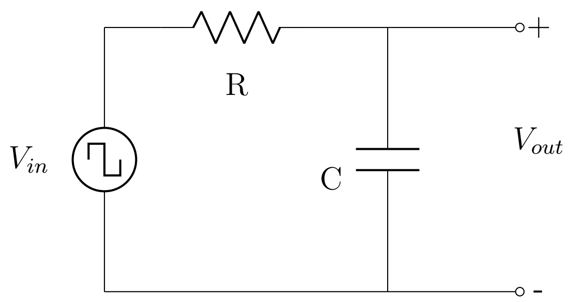
This document provides a step-by-step guide for setting up a simple RC circuit on a breadboard, where:

- A resistor ($R = 100\ \Omega$) and a capacitor ($C = 1\ \mu F$) are connected in series.
- A function generator provides an AC signal across the entire circuit.
- An oscilloscope measures the voltage across the capacitor.

Components Required

- Breadboard
- Resistor: 100Ω
- Capacitor: $1\mu F$
- Function Generator
- Oscilloscope with probes
- Connecting Wires

Circuit Diagram



Step-by-Step Connection Instructions

1. Place the 100Ω resistor and the $1\mu F$ capacitor on the breadboard.
2. Connect one terminal of the resistor to the positive output of the function generator.
3. Connect the other terminal of the resistor to one terminal of the capacitor.
4. Connect the other terminal of the capacitor to the ground of the function generator.
5. Connect the oscilloscope probes across the capacitor:
   - The positive probe to the junction between the resistor and the capacitor.
   - The ground probe to the ground of the function generator.
6. Turn on the function generator and set the desired frequency and amplitude.
7. Observe the voltage waveform across the capacitor on the oscilloscope.

Conclusion

This setup allows you to study the charging and discharging behavior of the capacitor in response to the applied AC signal. The oscilloscope displays the capacitor voltage, showing phase shift and amplitude variations based on the input frequency.

1.2 Response to Square Wave Input

- A square wave input of frequency f and peak voltage switching between 5V and 0V is applied. The input voltage can be expressed as a piecewise function:

$$V_{in}(t) = \begin{cases} 5V, & 0 \leq t < T/2 \\ 0V, & T/2 \leq t < T \end{cases} \tag{1.1}$$

  where $T = \frac{1}{f}$ is the period of the square wave.

- The voltage across the capacitor follows the charging and discharging equations:

$$V_C(t) = \begin{cases} 5(1 - e^{-t/\tau}), & 0 \leq t < T/2 \\ V_C(T/2)e^{-(t-T/2)/\tau}, & T/2 \leq t < T \end{cases} \tag{1.2}$$

  where $\tau = RC$ is the time constant of the circuit.

- At the end of each half-cycle, the capacitor voltage reaches:

$$V_C(T/2) = 5(1 - e^{-T/2\tau}) \tag{1.3}$$

  for the charging phase and

$$V_C(T) = V_C(T/2)e^{-T/2\tau} \tag{1.4}$$

  for the discharging phase.

- This theoretical derivation shows the capacitor voltage exhibits an exponential rise and fall pattern, rather than an abrupt transition.

Transient and Steady-State Response

The response of an RC circuit can be divided into two phases:

- **Transient Response:** This occurs immediately after a change in input voltage. It represents the period where the capacitor voltage is adjusting and follows an exponential rise or decay.

$$V_C(t) = V_f + (V_i - V_f)e^{-t/\tau} \tag{1.5}$$

  where V_i is the initial voltage, V_f is the final voltage the capacitor attempts to reach, and $\tau = RC$ is the time constant.

- **Steady-State Response:** This occurs when sufficient time has passed, and the capacitor voltage no longer changes significantly with time. For a periodic input like a square wave, the capacitor voltage oscillates between fixed values without further long-term variation.

The transition from transient to steady-state depends on the time constant τ, with a common rule of thumb being that the transient phase lasts about 5τ, after which the circuit is considered to have reached steady state.

1.3 Results

1.3.1 $RC = T$

- Transient response:

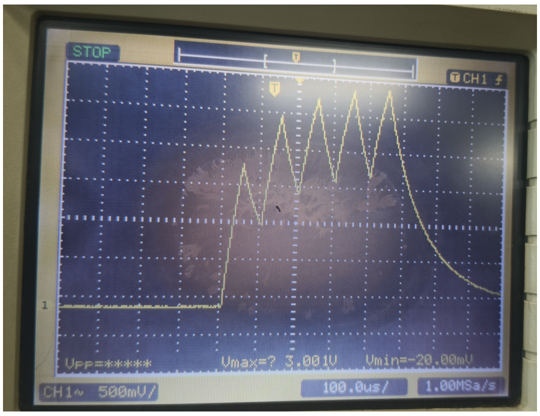


Figure 1.1: Transient RC=T

- Steady-state response:

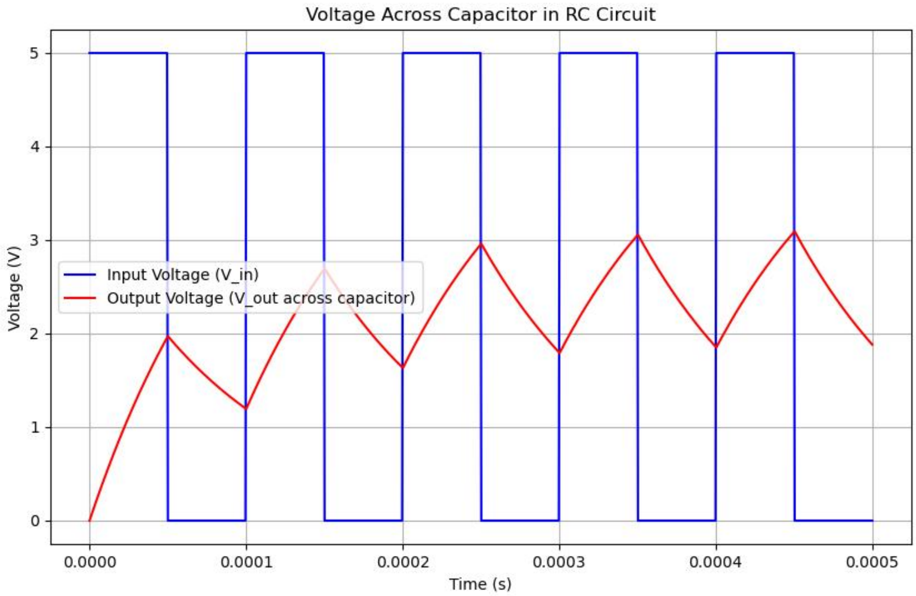


Figure 1.2: Python RC = T

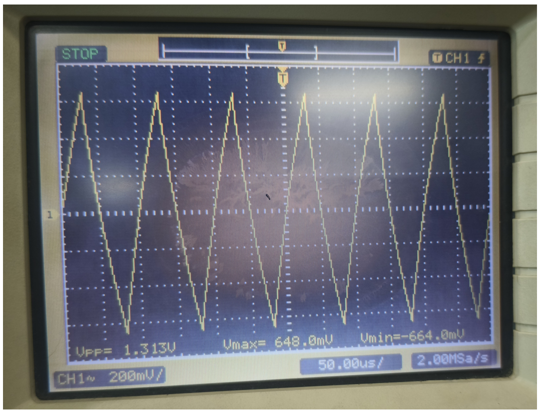


Figure 1.3: Steady State RC=T

1.3.2 $RC \ll T$

- Transient response:

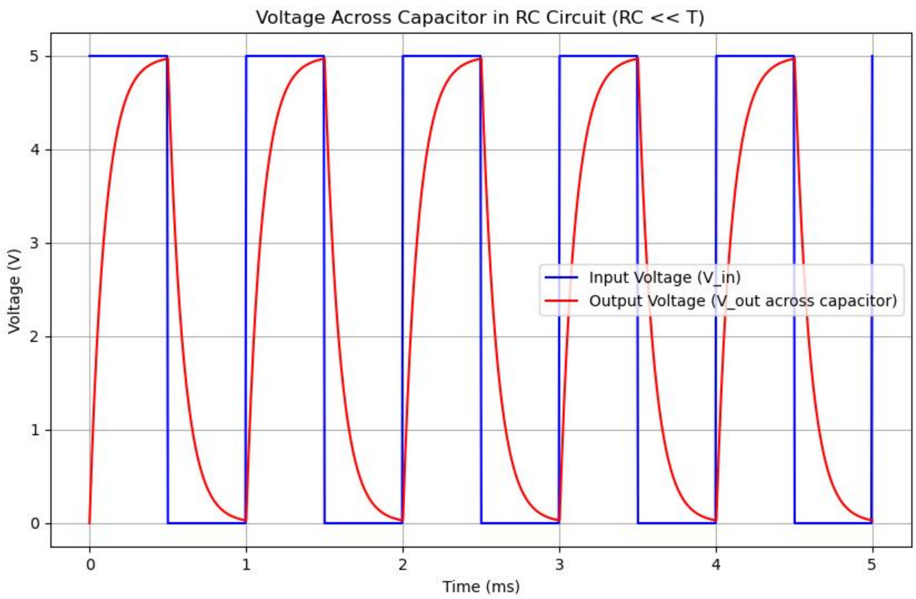


Figure 1.5: Python $RC \ll T$

Figure 1.4: Transient $RC \ll T$

- Steady-state response:

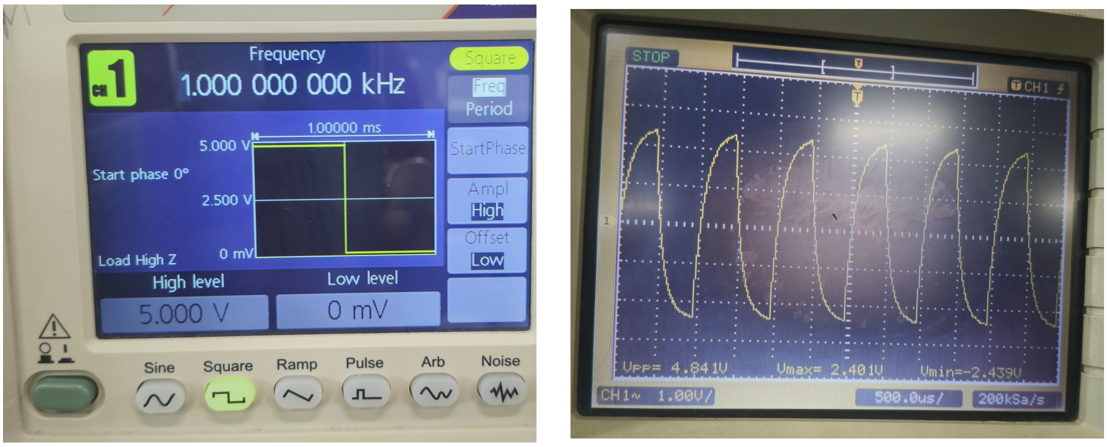
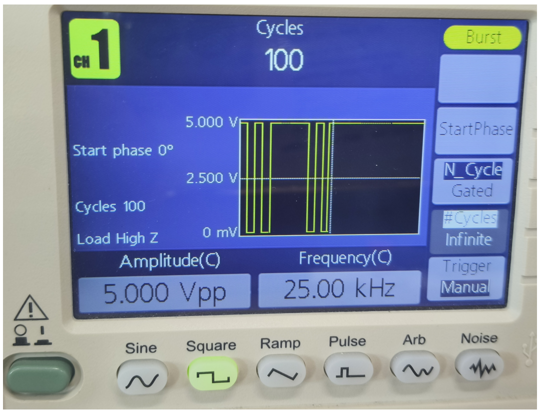
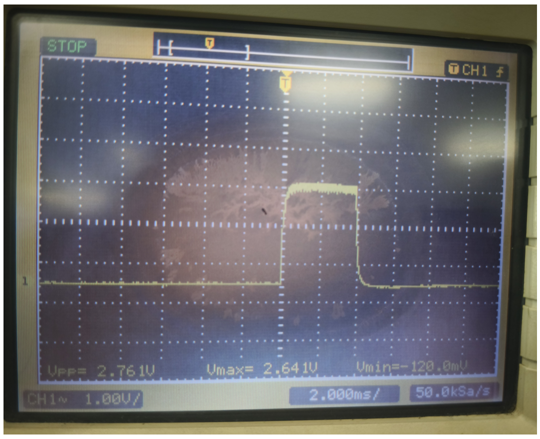


Figure 1.6: Steady State $RC \ll T$

1.3.3 $RC \gg T$

- Transient response: For Finite Cycles





For Infinite Cycles

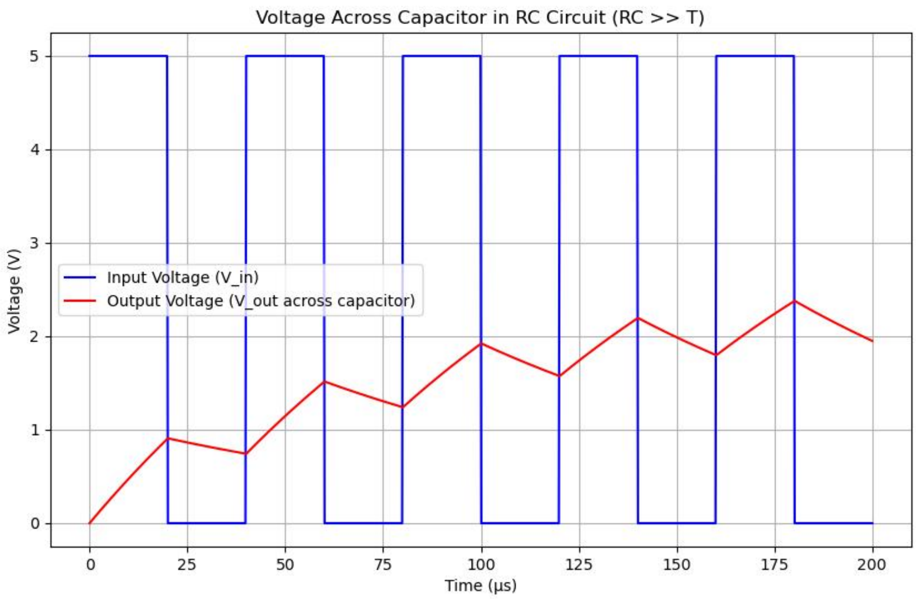


Figure 1.8: Python $RC \gg T$

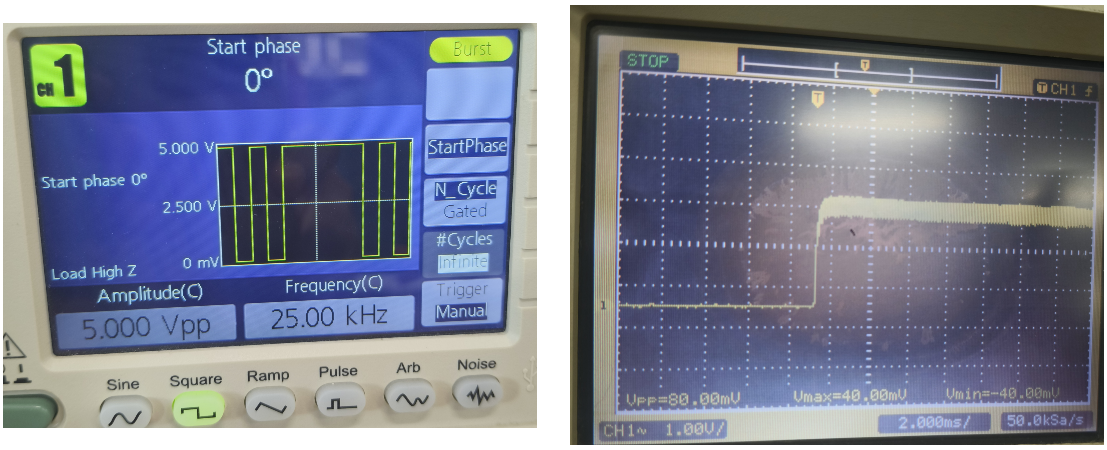


Figure 1.7: Transient $RC \gg T$

- Steady-state response:

Figure 1.9: Steady State $RC \gg T$

1.4 Conclusion

In this document, we explored the step-by-step process of setting up an RC circuit on a breadboard and analyzed the voltage response across the capacitor when subjected to a square wave input. We derived the mathematical expressions governing the transient and steady-state behaviors of the circuit. The capacitor voltage follows an exponential pattern of charging and discharging, dictated by the circuit's time constant $\tau = RC$. Understanding these concepts is essential for analyzing RC circuits in practical applications such as signal processing, filtering, and timing circuits.