RC Circuit Response to Square Wave Input

Lab Experiment Report

January 27, 2025

Objective

To analyze the transient and steady-state responses of an RC circuit to a square wave input in three cases: $RC = T$, $RC >> T$, and $RC << T$, where T is the time period of the input square wave. Input and output voltages will be observed for the first five cycles and in steady state, and theoretical values will be matched with experimental observations.

Apparatus

- Function generator
- Resistor R
- Capacitor C
- Oscilloscope (CRO)
- Connecting wires
- Multimeter

Circuit Diagram

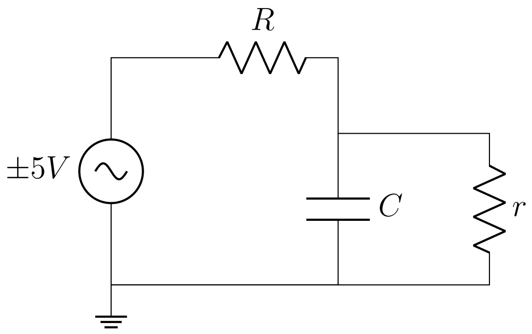

Figure 1: RC Circuit for Square Wave Input

Image of the actual circuit we connected on the breadboard is below,

Attach circuit image here.

Theory

An RC circuit responds to a square wave input differently based on the relationship between the circuit's time constant $\tau = RC$ and the input time period T:

1. $RC = T$: The circuit responds in a manner where the charging and discharging curves overlap significantly within one cycle.
2. $RC >> T$: The capacitor does not have sufficient time to charge or discharge completely within a cycle, resulting in a nearly constant output.
3. $RC << T$: The capacitor charges and discharges very quickly, producing an output waveform nearly identical to the input.

The output voltage V_{out} is given by:

$V_{out}(t) = V_{in}(1-e^{-t/RC})$ during charging, and $V_{out}(t) = V_{in}e^{-t/RC}$ during discharging.

Procedure

1. Construct the circuit as shown in the above figures.

(a) Connect the positive end of the function generator in series with a resistor

(b) Connect the capacitor and a small resistance in parallel, connect the combination in series with the rest of the circuit.

2. Set the function generator to output a square wave with $5V$ amplitude (Peak Voltage V, Minimum Voltage $0V$) and a specific frequency T. Select the type of cycle as *N-CYCLES*.

3. On the second channel of function generator, tune it to output the same wave as the first channel with the exact same configurations (even burst mode, manual trigger). Connect this to the second channel of the oscilloscope. This channel will serve to compare output of voltage across capacitor with input square wave.

4. This configuration enables the generation of a square wave with a predefined number of cycles when the trigger button is pressed on the function generator. On the oscilloscope, press the *SINGLE* button. This ensures that the next event captured by the oscilloscope is displayed and then the display pauses automatically.

5. Trigger the burst mode manually on the function generator to generate the single pulse or event.

6. Observe and record the captured waveforms on the oscilloscope.

Results

Case 1: $RC = T$

attach_first_case_plot.png

Hand Calculations:

$$\tau = RC, \quad T = \tau$$

$$V_{out}(t) = V_{in}(1 - e^{-t/RC})$$

Observations: Voltage values and time periods from CRO:

- Peak voltage: $V_p = \dots$
- Time period: $T = \dots$

Case 2: $RC >> T$

`attach_second_case_plot.png`

Hand Calculations:

$$\tau = RC, \quad \tau \gg T$$

$$V_{out}(t) \approx \text{constant over a cycle.}$$

Observations: Voltage values and time periods from CRO:

- Peak voltage: $V_p = \ldots$
- Time period: $T = \ldots$

Case 3: $RC << T$

attach_third_case_plot.png

Hand Calculations:

$$\tau = RC, \quad \tau \ll T$$

$$V_{out}(t) \approx V_{in}(t).$$

Observations: Voltage values and time periods from CRO:

- Peak voltage: $V_p = \ldots$
- Time period: $T = \ldots$

Discussion

- Compare the experimental results with the theoretical calculations.

- Discuss the effect of RC on the circuit response.
- Comment on any discrepancies between observed and theoretical values.

Conclusion

The transient and steady-state behaviors of the RC circuit under a square wave input were successfully analyzed for the cases $RC = T$, $RC >> T$, and $RC << T$. The observations matched the theoretical predictions within acceptable experimental error.