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2024-2025 Fall

1-Introduction

This lab explores the behavior of a simple RC circuit when different types of input signals are applied. We will focus on observing the output voltage across the capacitor when the circuit is subjected to both square and sine wave pulses.

Our main objective is to understand how the capacitor charges and discharges in response to these different waveforms. We expect to see a distinct difference in the capacitor's voltage-time (V-t) graph depending on the input signal.

By investigating these fundamental characteristics of RC circuits, we can gain a better understanding of their potential applications in various scenarios. This experiment serves as a starting point for exploring how different input signals can shape the output of an RC circuit, paving the way for more advanced studies and practical applications.

General Formula of Capacitor Charging Equation: $Vout(t) = V_{in} \cdot \left(1 - e^{\frac{-t}{RC}}\right)$

General Formula of Capacitor Discharging Equation: $Vout(t) = V_{initial} \cdot \left(e^{\frac{-t}{RC}}\right)$

I choose T_1 and T_0 as:

$T_1 = 2.9\tau$

$T_0 = 46\tau$

2. Analysis

A- Square Wave Pulse

$0 < t < T_1$

$$Vout(t) = 6V \cdot \left(1 - e^{\frac{-t}{RC}}\right)$$

$T_1 < t < T_0$

$$Vout(t) = Vout(\, T_1 \,) \cdot e^{\frac{-(t-T1)}{RC}}$$

Square Wave Pulse Observations:

The charging and discharging dynamics of an RC circuit were investigated for specific values of R and C, and time intervals T_0 and T_1. Initial analysis involved hand calculations to predict the circuit's behavior.

At the end of the charging period, $Vout \; \cong \; 5.6\,V$
At the end of the discharging period, $Vout \; \cong \; 0$

A MATLAB script was then developed to simulate the RC circuit's response. An LTspice simulation was also performed to provide an independent verification of the MATLAB results.

Following the charging period, an approximate voltage of 5.6 V was observed across the capacitor. This voltage served as the initial condition for the subsequent discharging phase. After the discharging period, the voltage across the capacitor approached zero. The convergence of the capacitor voltage to zero after T_0 confirms the expected discharging behavior of the RC circuit. The close agreement between the hand calculations, MATLAB simulation, and LTspice simulation validates the accuracy of the implemented models and reinforces the theoretical understanding of the RC circuit's charging and discharging characteristics.

```
R = 8.2e3;
C = 820e-9;
tau = R * C;
T1 = (2.9)*tau;
T0 = 46 * tau;

t = linspace(0, T0, 1000);
V_in = 6;
V_out = zeros(size(t));

for i = 1:length(t)
    t_mod = mod(t(i), T0);

    % Charge phase
    if t_mod < T1
        V_out(i) = V_in * (1 - exp(-t_mod / tau));
    % Discharge phase
    else
        V_out(i) = V_in * (1 - exp(-T1 / tau)) * exp(-(t_mod - T1) / tau);
    end
end

figure;
plot(t, V_out);
title('Capacitor Voltage Response to a Periodic Pulse');
xlabel('Time (s)');
ylabel('Voltage (V)');
grid on;
```

Figure.1: MATLAB simulation code of Square Wave Pulse

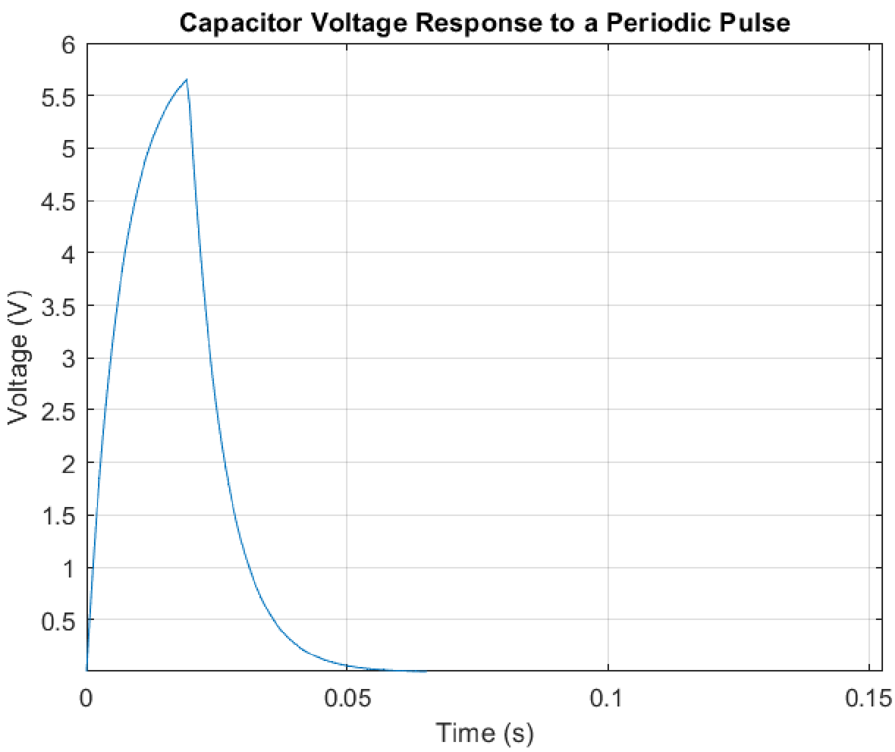

Figure.2: Square Wave Pulse Response of the Capacitor, MATLAB simulation

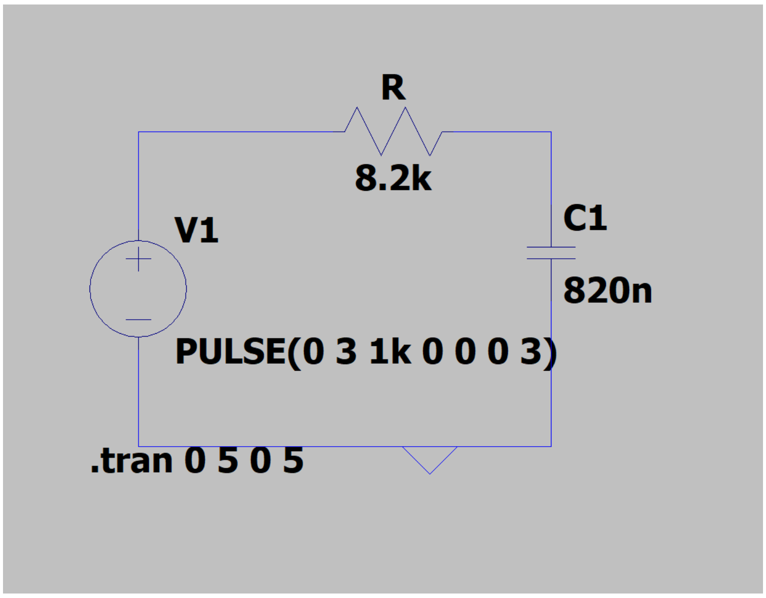

Figure.3: LTspice schematic of the circuit

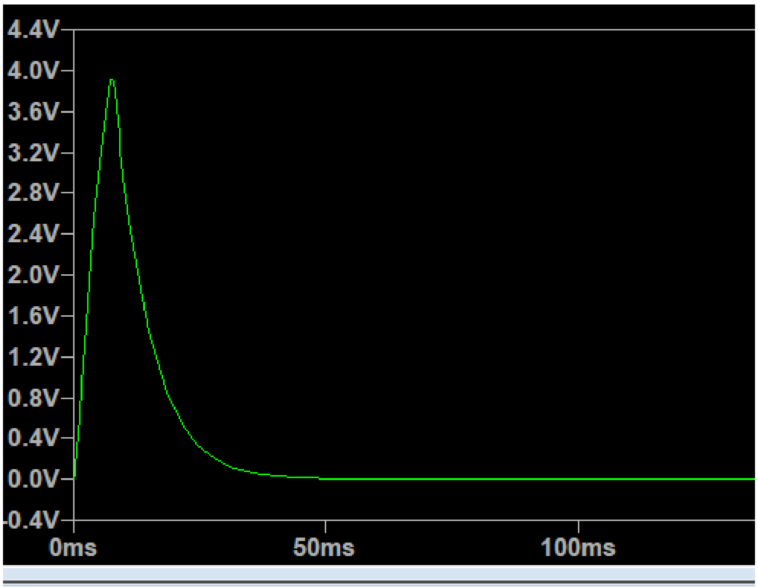

Figure.4: Square Wave Pulse Response of the Capacitor, LTspice simulation

B- Sine Wave Pulse

$0 < t < T_1$

$$Vout(t) = 3\sin\frac{2\pi t}{\mathrm{T}_1} \cdot \left(1 - e^{\frac{-t}{RC}}\right)$$

$T_1 < t < T_0$

$$Vout(t) = Vout(\, T_1 \,) \cdot e^{\frac{-(t - T1)}{RC}}$$

Square Wave Pulse Observations:

The charging and discharging behavior of an RC circuit subject to a sinusoidal pulse input was investigated for specified time intervals T_0 and T_1. Due to the complexity of the sinusoidal input, hand calculations were not performed. Instead, a MATLAB script was developed to simulate the circuit's response. The output of the MATLAB simulation was compared to an example waveform showing good agreement.

```
R = 8.2e3;
C = 820e-9;
tau = R * C;
T1 = (2.9) * tau;
T0 = 46 * tau;

% Zaman vektörü
t = linspace(0, T0, 1000);

V_in_peak = 3;
V_out = zeros(size(t));

for i = 1:length(t)
    t_mod = mod(t(i), T0);


    if t_mod < T1
        V_in_t = V_in_peak * sin(2 * pi * t_mod / T1);
        V_out(i) = V_in_t * (1 - exp(-t_mod / (R * C)));
    else

        V_out(i) = V_out(i-1) * exp(-(t_mod - T1) / (R * C));
    end
end

figure;
plot(t, V_out);
title('Capacitor Voltage Response to a Sinusoidal Pulse');
xlabel('Time (s)');
ylabel('Voltage (V)');
```

Figure.5: MATLAB simulation code of Sine Wave Pulse

During the charging period (T_1), the capacitor voltage followed the sinusoidal pulse, charging to approximately 1.5V. After the sine wave began its descent, the capacitor voltage also decreased, approaching zero. The capacitor then charged to a negative voltage, reaching approximately -2.6V, mirroring the negative half-cycle of the sine wave. Finally, as the sine wave returned to zero, the capacitor discharged, with its voltage approaching zero by the end of the discharging period.

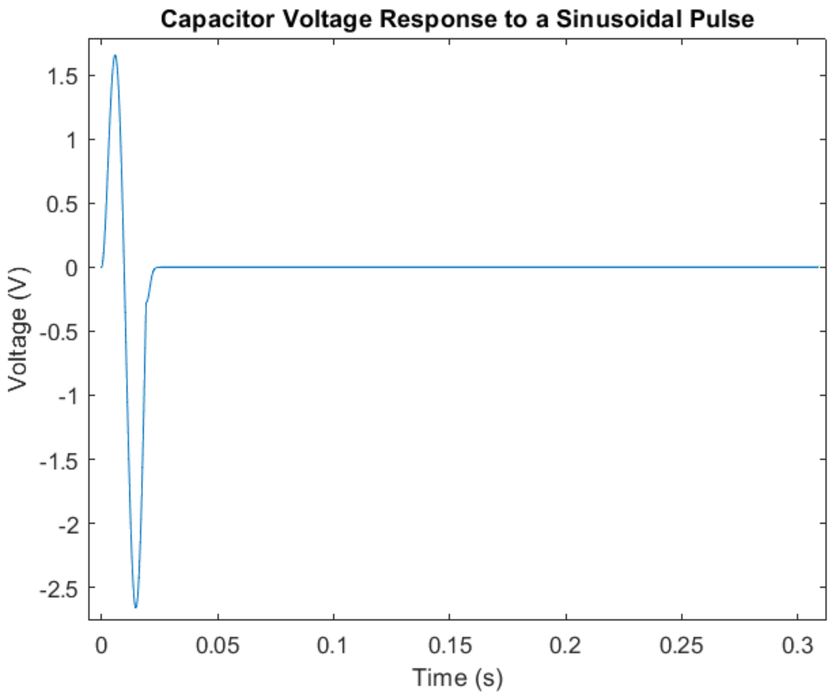

Figure.6: Sine Wave Pulse Response of the Capacitor, MATLAB simulation

The observed sinusoidal-like charging and discharging behavior of the capacitor voltage is consistent with the sinusoidal nature of the input pulse. The MATLAB simulation effectively captured the circuit's response to this time-varying input, demonstrating the expected charging and discharging dynamics. This close correspondence between the simulation and the example waveform provides confidence in the accuracy of the MATLAB model.

3. Conclusion

This experiment investigated the charging and discharging behavior of RC circuits under different input signals. First, with a DC source, the circuit charged and discharged as expected for the chosen R and C values and T_0 and T_1 durations. The theoretical calculations, MATLAB simulation, and LTspice simulation results showed strong agreement. The capacitor voltage reached approximately 5.6 V after the charging period (T_1) and discharged to near zero after the discharging period. These results confirm the fundamental operating principles of RC circuits.

Second, when a sine wave pulse was used as the input, the capacitor voltage exhibited a sinusoidal-like charging and discharging pattern, mirroring the input signal with slight delay. The MATLAB simulation results closely matched an example waveform. During the positive half-cycle of the sine wave, the capacitor charged to approximately 1.5V, while during the negative half-cycle, it charged to approximately -2.6V. In both cases, the capacitor voltage approached zero by the end of the discharging period. These observations highlight how RC circuits respond to time-varying input signals. The shape of the input signal clearly influences the capacitor voltage waveform. These findings successfully address the objectives outlined in the introduction, providing a clearer understanding of RC circuit behavior.