Lab 9
The Response of an RC Circuit to Pulse Voltage Waveforms

OBJECTIVES
1. Validate the RC response for a partially and fully charging/discharging capacitor.
2. Check the validity of Kirchhoff’s Voltage Law for an RC circuit.

EQUIPMENT
Lab kit, Oscilloscope, Function Generator, Power Supply

THEORY
Consider the Thévenin RC circuit with the square wave voltage input. The time dependent voltage across the capacitor is

\[ v_c(t) = V_{OC} + (v_c(0^-) - V_{OC})e^{-t/\tau} = V_{final} + (V_{initial} - V_{final})e^{-t/\tau} \]

What determines whether a capacitor is partially or completely charged is the pulse width \( pw \) of the square wave input. Two cases will be considered: (1) \( pw = 5\tau \) and (2) \( pw = 2\tau \). For a pulse width of \( 5\tau \) or greater, the capacitor will have enough time to completely charge up and completely discharge. For a pulse width of \( 2\tau \), the capacitor will not have had enough time to completely charge up or completely discharge. It will require 5 cycles of the constant square wave input to reach its final steady state value. The repeated application of the complete response for a constant input for these 5 cycles will ultimately achieve the final steady-state value that is observed experimentally on the oscilloscope.

PROCEDURE
Part 1: Setting up the Function Generator
a. Set the function generator to the square-wave mode and set the frequency to 10 kHz. Adjust the sweep control until two full periods appear on the screen. Using the scope display, adjust the frequency of the function generator to ensure that the output frequency is exactly 10 kHz. (Hint: determine how many horizontal divisions should encompass a 10-kHz signal, and make the necessary adjustments.)
b. How is the pulse width \( pw \) and period \( T \) of the square wave voltage related to the frequency \( f \) for the cycle?

Part 2: RC Response for a pulse width of \( 5\tau \)
Construct the following circuit.

![RC Circuit Diagram]

Part 2: Measurements for a pulse width of \( 5\tau \)
a. **Determine** the time constant \( \tau \) of the circuit using the actual resistor and capacitor values that will be used in the experiment.
b. From the time constant \( \tau \), determine the period \( T = 10\tau \) required for a capacitor to charge and discharge. Using the period, determine the frequency for the voltage source.
c. Adjust the FG from your 10kHz setting from Part 1 (set the sweep speed to 10μs) to the required 10\( \tau \) period.
d. Use PSpice to simulate the RC circuit using the \(10\tau\) period. Plot \(v_C(t)\) and \(v_R(t)\) and label the voltages for the charging phase for time constants \((\tau, 3\tau, 5\tau)\) and for the discharging phase for time constants \((6\tau, 8\tau, 10\tau)\). Setup an Excel that lists these values where these values are used as guides to measured values in part (2e) below.

d. **Measure** the capacitor’s voltage \(v_{C,\text{exp}}(t)\) for the charging phase for time constants \((\tau, 3\tau, 5\tau)\) and for the discharging phase for time constants \((6\tau, 8\tau, 10\tau)\). Make sure that the capacitor is connected to the ground and make the necessary time adjustments to “spread out” the waveform as large as possible on the screen.

f. Switch the positions of the resistor and capacitor. **Measure** the resistor’s voltage \(v_{R,\text{exp}}(t)\) for the charging and discharging phases. Accurately plot \(v_{C,\text{exp}}(t)\) and \(v_{R,\text{exp}}(t)\) on the same graph paper.

g. **Predict** the capacitor’s and resistor’s voltage \((v_{C,\text{thy}}(t) \& v_{R,\text{thy}}(t))\) for the charging and discharging phases. Hint: an Excel spread sheet calculations will reduce the redundancy; however, a sample calculation is still required.

h. **Compare** the predicted and measured values for the capacitor’s and resistor’s voltages during the charging and discharging phases. How do they compare?

i. Use KVL to make sure that the voltage source value equals the sum of the resistor and capacitor voltages \((v_S = v_R + v_C)\) at time \(t = 3\tau\). Make this comparison graphically as well as numerically. Does KVL hold for RC circuits? Explain.

**Part 3: RC Response for a pulse width of \(2\tau\)**

a. From the time constant, determine the period \(T\), the pulse width \(T/2\), and the frequency \(f\) of the applied square wave.

c. Adjust the FG in order to see the charging and discharging of the capacitor. Is the capacitor full charging and discharging? Explain your reasoning.

d. Use PSpice to simulate the RC circuit using the \(2\tau\) period. Plot \(v_C(t)\) and \(v_R(t)\) and label the voltages for the charging phase for time constants \((\tau\text{ and } 2\tau)\) and for the discharging phase for time constants \((3\tau\text{ and } 4\tau)\). Setup an Excel that lists these values where these values are used as guides to measured values in part (3e) below.

d. **Predict** and **measure** the capacitor’s and resistor’s voltages (in steady-state) using the same process as in part (2).

e. **Compare** the predicted and measured values for the capacitor’s and resistor’s voltage during the charging and discharging phases. How do they compare?

f. Use KVL to make sure that the voltage source value equals the sum of the resistor and capacitor voltages \((v_S = v_R + v_C)\) at time \(t = \tau\). Make this comparison graphically as well as numerically. Does KVL hold for RC circuits? Explain.
Engr 15 Formal Lab Report Format

Formal Lab Report is due 2 weeks after the lab is completed

The formal lab report will be based on the Response of an RC Circuit to Pulse Voltage Waveforms experiment. The report should be

- 8 – 12 pages in length
- typed in the font style Arial or Times New Roman and font size point 12
- on 8.5 x 11 inch paper

The report must include the following sections in the following order:
1. Abstract (summarize the key points in the report in 100 words or less).
2. Introduction (creates interest, gives background information, an application of the topic, and states the theory).
3. Materials and Methods (describe equipment and procedures).
4. Data and data results (with calculations) presented in tables and graphs, error analysis, and predicted and experimental comparison.
5. Discussion (recaps key points and interprets the results).

The Review Sheet is a good check to see if you have included all the important elements that are required.

Review Guide Sheet

1. Abstract and Introduction
   - Is the abstract complete – including results?
   - Does it draw interest? Is the interest topic connected to the actual experiment?
   - Was an application of the topic included?
   - How does the application relate to the laboratory experiment?
   - Does it include theory and purpose?

2. Materials and Methods
   - Is it sufficiently complete even for a stranger?
   - The explanations should not be in “recipe form.” Are they?
   - Are the descriptions and illustrations clear?

3. Results
   - Are the derivations and sample calculations clear?
   - Are calculations explained with words also?
   - Are there clear presentations of data tables, graphs, and illustrations?
   - Is there a clear comparison between theory and experiment?
   - Explain what being consistent or not consistent with a 1σ- and 2σ-intervals.
   - Is there a clear estimated experimental uncertainty?
   - Are there too many repeated calculations?
   - Are all of the above in sequential order?

4. Discussion of Results
   - Is there a clear summary of key results?
   - Are significant discrepancies identified and discussed?
   - Does it show thoughtful/insightful discussion of results?
   - Is the discussion quantitative/specific rather than vague/general?
   - Is there too much opinion?