BRAC UNIVERSITY
Dept. of Computer Science and Engineering

CSE250L
Circuits and Electronics Laboratory

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Experiment No. 7

Study of the Transient Behavior in RC Circuits

Objective

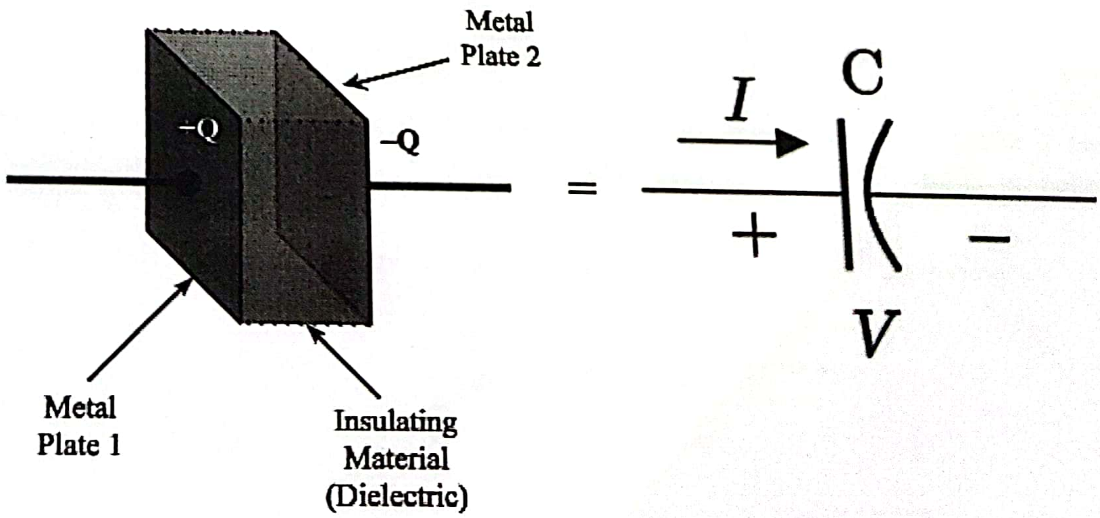
This experiment aims to investigate the transient response of first-order circuits. In this experiment, students will find the time constant τ of an RC circuit.

Theory

The word 'transient' means something that only lasts for a short time *(short-lived)*. In circuit theory, transient response is the response of a system to a change from an equilibrium or a steady state. In the context of RC circuits *(a circuit only consisting of resistors and capacitors but no inductor)*, we will study how the voltage and current in an RC circuit change due to external excitation, such as switching or sudden change in input. In today's experiment, we will construct RC circuits and observe their response due to sudden changes in input voltage.

Capacitor

Capacitors are passive elements that can store energy within its own electric field. A capacitor can be as simple as an insulating material *(dielectric)* consisting of two parallel conductive plates. Charges can build up within these plates which creates an electric field across the plates and a voltage difference between them.



The amount of charge accumulated in each plate is directly proportional to the voltage difference applied across the two plates of a capacitor. If the voltage across the capacitor is v_C and the accumulated charge is Q, then we can write,

Data Tables

Signature of Lab Faculty: Rela **Date:** 23-04-25

** ***For all the data tables, take data up to three decimal places, round to two, and then enter into the table.***

Table 1: Resistance and Capacitance Data

For all your future calculations, please use the observed values only **(even for theoretical calculations).**

Notation	Expected Resistance	Observed Resistance (kΩ)	Notation	Expected Capacitance	Observed Capacitance (μF)
R	1 kΩ	0.98	C_1	1 μF	0.98
			C_2	1 μF	0.98
			C_3	0.47 μF	0.48

Table 2: Data from Circuit 1 *(Initial)*

Keep the switch to the **initial position** (connect to 2V and keep 6V open).

Initial Circuit	Initial DC Supply Voltage $V_S(0)$ (V)			$v_C(0)$ (V)	$v_R(0)$ (V)	$I(0) = \frac{v_R(0)}{R}$ (mA)
	Expected Voltage	From DC power supply	Using multimeter			
Experi-mental	2.0	2	2.04	1.98	0	0
Theo-retical				0.0	2.0	2.0

Table 3: Data from Circuit 1 *(Final)*

Change the switch to the **final position** (connect to 6V and keep 2V open).

Final Circuit	Final DC Supply Voltage $V_S(\infty)$ (V)			$v_C(\infty)$ (V)	$v_R(\infty)$ (V)	$I(\infty) = \frac{v_R(\infty)}{R}$ (mA)
	Expected Voltage	From DC power supply	Using multimeter			
Experi-mental	6.0	6	6.07	6.07	0	0
Theo-retical				6.0	0.0	0.0

Table 4: Data from Circuit 2

Use the function generator for the supply voltage and observe all values from the oscilloscope.

Time constant, $\tau = RC =$ 1 ms

Theoretical charging / discharging time $= 5\tau = 5RC =$ 5 ms

Circuit 2	Supply Voltage V_S		Capacitor Voltage v_C		Charging / Discharging time t_{full} (ms)
	Minimum Value $V_{S_{min}}$ (V)	Maximum Value $V_{S_{max}}$ (V)	Minimum Value $v_{C_{min}}$ (V)	Maximum Value $v_{C_{max}}$ (V)	
Experimental (from oscilloscope)	2.16	6.16	2.16	6.16	3.7
Theoretical			0V	5V	5

Table 5: Data from Circuit 3

Use the function generator for the supply voltage and observe all values from the oscilloscope.

Circuit 3	Charging Phase				Discharging Phase			
	Resistor Voltage		Circuit Current $I = \frac{v_R}{R}$		Resistor Voltage		Circuit Current $I = \frac{v_R}{R}$	
	$v_{R_{max}}$ (V)	$v_{R_{min}}$ (V)	I_{max} (mA)	I_{min} (mA)	$v_{R_{max}}$ (V)	$v_{R_{min}}$ (V)	I_{max} (mA)	I_{min} (mA)
Experi-mental	3.68	0.04	3.75	0.04	-3.6	-0.04	3.67	-0.04
Theo-retical	5.0	0.0	5.0	0.0	5.0	0.0	5.0	0.0

Table 6: Data from Circuit 4 and Circuit 5

Use the function generator for the supply voltage and observe all values from the oscilloscope.

Amplitude of voltage to set on the function generator = 2.5 V

DC offset to set on the function generator = -2.5 V

Circuit 4	Capacitor Voltage v_C		Charging / Discharging time t_{full} (ms)	Time constant $\tau = \frac{t_{full}}{5}$ (ms)	Equivalent Capacitance		
	Minimum Value $v_{C_{min}}$ (V)	Maximum Value $v_{C_{max}}$ (V)			(from osc.) $C = \frac{\tau}{R}$ (μF)	From Circuit 5 using multimeter C_{eq} (μF)	Error $\frac{\lvert C-C_{eq}\rvert \times 100\%}{C_{eq}}$ (%)
Experi-mental	-1.6	3.12	4.9	0.98	1	1	0
Theo-retical			4.5	0.9	1		

Questions

1. A capacitor stores energy-

   ☐ Magnetically ☑ Electrically ☐ Chemically ☐ Electro-chemically

2. If the capacitance (C) of a capacitor is related with the voltage (V) applied and the charge on the plate (q) of the capacitor as $C = \frac{q}{V}$, which one of the following statements is correct? The capacitance of a capacitor can be increased by–

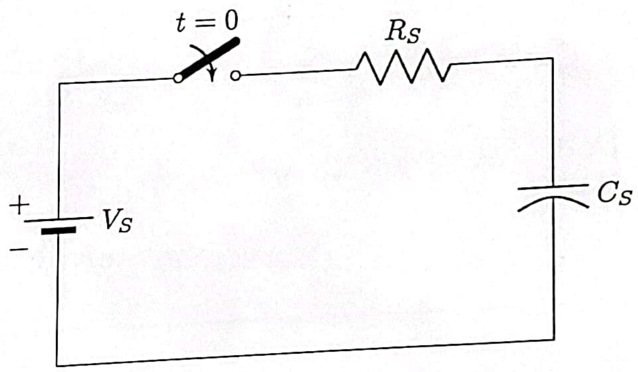
   ☐ decreasing the applied voltage across the capacitor.

   ☐ increasing the initial current through the capacitor.

   ☑ increasing the surface area of the plates.

   ☐ decreasing the size of the capacitor.

3. When the switch in the following circuit is closed at $t = 0$, the following energy conversions happen–



[use the keywords ***electrical/mechanical/chemical/electro-chemical/thermal*** *to answer (a) (b) and (c)]*

(a) The battery converts chemical energy to electrical energy.

(b) The capacitor receives electrical energy from the battery and stores it in the form of electrical energy.

(c) The resistor dissipates energy into thermal energy.

(d) Upon being fully charged by the battery (not to be dead so quickly), the capacitor–

   ☐ spontaneously releases the stored energy after some time to the resistor connected.

   ☐ gives the stored energy back to the battery after some time.

   ☑ holds the energy until some other circuit elements are connected to receive it.

   ☐ can better tell what it wants to do.

4. Why was it necessary to short the two terminals of a capacitor before measuring the capacitance in the laboratory?

Because a capacitor may retain residual charge which can effect the measurement. Shorting ensures it is fully discharged, allowing accurate capacitance measurement.

5. We know the time constant (τ) depends on the equivalent resistance and the capacitance as $\tau = R_{eq}C$. Let's say, for a particular circuit, under a certain dc bias, **the time it requires** for increasing the voltage of a capacitor from $0\ V$ to $5\ V$ is $5\ ms$. If there were an initial voltage in the capacitor equal to $2\ V$, would the time now to increase the voltage to $5\ V$ be the same?

☐ Yes ☑ No

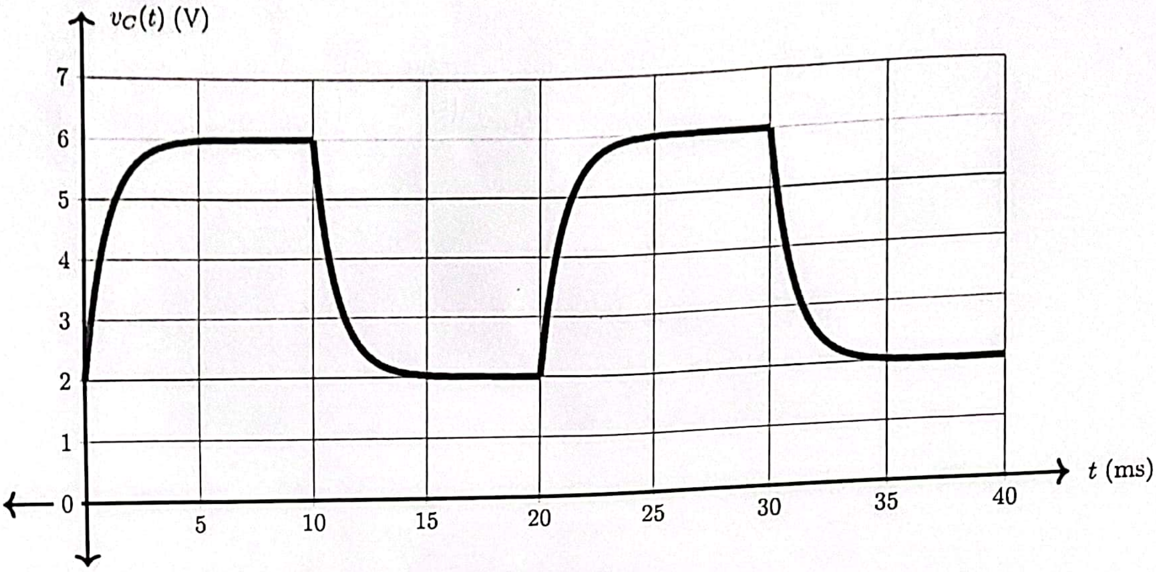
Why?

Because the voltage change is now smaller, so it requires less time to approach 5V within the same time constant.

6. Based on your understanding and choice in question **5**, write briefly the significance of the time constant (τ) related to charging and discharging in an RC circuit.

The significance of τ is that the time constant τ determines how quickly the voltage across a capacitor charges or discharges. After time τ, the voltage changes approximately 63.2% towards its final value. It governs how fast the circuit responds to voltage changes.

7. The capacitor voltage waveform you observed in the laboratory for **Circuit 3** is shown below where the input bias to the capacitance alternates between $-2\,V$ to $5\,V$ at a frequency of $100\,Hz$.



(a) Mark the following in the diagram for one cycle:

(i) Charging and discharging portions, ~~rise:~~ (Voltage rises while charging.)

(ii) Initial and final voltages for both charging and discharging phases, (−2V and 5V)

(iii) The times when the capacitor gets fully charged and discharged.

$t = 5\tau$

(b) Explain how you can change the time-period of the voltage waveform keeping the duty cycle unchanged.

The time-period of the waveform can be changed by adjusting the frequency of the waveform from the function generator while keeping the high and low duration ratio constant.

(c) If the resistance in Circuit 3 is changed, will the duty cycle of the waveform change?

☐ Yes ☑ No

Why?

The duty cycle depends on the input signal from the function generator, not on the circuit resistance.

(d) Will decreasing the frequency of switching (slower switching, expansion in time) have any effect on the charging or discharging times of the capacitor?

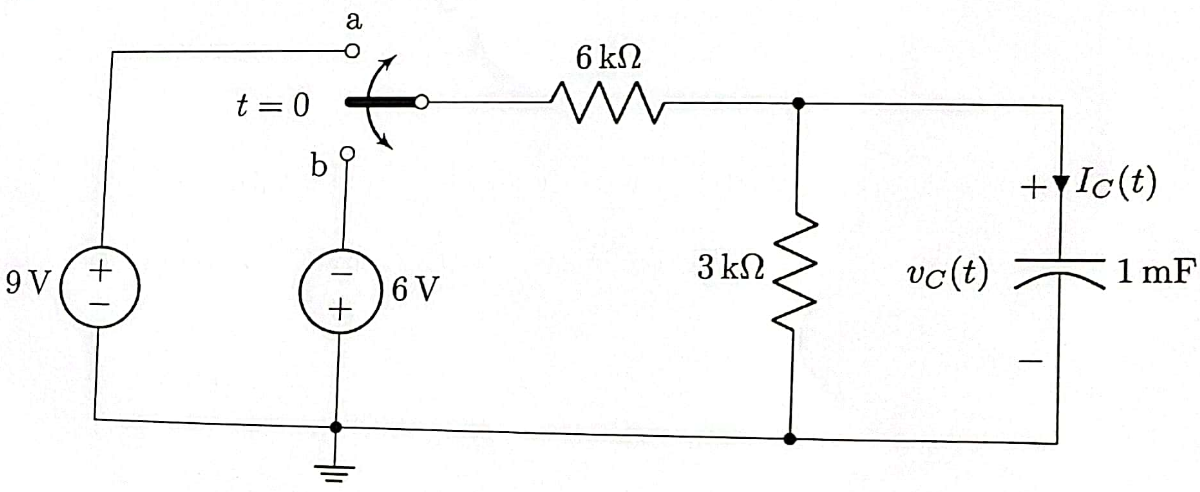
Decreasing the frequency of switching will have ☐ no ☑ an effect on the charging and discharging time of the capacitor. Because

Decreasing frequency increases the time period, giving the capacitor more time to charge or discharge fully before the input switches again.

8. If you are asked to set a sinusoidal voltage with a dc offset $v(t) = 5 + 5sin(2\pi 100t)\ (Volt)$ in a **Function Generator**, specify the values of the following parameters. On the rightmost boxes, put a checkmark ✔ to indicate the ones that need to be set on the Function Generator.

• Amplitude of the voltage =	5 V	
• Peak to peak of the voltage =	10 V	
• Natural Frequency, f =	100 Hz	
• Angular Frequency, ω = ($2\pi \times 100$)	628.32 $rads^{-1}$	
• Initial Phase, ϕ =	0 ^{o}	
• DC Offset =	5 V	

9. Consider the RC circuit shown below. At $t = 0$, the switch starts to alternate between positions a and b at a frequency of **25 Hz**.



(a) Which one of the following instruments do you need in the laboratory to set up the **switching mechanism** between a and b as shown in the circuit diagram above?

☐ Two separate DC Power supplies.

☑ A Function Generator with the functionality of providing a dc offset.

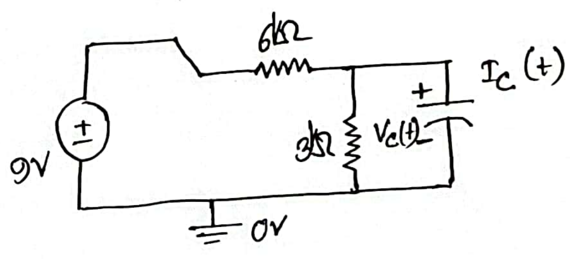
☐ An Oscilloscope.

☐ A DC Power Supply with two channels.

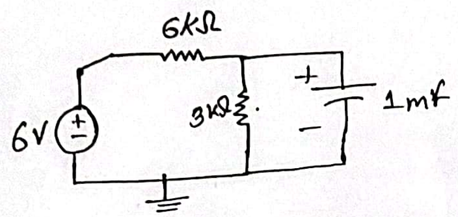
(b) Based on your selection in (a) and the values of the input voltages in the circuit diagram, specify the values of the following parameters. On the rightmost boxes, put a checkmark ✔ to indicate the ones that need to be set on the Function Generator.

• Amplitude of the voltage =	1.5 V	
• Peak to peak of the voltage =	3 V	
• Natural Frequency, f =	25 Hz	
• Angular Frequency, ω = $(2\pi \times 25)$	157.08 $rads^{-1}$	
• Initial Phase, ϕ =	0 °	
• DC Offset =	7.5 V	

(c) Draw the active portion of the circuit when the switch is in position a and determine the voltage across the capacitor, $v_C(t, switch \rightarrow a)$. *See the **Theory** section of this sheet if necessary.*



(d) Draw the active portion of the circuit when the switch is in position b and determine the voltage across the capacitor, $v_C(t,\ switch \rightarrow b)$. *See the Theory section of this sheet if necessary.*



(e) So, the capacitor voltage $v_C(t)$ alternates between the values 6 (V) and 9 (V).

(f) Now, determine the equivalent resistance as seen from the capacitor terminals (for $t > 0$).

$R_{eq} =$ 2 $(k\Omega)$

(g) The time constant τ is thus—

$\tau = R_{eq}C =$ 2 (ms)

(h) If the time constant (τ) is 2 (ms), it will take 10 (ms) for the capacitor to reach to steady-state.

(i) In general, the voltage across a capacitor under a sudden change in the applied dc bias is,

$$v_C(t) = v_C(final) + [v_C(initial) - v_C(final)]e^{-\frac{t}{\tau}}$$

or

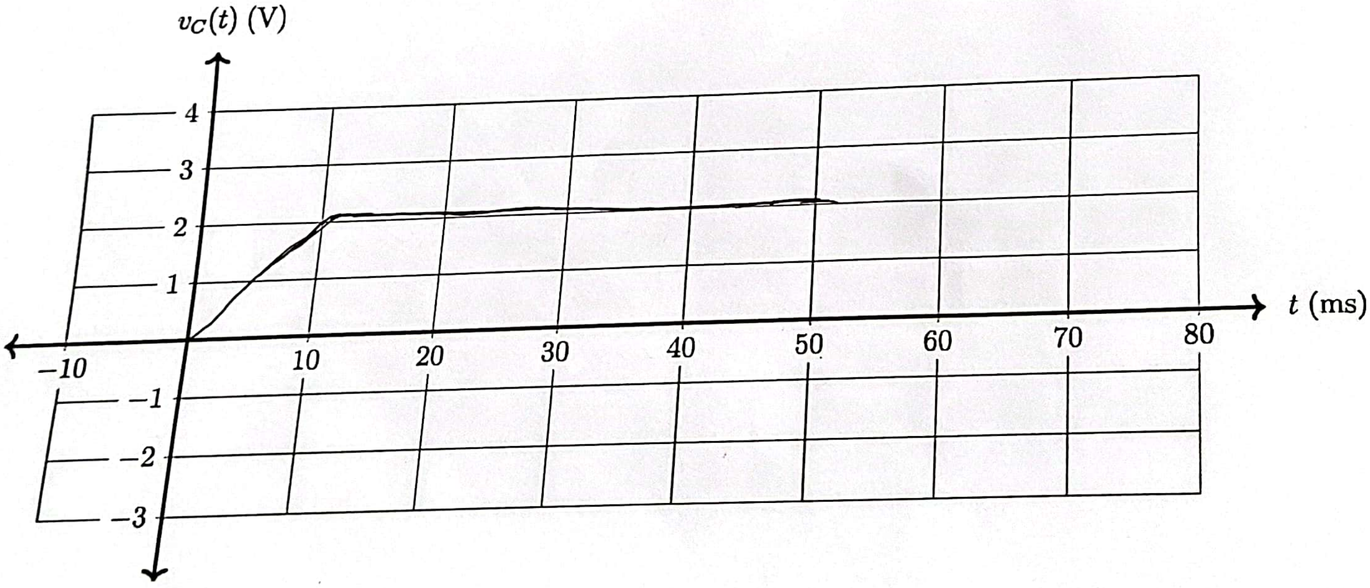
$$v_C(t) = v_C(\infty) + [v_C(0) - v_C(\infty)]e^{-\frac{t}{\tau}}$$

Now, plug in the values you got in (e) and (g) appropriately in the equation for $v_C(t)$ and write down the expression for $v_C(t)$ as a function of time for–

Increasing phase: $v_C(t) = V_c(0) + [V_c(6) - V_c(0)] e^{-t/\tau}$

Decreasing phase: $v_C(t) = V_c(6) + [V_c(0) - V_c(6)] e^{-t/\tau}$

(j) Based on the values in (e) and (h), draw the waveform of the voltage across the capacitor v_C for $t > 0$, that we could observe in an Oscilloscope as a function of time as it gets increases and decreases continuously. Note that one cycle of the input voltage is equal to $\frac{1}{25\ Hz} = 40\ ms$. See the plot in **Question 7** to help yourself.



Report

1. *Fill up the theoretical parts of all the data tables.*
2. Answers to the questions.
3. Attach the captured images of the plots observed in the oscilloscope for **Circuits 2, 3,** and **4**. Fit all the images in a single page and print.