BRAC UNIVERSITY

Dept. of Computer Science and Engineering

CSE250L

Circuits and Electronics Laboratory

Student ID:	M 22299079	Lab Section:	02
Name:	MD. Sohanur Rahman Shimul	Lab Group:	12

Experiment No. 7

Study of the Transient Behavior in RC Circuits

Objective

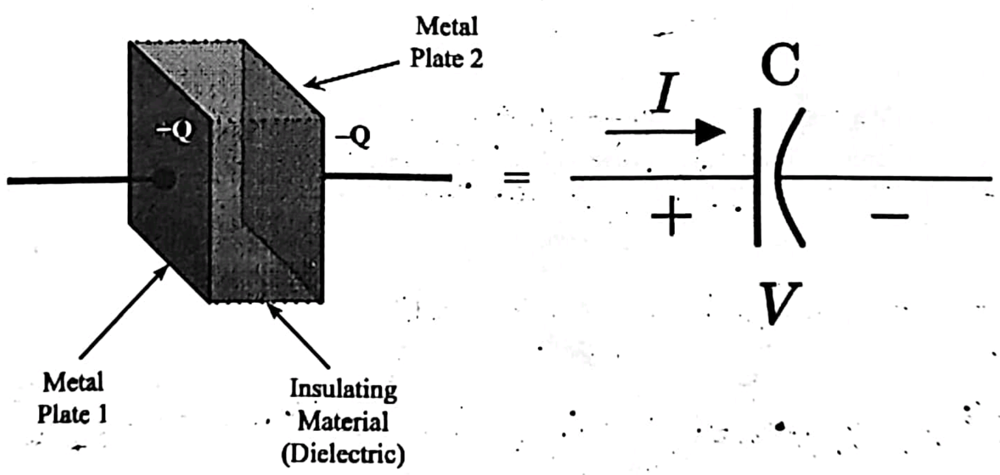
This experiment aims to investigate the transient response of first-order circuits. In this experiment, students will find the time constant τ of an RC circuit.

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: ______ **Date:** ______

** ***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	0.982	C_1	1 μF	1.02
			C_2	1 μF	0.979
			C_3	0.47 μF	0.47

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	2	0	0
Theo-retical				2	0	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	5.9	5.9	0	0
Theo-retical				6	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, $\tau = RC$ = 1.001 *ms*

Theoretical charging / discharging time = $5\tau = 5RC$ = 5.008 *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	6	1.76	5.92	4.95
Theoretical			2	6	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 $I = \frac{v_R}{R}$	
	$v_{R_{min}}$ (V)	$v_{R_{max}}$ (V)	I_{min} (mA)	I_{max} (mA)	$v_{R_{min}}$ (V)	$v_{R_{max}}$ (V)	I_{min} (mA)	I_{max} (mA)
Experi-mental	0	3.68	0	3.68	-3.64	0	-3.64	0
Theo-retical	0	4	0	4	-4	0	-4	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 = 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	-1.44	3.12	4.98	0.996	0.996	0.937	0.069%
Theo-retical			14.28-9.30 = 4.98	1.04	1.04	1.04	

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) and the current (I) 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–

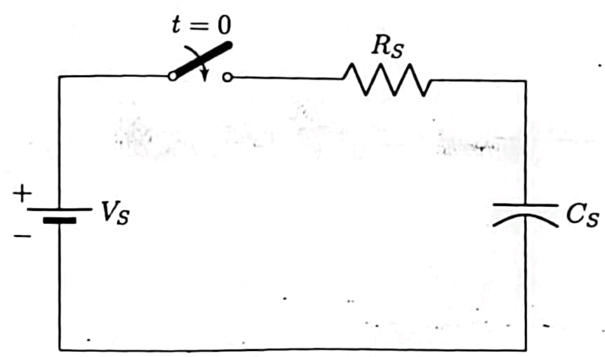
   ☐ decreasing the applied voltage across the capacitor.

   ☑ increasing the charge accumulation on the plates of 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/heat** 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 in the form of electro-chemical 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 it is important to ensure that there is no residual charge in the capacitor. If there is a residual charge on the capacitor, it could affect the accuracy of the capacitor.

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 of 2 V, would the time now to increase the voltage to 5 V be the same?

☐ Yes ☑ No

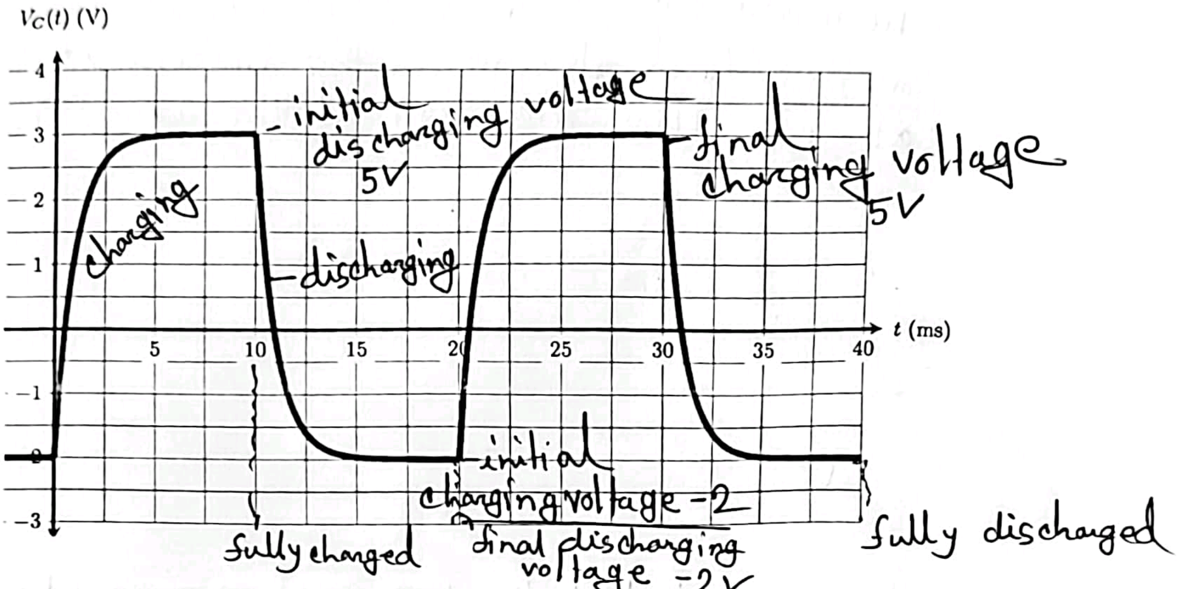
Why?

The reason is that the time constant $\tau = RC$ determines the rate at which the capacitor charges or discharges and this rate depends on the initial and final voltages across the capacitor. When the initial is 0V, the capacitor charges faster to reach the 5V within 5ms (given). But when it is 2V, for smaller difference, it will take longer.

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 it defines a capacitor's rate of discharging and charging. Longer constants cause process to move slowly, while smaller constants cause charges to move quickly. It analyses and controls the capacitors and controls exponential voltage across them.

7. The capacitor voltage waveform you observed in the laboratory for **Circuit 3** is shown below where the excitation to the capacitance alternates between $-2\ V$ to $5\ V$ at a frequency of $100\ Hz$. The capacitor gets charged and discharged periodically.



(a) Mark the following things in the diagram:

(i) Charging and discharging phases (or timestamps)

(ii) The time constant (τ) for both charging and discharging phases

(iii) Initial and final voltages for both charging and discharging phases

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

(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 the volume of the capacitor or resistor in the circuit. This is because the time constant(τ) of an RC circuit which determinus the charging and discharging rates of the capacitor.

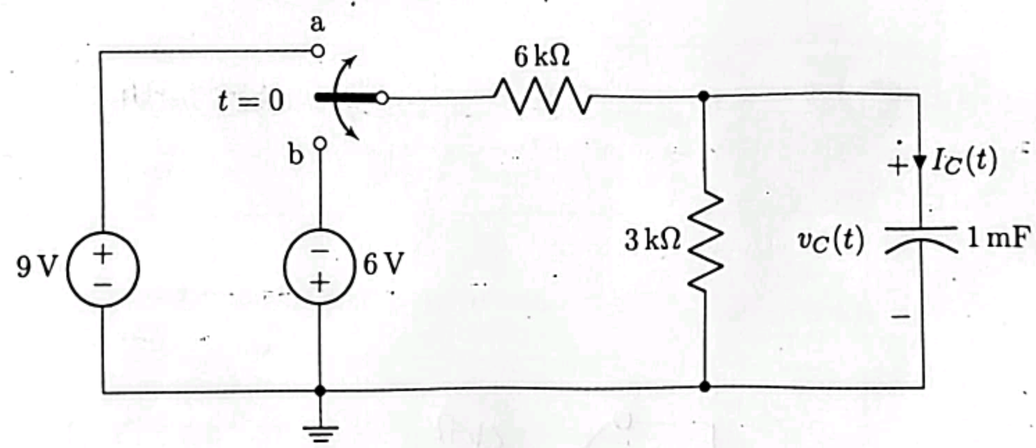
(c) Can you think of a way to change the duty cycle of the voltage waveform? How? *(Hint: think in terms of time constant)*

The duty cycle ☑ can ☐ cannot be changed. Because the values of the voltage and circuit will chage, so it will varying the resistor or capacitor.

(d) Will increasing the frequency of switching have any effect on the charging or discharging times of the capacitor?

Increasing the frequency of switching will have ☐ no ☑ an effect on the charging and discharging time of the capacitor. Because in RC circuit the charging and discharging ~~th~~ time of the capacitor is determined by the time constant (τ), which is the product of resistance and capacitance, $\tau = R_{eq} C_{eq}$. Increasing the frequency of switching, effectively decreases the time available for the capacitor to charge or discharge in each cycle. This will result in smaller voltage swing on the capacitor.

8. Consider the RC circuit shown below. At $t = 0$, the switch starts to alternate between positions a and b at a frequency of **500 Hz**.



(a) Which one of the following instruments do you need in the laboratory to set up the **switching mechanism** 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.

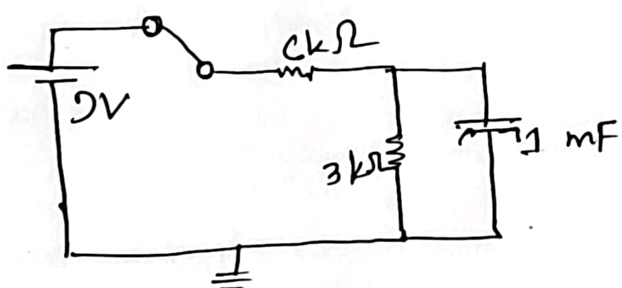
☐ A DC Power Supply with two channels.

(b) Based on your selection in (a) and the values of the voltages in the circuit diagram, list down the parametric (amplitude of voltage, frequency, offset, scale, etc.) values that you will set on the selected instrument.

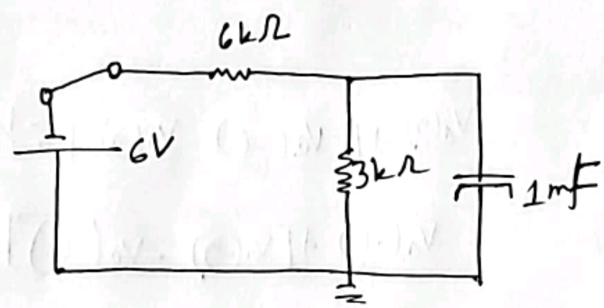
As I will use *(instrument name:)* Function genarator to model the switching mechanism as described in the question statement, I will need to set only the *(list:)* amplitude, frequency, offset, waveform type on the instrument as follows *(leave those blank which are not required to set)*:

1. Amplitude of the voltage: 5 V
2. Frequency: 100 Hz
3. DC Offset: 5 V
4. Others *(specify with values if any)*:

(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 9 (V) and −6 (V).

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

R_{eq} = 9 (kΩ)

(g) The time constant τ is thus–

$\tau = R_{eq}C =$ 9X1 = 9 (ms)

(h) If the time constant (τ) is 9 (ms), it will take 9 (ms) for the capacitor to be fully charged or discharged.

(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

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

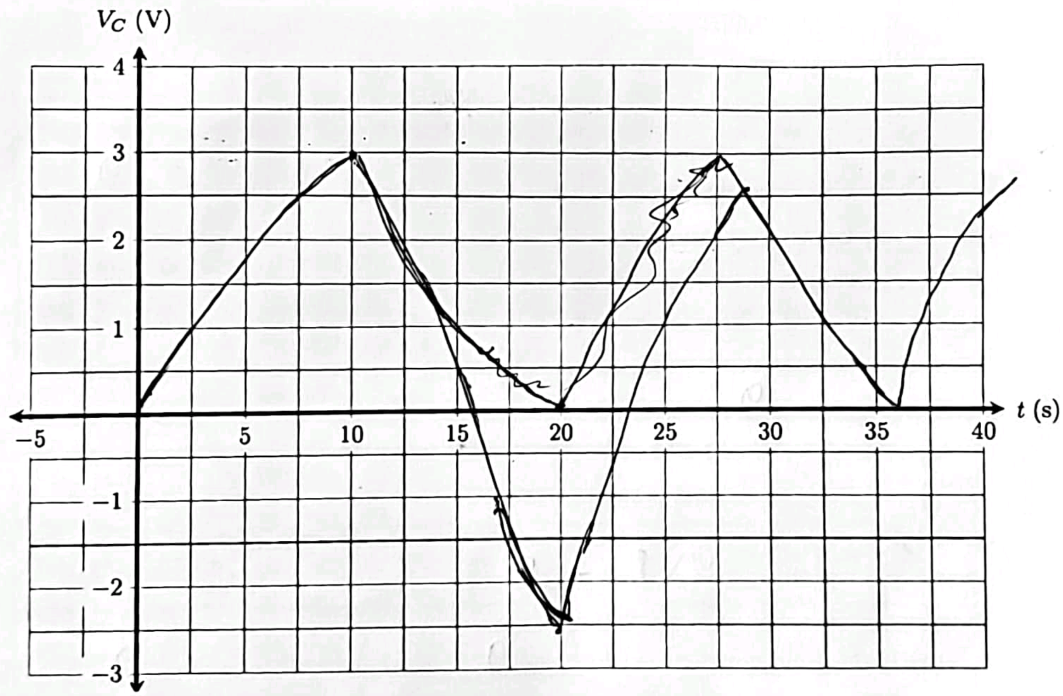
So, when $v_C(final) > v_C(initial)$, the capacitor gets charged and when $v_C(final) < v_C(initial)$, the capacitor gets discharged.

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

Charging: $v_C(t)$ = $V_c(9) + [V_c(-6) - V_c(9)]\, e^{-t/\tau}$

Discharging: $v_C(t)$ = $V_c(-6) + [V_c(9) - V_c(-6)]\, e^{t/\tau}$

(j) Given the frequency of switching 500 Hz, 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 charged and discharged continuously.



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.**