Student ID:		**Lab Section:**	
Name:		**Lab Group:**	

Experiment No. 7

Study of the Transient Behavior in RC Circuits

Objective

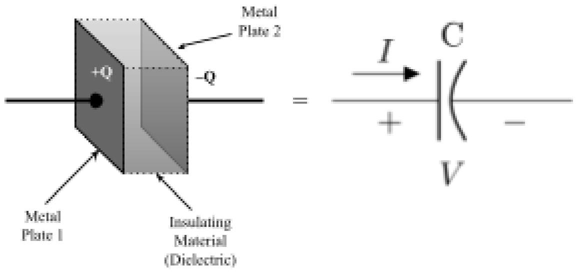
This experiment aims to investigate the transient response of first-order circuits. In this experiment, students will find the time constant τ of an RC circuit.

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.

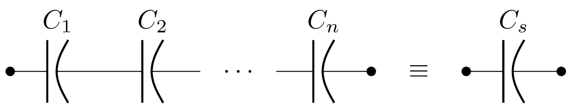


The amount of charge accumulated in each plate is directly proportional to the voltage difference applied across the two plates of a capacitor. If the voltage across the capacitor is v_C and the accumulated charge is Q, then we can write,

$$Q \propto V$$
$$\Rightarrow Q = CV$$
$$\Rightarrow \frac{d}{dt}(Q) = \frac{d}{dt}(CV) = C\frac{d}{dt}(V)$$
$$\boxed{\Rightarrow I = C\frac{dV}{dt}}$$

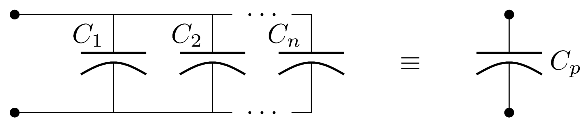
Here, I is the current through the capacitor and C is the **capacitance** [*S.I. unit is **Farad (F)***]. This boxed equation dictates the behavior of a capacitor. As we can see, there is a current through the capacitor if and only if the voltage across the capacitor changes over time.

From this equation, we can find the equivalent series and parallel capacitance.



$$\frac{1}{C_s} = \sum \frac{1}{C_n} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}$$

Series combination



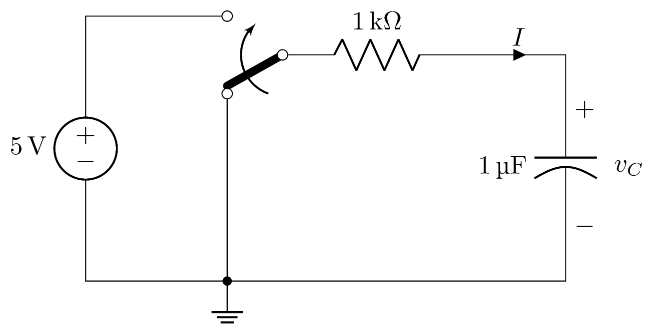
$$C_p = \sum C_n = C_1 + C_2 + \cdots + C_n$$

Parallel combination

RC circuit

An RC circuit is an electric circuit composed of resistors and capacitors as the only passive components (may contain other active components). Such circuits exhibit transient behaviors if the input voltage is suddenly changed.

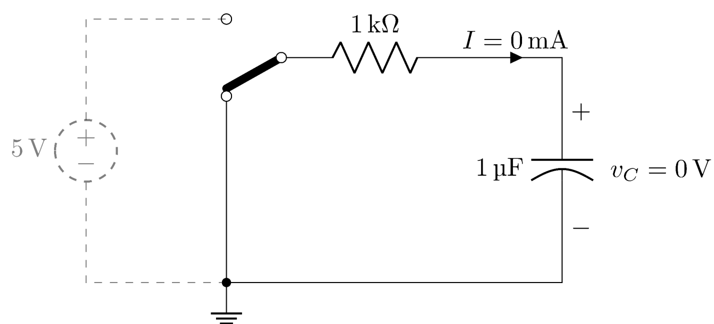
Consider this RC circuit with a switch (arrow indicates the direction of switching):



We can break this circuit into two separate circuits:

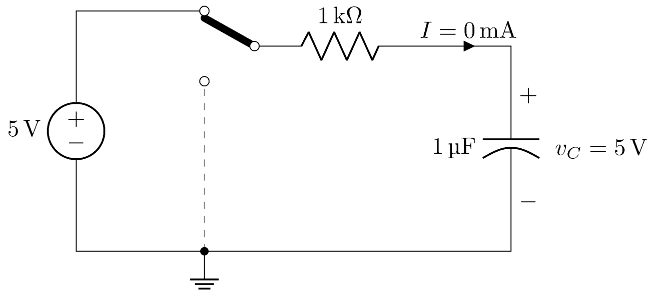
- ➢ Initial circuit
- ➢ Final circuit

The initial position of the switch indicates that the voltage source was open and the resistor was grounded. Since there is no source in the circuit, the elements will have no current. Furthermore, **at steady-state conditions, a capacitor acts like an open circuit.** As a result, the voltage across the capacitor v_C will be 0V.



Initial Circuit

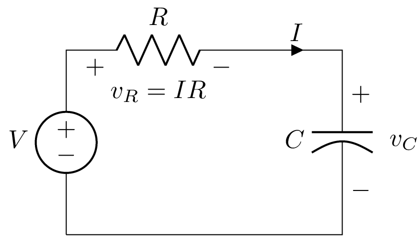
On the other hand, the final position of the switch indicates that the voltage source will now supply voltage. However, **after reaching a steady-state condition, the capacitor will again act like an open circuit.** As a result, the voltage across the capacitor v_C will be 5V.



Final Circuit (after reaching steady-state)

Transient Behavior

In the previous circuit, the voltage across the capacitor v_C rises from 0V to 5V. Unlike resistors, it takes a significant amount of time for the voltage across a capacitor to change. This behavior is called transient behavior. We can figure out how the voltage will change over time using KVL and KCL.



Applying KVL on the circuit we get,

$$v_R + v_C - V = 0.$$

$$\Rightarrow IR + v_C - V = 0$$

$$\Rightarrow \left(C \frac{d}{dt} v_C\right) \cdot R + v_C - V = 0$$

$$\Rightarrow v_C + RC \frac{d}{dt} v_C - V = 0$$

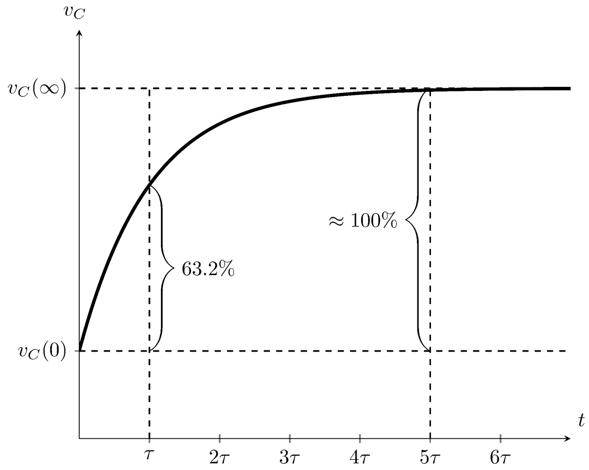
$$\Rightarrow v_C + \tau \frac{d}{dt} v_C - V = 0$$

Let, $\tau = RC$. This quantity is called the **<u>time constant</u>** and the S.I unit is **seconds (s)**. In this example, $\tau = 1k\Omega \times 1\mu F = 1ms$. Time constant has physical significance. It determines how fast the transient response dies out.

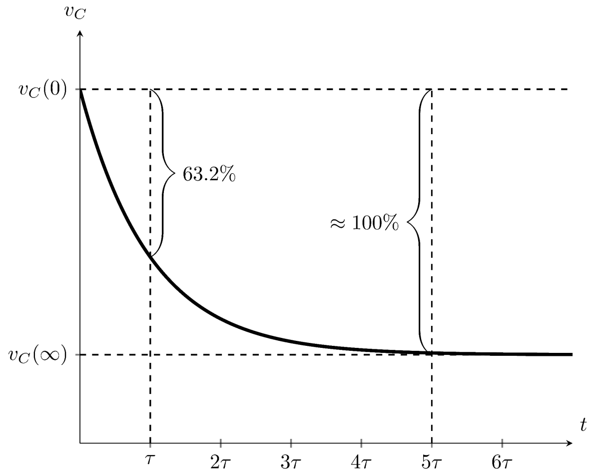
Solving the above differential equation, we get,

$$\boxed{v_c(t) = v_C(\infty) + \left[v_C(0) - v_C(\infty)\right] e^{-t/\tau}}$$

Here, $v_C(t)$ is the voltage across the capacitor at time t. Therefore, $v_C(0)$ **refers to the capacitor voltage of the initial circuit and** $v_C(\infty)$ **refers to the capacitor voltage of the final circuit after it has reached steady-state.** If $\left|v_C(0)\right| < \left|v_C(\infty)\right|$, then the capacitor is said to be lost energy. And the capacitor will gain energy if $\left|v_C(0)\right| > \left|v_C(\infty)\right|$.



Charging Phase



Discharging Phase

Time Constant

For a given circuit with a resistance of R and a capacitance of C, the time constant is $\tau = RC$. However, it is also possible to find the time constant from the plot of transient response. Higher the value of time constant, the longer it takes for the voltage to reach steady-state. At time $t = \tau$,

$$v_C(\tau) = v_C(\infty) + \left[v_C(0) - v_C(\infty)\right]e^{-\tau/\tau} = v_C(\infty) + \left[v_C(0) - v_C(\infty)\right]e^{-1}$$

$$\therefore \frac{v_C(\tau) - v_C(0)}{v_C(\infty) - v_C(0)} = 1 - e^{-1} \approx 0.632 = 63.2\%$$

For example, if $\tau = 1ms$, then $1ms$ after switching, the voltage has already reached 63.2% of its way to the final steady-state voltage.

A similar analysis shows that, after $t = 5\tau$, the voltage almost reaches the final steady-state voltage. So we can conclude **it takes approximately** 5τ **time for a transient circuit to reach steady-state.**

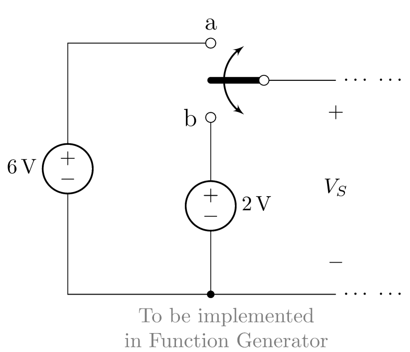
Apparatus

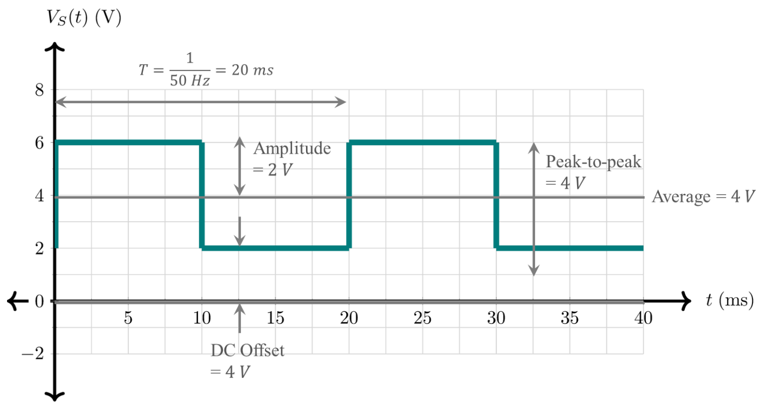
- ➢ Multimeter
- ➢ Resistors
- ➢ Capacitors
- ➢ Breadboard
- ➢ Jumper wires
- ➢ DC power supply
- ➢ Function Generator
- ➢ Oscilloscope

Procedures

- ➢ Measure the resistances and capacitances of the provided resistors and capacitors, and fill in *Data Table 0*.

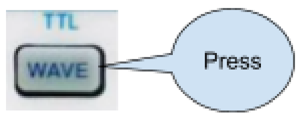
- ➢ **<u>Setting up a voltage on the Function Generator</u>**
  - ➔ Before constructing any circuit, we'll implement the following switching mechanism by setting appropriate voltages in a Function Generator.
  - ➔ The switch moves between terminals a and b continuously following a frequency (for example 50 Hz). The voltage V_S looks like the following:



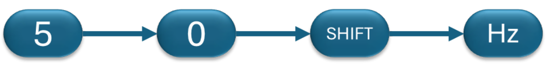


  - ➔ Turn on the Function Generator by pushing the **POWER** button.
  - ➔ Make sure the **`DUTY`** and **`OFFSET`** adjustment knobs are **<u>pushed in</u> (default mode).**

  - ➔ Press the **WAVE** button once to set the voltage waveform to a <u>square</u> wave.

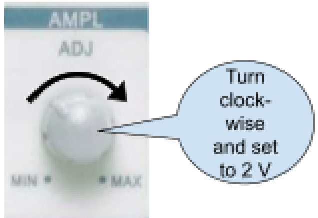


  - ➔ Set the frequency to 50 Hz by pressing sequentially the following buttons.



➔ Press the following buttons to display voltage.

➔ Turn the **AMPL** (amplitude) adjustment knob and set the voltage to $2\,V$. Note that a square wave-like voltage oscillating between $2\,V$ and $6\,V$ has a peak-to-peak value of $4\,V$ and an amplitude of $2\,V$. <u>We always set the amplitude on the function generator.</u>

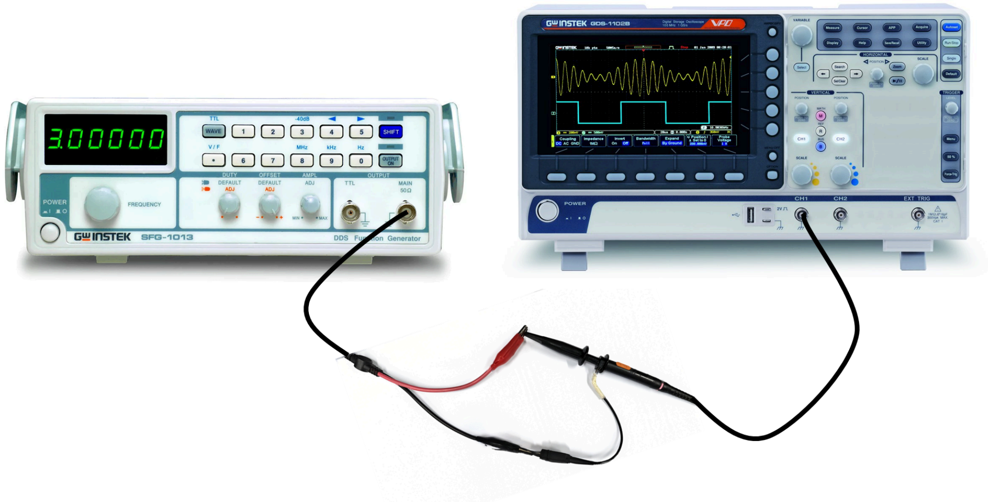


➔ Turn **<u>on</u>** the **output**.

➢ **<u>Setting up the oscilloscope to observe the voltage set on the Function Generator</u>**

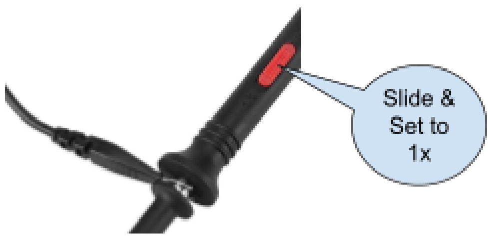
➔ Turn on the Function Generator by pushing the **POWER** button.

➔ Connect the probes from the function generator with any of the channels (let's say CH1) in the Oscilloscope as shown below.

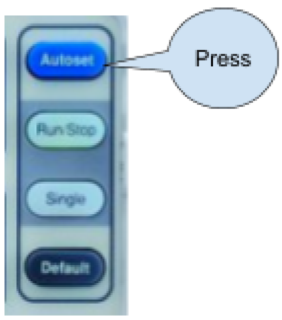


➔ If the CH2 button is glowing as shown below, press it <u>twice</u> to turn it off.

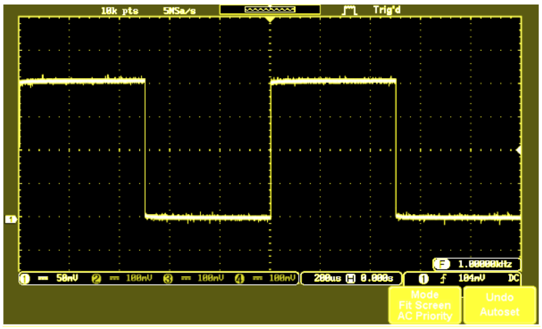
➔ Set the oscilloscope probe scaling to **<u>1x</u>** (not 10x).



➔ Press the **Autoset** button.

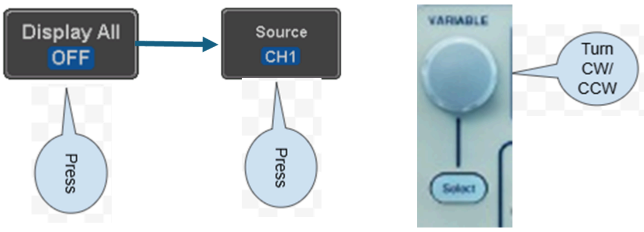


➔ You should see a yellow square wave voltage graph as shown below.



➔ Press the **Measure** button to check the peak-to-peak, maximum voltage, minimum voltage, frequency, etc.

➔ If the floating display shows "**OFF**" for the parameters of the voltage, press the following buttons.

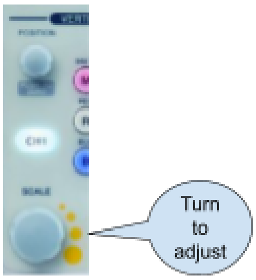


➔ You should see a window as shown below. The values for the parameters should be different than those shown in the figure.

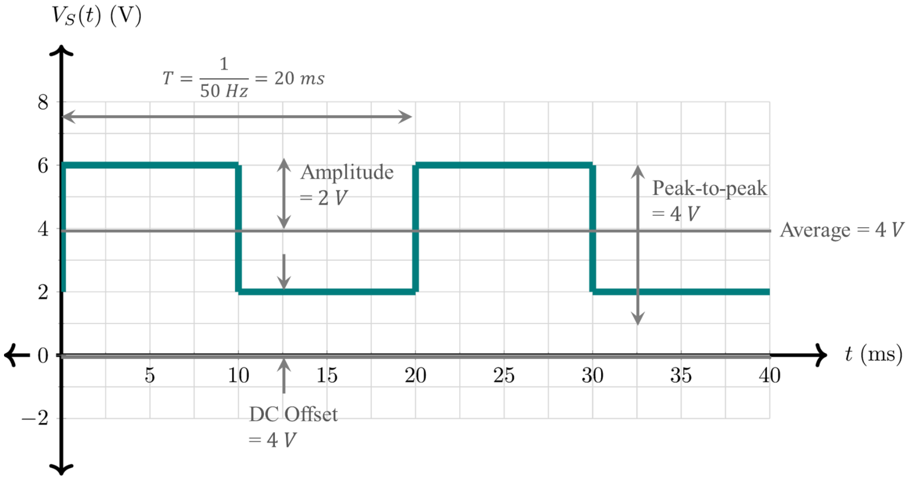
➔ Keeping the window open on the oscilloscope, pull out the **OFFSET (Default ADJ)** knob in the function generator
.

➔ Turn the **OFFSET** knob clockwise and observe the **Min** and **Max** voltage on the oscilloscope. The minimum value should be 2 V, and the maximum should be 6 V.

➔ If you see '?' mark as the yellow square waveform goes beyond the display window, scale down the voltage to keep it within the screen. To do this, turn the **Scale** knob for *Channel 1* counterclockwise.



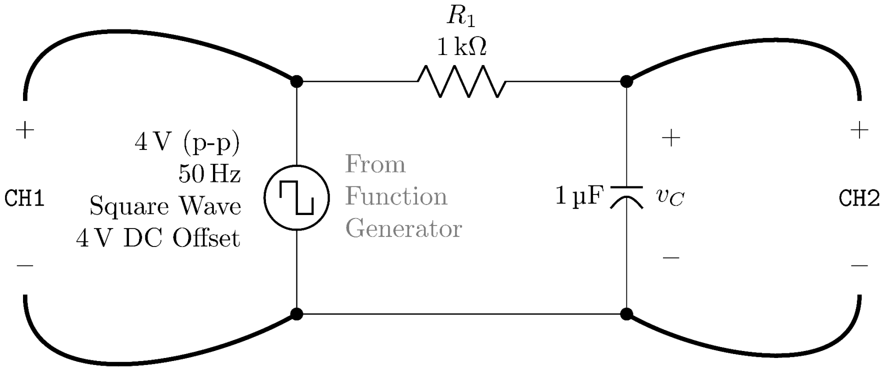
➔ You should have a square dc voltage wave having $4\,V$ amplitude at $50\,Hz$ frequency, with $4\,V$ offset (max $= 6\,V$ and min $= 2\,V$) as shown below.



➔ Note the necessary data from the **Measure** window in the oscilloscope and fill in *Data Table 1*.

➔ Disconnect the probes of the oscilloscope and the function generator, then proceed to build the circuits and apply the input voltage.

➢ Construct the following circuit on a breadboard. Try to use minimum number of jumper wires.

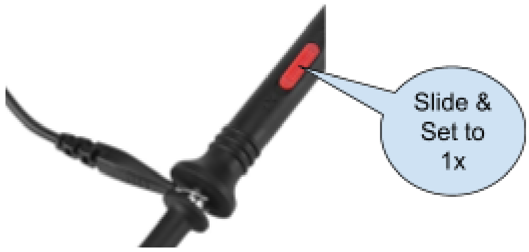


Circuit 1

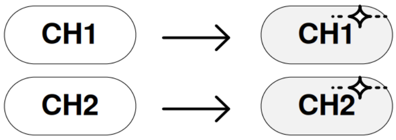
➢ Apply the voltage set on the function generator by connecting the probes from the function generator to the circuit as shown above

➢ Connect the two oscilloscope channels as shown in the schematic.

➢ Set the oscilloscope probe scaling to **<u>1x</u>** (not 10x).



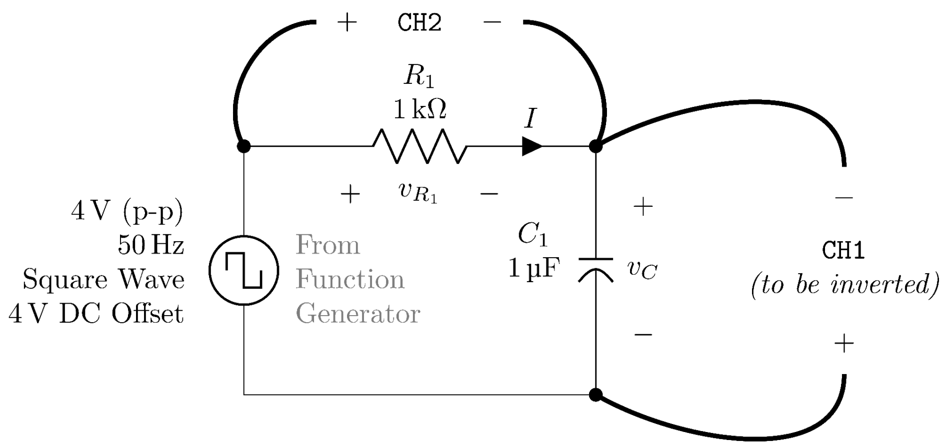
➢ Make sure both channels are turned on. These buttons should be glowing:



➢ Set position to origin by **<u>pushing</u>** the **<u>position</u> knobs** on each channel.

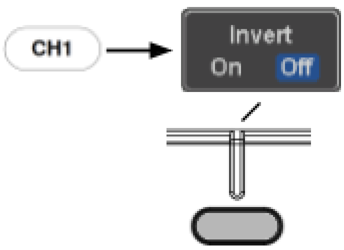
➢ Take a picture of the graphs. Identify the charging and discharging phases from the graph… and fill in *Data Table 2*.

➢ Reconnect the probes of the oscilloscope in **Circuit 1** so that it looks like **Circuit 2**.



Circuit 2

➢ Invert **<u>`CH1`</u>** by pressing the bottom menu buttons and set it to **<u>`On`</u>**.

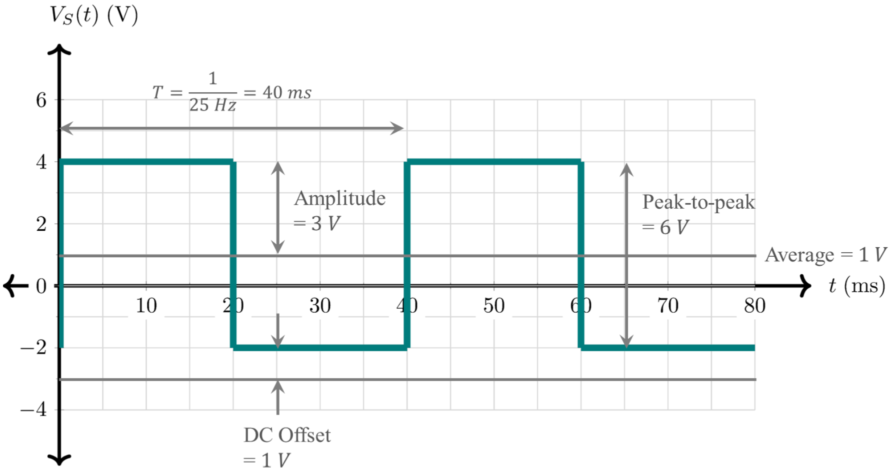


➢ Set position to origin by **pushing** the **position** **knobs** on each channel.

➢ Take a picture of the graphs and fill in *Data Table 3*.

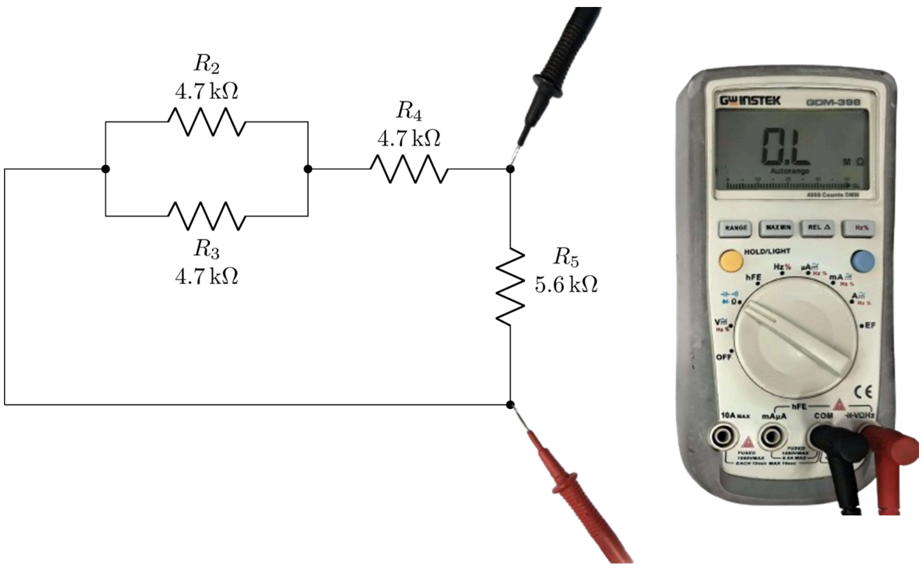
➢ Disassemble the circuit and connect the probes of the function generator to *Channel 1* of the oscilloscope again.

➢ Observe the voltage generated by the function generator on the oscilloscope while adjusting the **AMPL** and **OFFSET** knobs to set a voltage as plotted below.



➢ Note the necessary data from the **Measure** window in the oscilloscope and fill in *Data Table 4*.

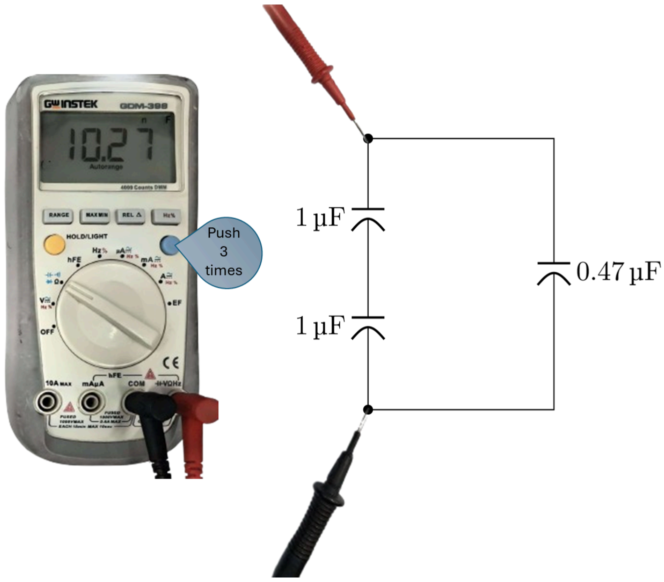
➢ Construct the following resistive network as shown below.



Circuit 3

➢ Connect and hold the probes of the multimeter with the network as shown in **Circuit 3**… and note down the resistance value on *Data Table 5*. This is the experimentally measured equivalent resistance (R_{eq}) of the circuit to be constructed next.

➢ Disconnect the probes of the multimeter and construct the following capacitor network separately.



Circuit 4

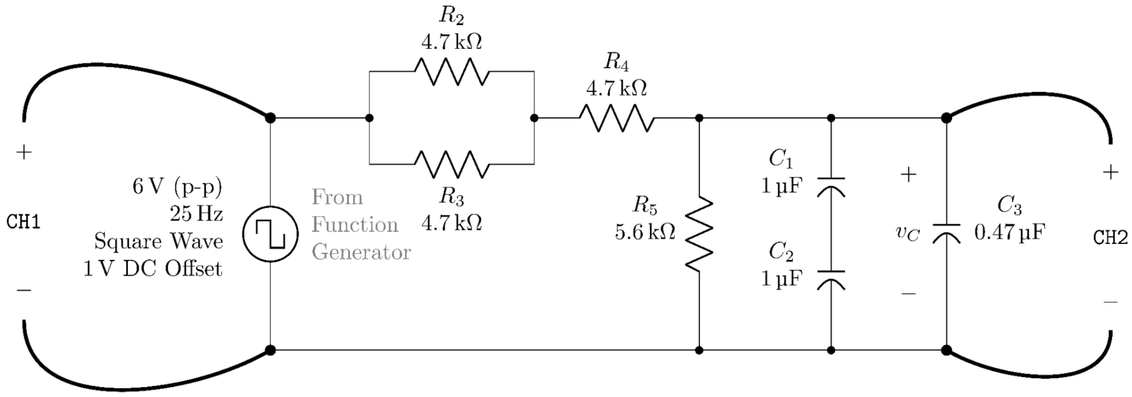
➢ Tune the multimeter in *Capacitance Measuring Mode*. To do this, turn the *Rotary Switch* and align it with *Ω*.

➢ Press the ***Blue Button*** 3 times. The multimeter will enter capacitance measuring mode with the unit nF shown by default on the display.

➢ Connect and hold the probes of the multimeter with the capacitor network's terminals as shown in **Circuit 4**… and note down the capacitance value on *Data Table 5*. This is the experimentally measured equivalent capacitance (C_{eq}).

➢ Compare this measured C_{eq} with the one calculated from the value of the time constant as $C_{eq} = \frac{\tau}{R_{eq}}$ in *Data Table 6*. Find the percentage of error.

➢ Combine the resistive network in **Circuit 3**, the capacitor bank in **Circuit 4**, and the voltage set on the function generator as shown in **Circuit 5**.



Circuit 5

➢ Connect the oscilloscope channels as shown in the schematic. Make sure the x-axes of both graphs are at the same position *(push both position knobs)*.

➢ Take a picture of the graphs. Identify the charging and discharging phases from the graph… and fill in *Data Table 6*.

Data Tables

Signature of Lab Faculty: **Date:**

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

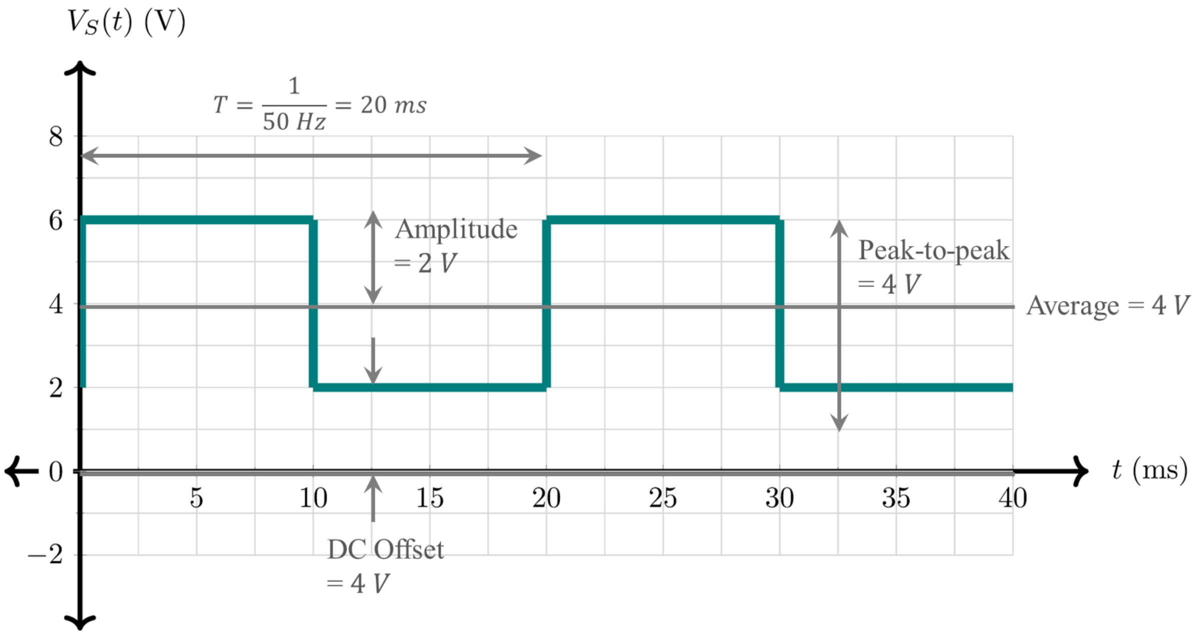
Table 0: Resistance and Capacitance Data

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 Values
R_1	1 kΩ		R_5	5.6 kΩ	kΩ
R_2	4.7 kΩ		C_1	1 µF	µF
R_3	4.7 kΩ		C_2	1 µF	µF
R_4	4.7 kΩ		C_3	0.47 µF	µF

Table 1: Switching Voltage for Circuits 1 and 2

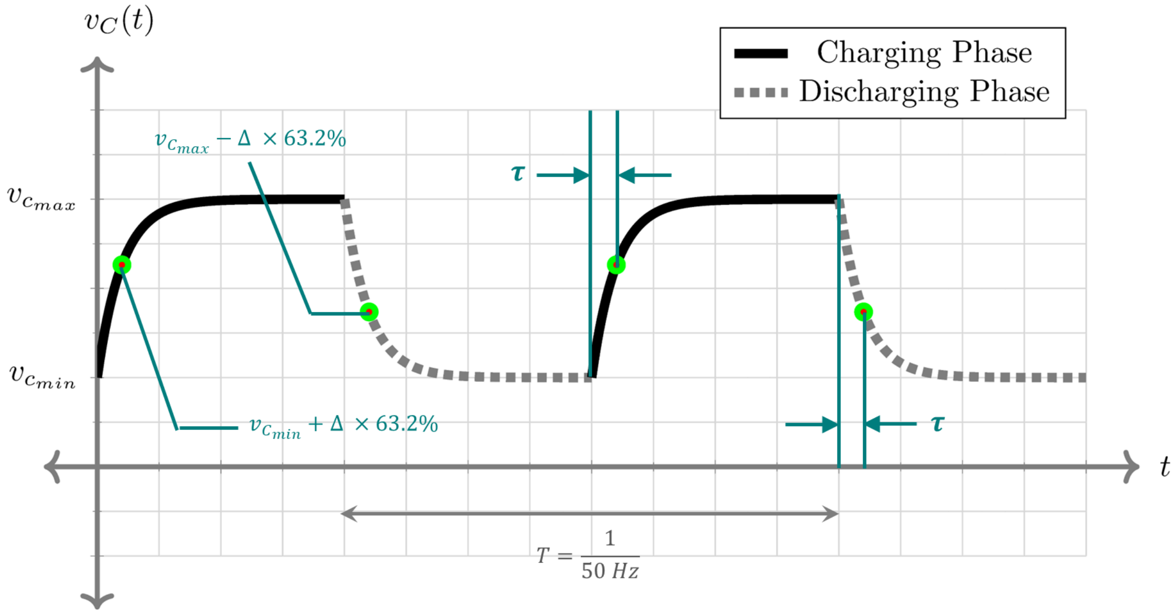
After connecting the source voltage set at the function generator to the oscilloscope, take data from the oscilloscope and fill out the following table.



Function Generator connected to the Oscilloscope	Max Value max (V)	Min Value min (V)	Frequency f (Hz)	Time Period $T = \frac{1}{f}$ (ms)	Peak to peak voltage $p - p$ (V)	Amplitude $\frac{p-p}{2}$ (V)	Average Voltage $\frac{max+min}{2}$ (V)	DC Offset /Shifted by $min + \frac{p-p}{2}$ (V)
Experimental	From Osc. *Measure*	From Osc. *Measure*	From Osc. *Measure*	Calc.	From Osc. *Measure*	Calc.	Calc.	Calc.
Theoretical	$6\ V$	$2\ V$	$50\ Hz$	$20\ ms$	$4\ V$	$2\ V$	$4\ V$	$4\ V$

Table 2: Data from Circuit 1

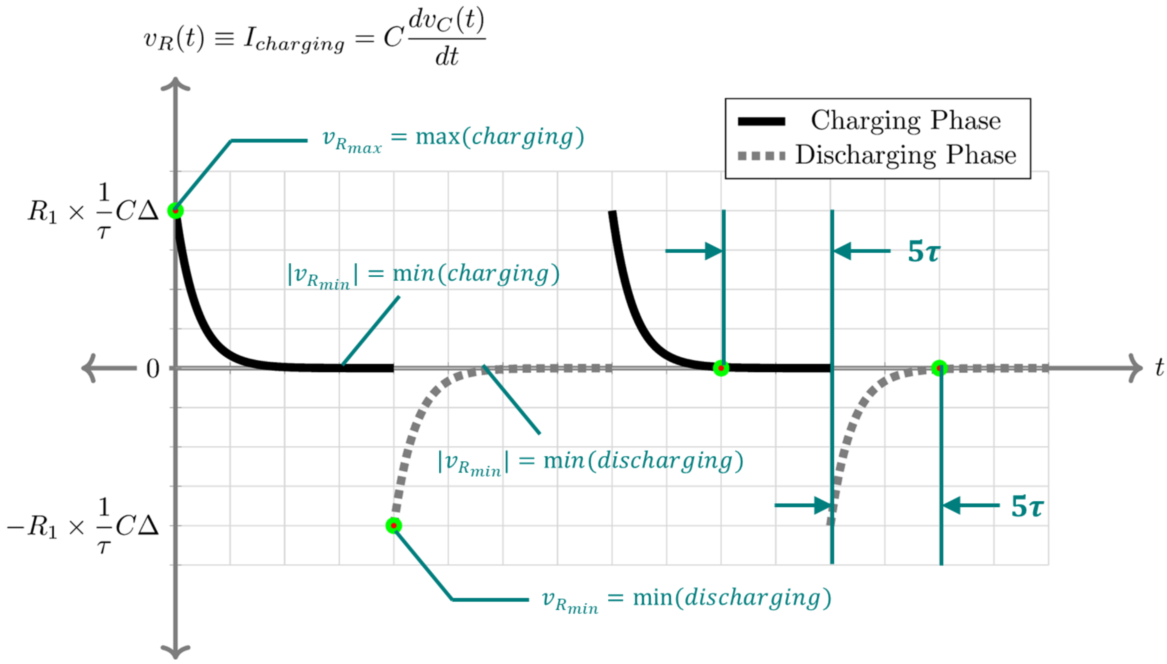
The input square wave voltage set on the function generator should be observed on *Channel 1*, while the capacitor voltage $v_C(t)$ $vs.$ t plot should be observed on *Channel 2* of the oscilloscope, similar to the one below. For the latter one, take data from the oscilloscope and fill in the following table.



Circuit 1	Capacitor Voltage, $v_C(t)$					Time t when $v_C(t) = v_C(\boldsymbol{\tau})$ Charging /Discharging $\boldsymbol{\tau}$ (ms)	Charging /Discharging Time $5\boldsymbol{\tau}$ (ms)
	Maximum Value $v_{C_{max}}$ (V)	Minimum Value $v_{C_{min}}$ (V)	Difference between max and min $\Delta = v_{C_{max}} - v_{C_{min}}$ (V)	Charging Phase $v_C(at\ t = \boldsymbol{\tau})$ $v_{C_{min}} + \Delta \times 63.2\%$ (V)	Discharging Phase $v_C(at\ t = \boldsymbol{\tau})$, $v_{C_{max}} - \Delta \times 63.2\%$ (V)		
Experi-mental	From Osc. *Measure*	From Osc. *Measure*	Calc.	Calc.	Calc.	From Osc. *Using Cursor*	Calc.
Theo-retical							

Table 3: Data from Circuit 2

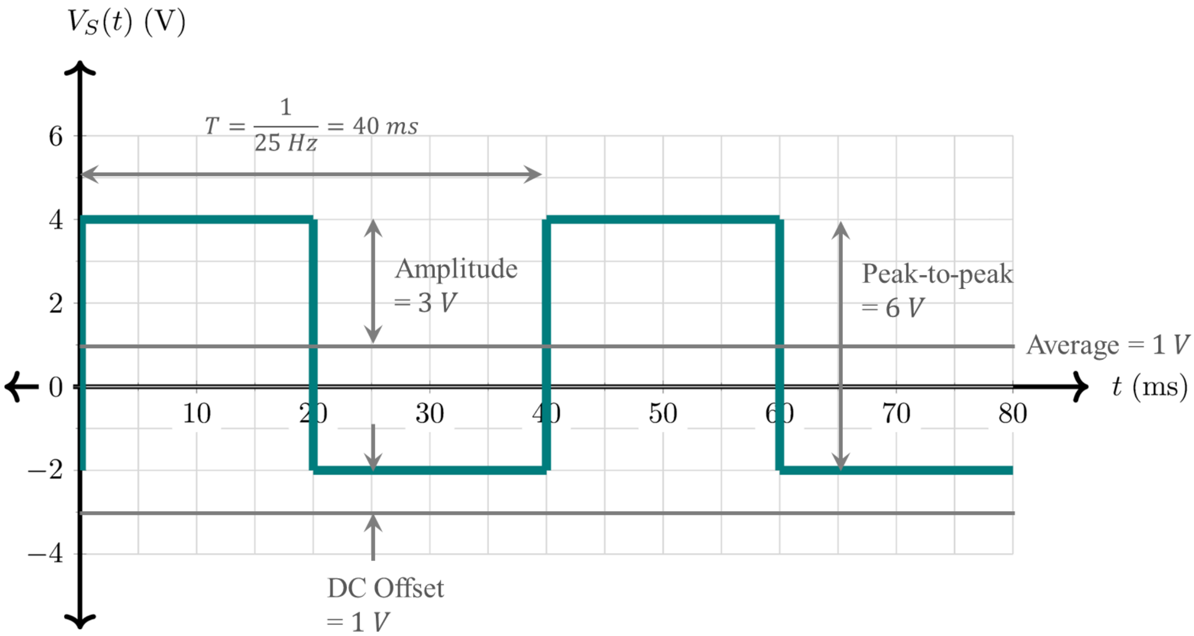
A resistor voltage $v_R(t)$ $vs.$ t plot should be observed on *Channel 2* of the oscilloscope, similar to the one below. On *Channel 1,* the previous capacitor voltage $v_C(t)$ $vs.$ t plot should be visible. Take data from *Channel 2* of the oscilloscope and fill in the following table.



Circuit 2	Charging Phase				Discharging Phase			
	Resistor Voltage, v_R		Circuit Current $I = \frac{v_R}{R}$		Resistor Voltage		Circuit Current $I = \frac{v_R}{R}$	
	$v_{R_{max}}$ (V)	$\lvert v_R \rvert_{min}$ (V)	I_{max} (mA)	I_{min} (mA)	$v_{R_{min}}$ (V)	$\lvert v_R \rvert_{min}$ (V)	I_{max} (mA)	I_{min} (mA)
Experi-mental	From Osc. *Measure*	From Osc. *Cursor*	Calc.	Calc.	From Osc. *Measure*	From Osc. *Using Cursor*	Calc.	Calc.
Theo-retical								

Table 4: Switching Voltage for Circuit 5

After connecting the source voltage set at the function generator to the oscilloscope, take data from the oscilloscope and fill out the following table.



Function generator connected to Oscilloscope	Max Value max (V)	Min Value min (V)	Frequency f (Hz)	Time Period $T = \frac{1}{f}$ (ms)	Peak to peak $p - p$ (V)	Amplitude $\frac{p-p}{2}$ (V)	Average Voltage $\frac{max+min}{2}$ (V)	DC Offset /Shifted by $min + \frac{p-p}{2}$ (V)
Experimental	From Osc. *Measure*	From Osc. *Measure*	From Osc. *Measure*	Calc.	From Osc. *Measure*	Calc.	Calc.	Calc.
Theoretical	$4\ V$	$-2\ V$	$25\ Hz$	$40\ ms$	$6\ V$	$3\ V$	$1\ V$	$1\ V$

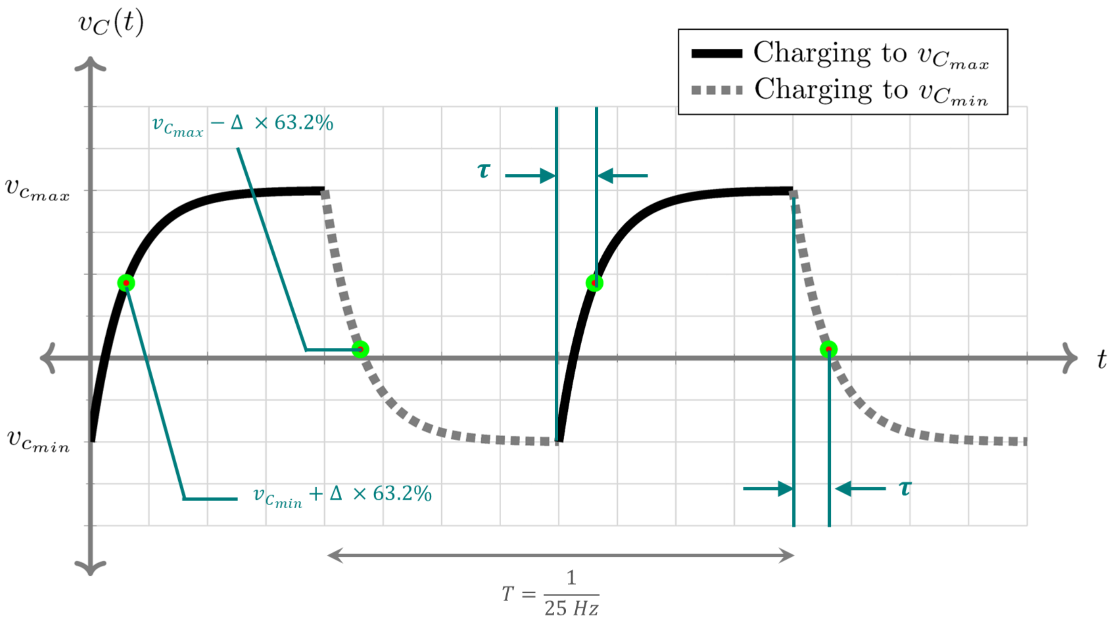
Table 5: Data from Circuit 3 and Circuit 4

Measure the equivalent resistance seen from the capacitors' terminals in **Circuit 3** using a multimeter. Similarly, measure the equivalent capacitance of the capacitor bank in **Circuit 4**. Record the obtained values in the table below.

Circuit 3 & 4	Equivalent Resistance (From **Circuit 3**) R_{eq} ($k\Omega$)	Time constant, τ (From **Table 6**) (ms)	Equivalent Capacitance		
			$C_{eq,\,osc.} = \frac{\tau}{R_{eq}}$ (Calc.) (μF)	From **Circuit 4** $C_{eq,\,mult.}$ (μF)	Error $\frac{\left\|C_{eq,\,osc.} - C_{eq,\,mult.}\right\|}{C_{eq,\,mult.}} \times 100\%$ (%)
Experi-mental					
Theo-retical					

Table 6: Data from Circuit 5

The input square wave voltage set on the function generator should be observed on *Channel 1*, while the capacitor voltage $v_C(t)$ $vs.$ t plot (similar to the one below) should be observed on *Channel 2* of the oscilloscope. For the latter one, take data from the oscilloscope and fill in the following table.



Circuit 5	Capacitor Voltage, $v_C(t)$					Time t when $v_C(t) = v_C(\boldsymbol{\tau})$ Charging to $v_{C_{max}}$ or $v_{C_{min}}$ $\boldsymbol{\tau}$ (ms)	Charging /Discharging Time $5\boldsymbol{\tau}$ (ms)
	Maximum Value $v_{C_{max}}$ (V)	Minimum Value $v_{C_{min}}$ (V)	Difference between max and min $\Delta = v_{C_{max}} - v_{C_{min}}$ (V)	Charging to $v_{C_{max}}$ $v_C(at\ t = \boldsymbol{\tau})$ $v_{C_{min}} + \Delta \times 63.2\%$ (V)	Charging to $v_{C_{min}}$ $v_C(at\ t = \boldsymbol{\tau})$, $v_{C_{max}} - \Delta \times 63.2\%$ (V)		
Experi-mental	From Osc. *Measure*	From Osc. *Measure*	Calc.	Calc.	Calc.	From Osc. *Using Cursor*	Calc.
Theo-retical							

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−

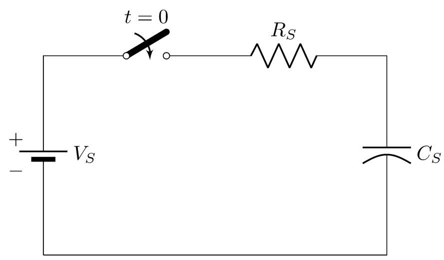
☐ decreasing the applied voltage across the capacitor.

☐ 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 ________________ energy to _________________ energy.

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

(c) The resistor dissipates energy into __________________ 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

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?

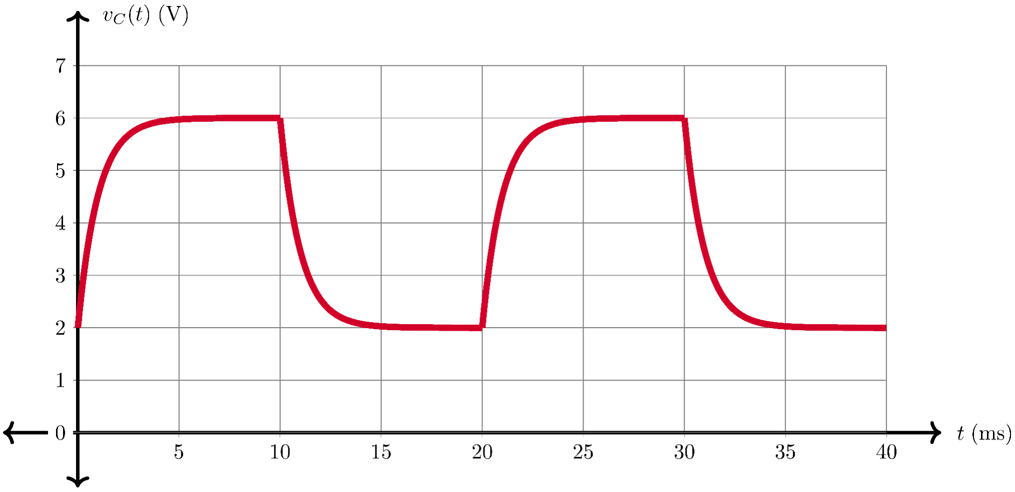
☐ Yes ☐ No

Why?

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

7. The capacitor voltage waveform you observed in the laboratory for **Circuit 1** is shown below, where the input bias to the capacitance alternates between 2 V to 6 V at a frequency of 50 Hz.



(a) Mark the times using circles when the capacitor is fully charged and discharged.

(b) Explain how you can change the time-period of the voltage waveform, keeping the percentage of charging or discharging time unchanged.

The time-period of the waveform can be changed by

(c) If the resistance in **Circuit 2** is changed, will the percentage of the charging or discharging phase change?

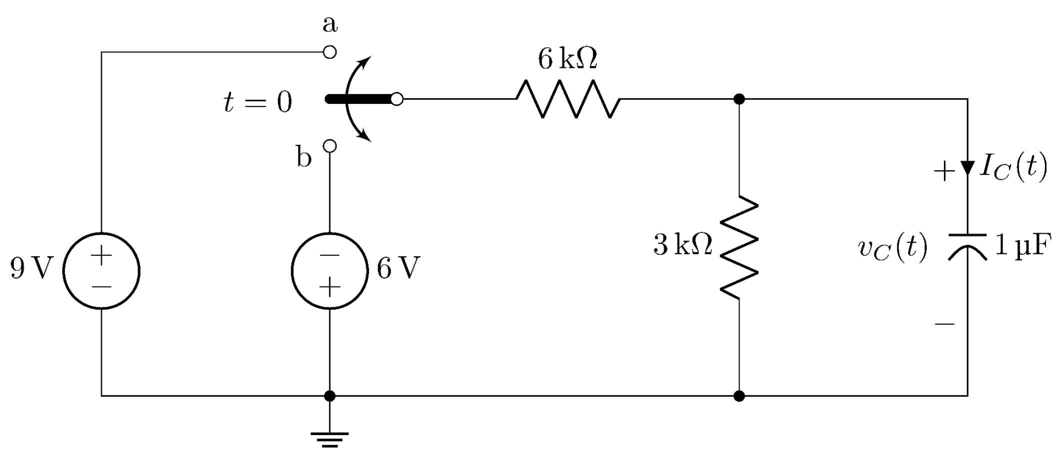
☐ Yes ☐ No

Why?

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 =	V	
• Peak to peak of the voltage =	V	
• Natural Frequency, f =	Hz	
• Angular Frequency, ω =	$rads^{-1}$	
• Initial Phase, ϕ =	^{o}	
• DC Offset =	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 **125 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 =	V	
• Peak to peak of the voltage =	V	
• Natural Frequency, f =	Hz	
• Angular Frequency, ω =	$rads^{-1}$	
• Initial Phase, ϕ =	^{o}	
• DC Offset =	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 __________(V) and _________(V).

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

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

(g) The time constant τ is thus−

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

(h) If the time constant (τ) is ___________(ms), it will take ______________(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

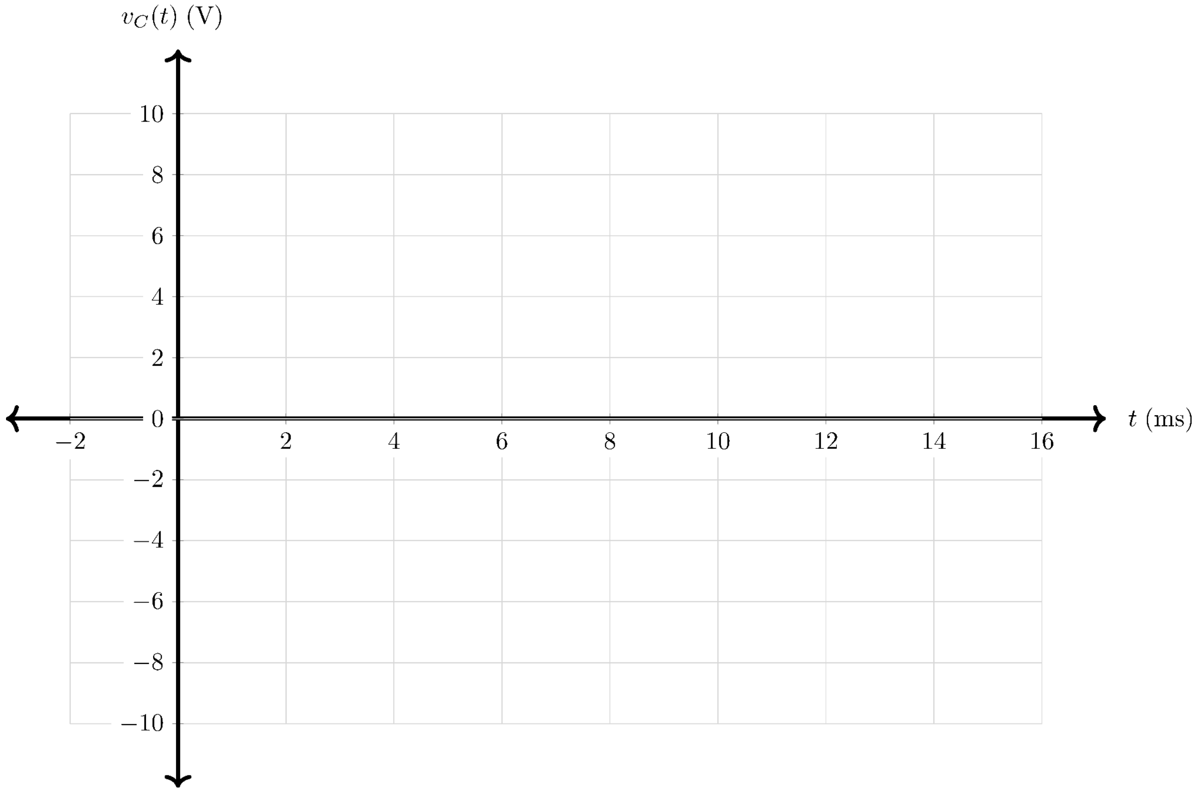
$$v_C(t) = v_C(\infty) + [v_C(0) - v_C(\infty)]e^{-\frac{t}{\tau}}$$

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: $v_C(t) =$

Decreasing phase: $v_C(t) =$

(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 $\frac{1}{125\ Hz} = 8\ ms$. 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 1**, **2,** and **3**. Fit all the images on a single page and print.