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

Experiment No. 8

Study of the Transient Behavior of RC Circuit Using Software (LTSpice) Simulation.

Objective

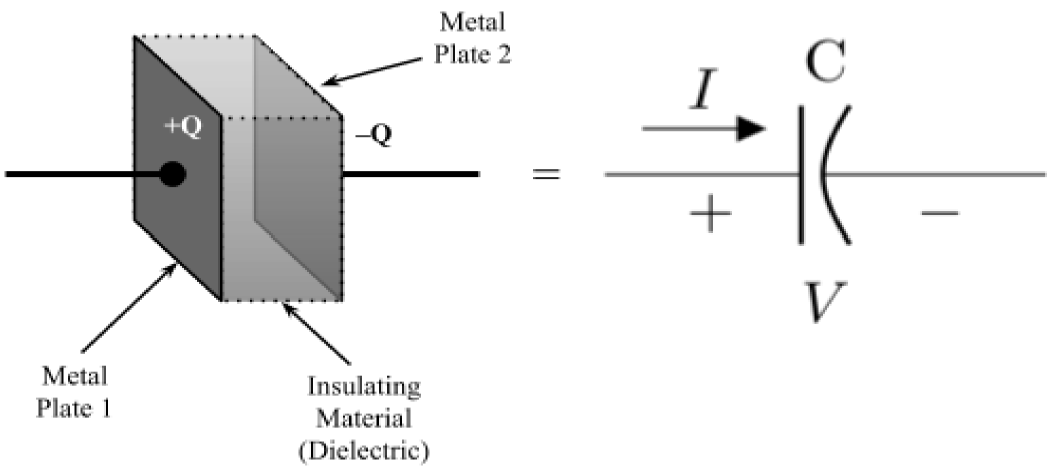
The objective of this experiment is to study the Transient Response of the first order RC circuit with step input. In this experiment, we shall apply a square wave input to an RC circuit separately and observe the respective wave shapes and determine the time constant, τ.

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.



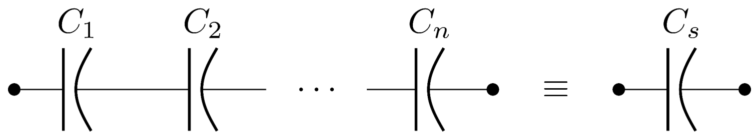
The amount of charge accumulated in each plate is directly proportional to the voltage difference applied across the two plates of a capacitor. If the voltage across the capacitor is v_C and the accumulated charge is Q, then we can write,

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

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.

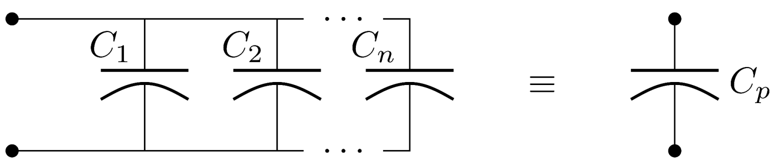
From this equation, we can find the equivalent series and parallel capacitance.

- Series combination:



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

- Parallel combination:

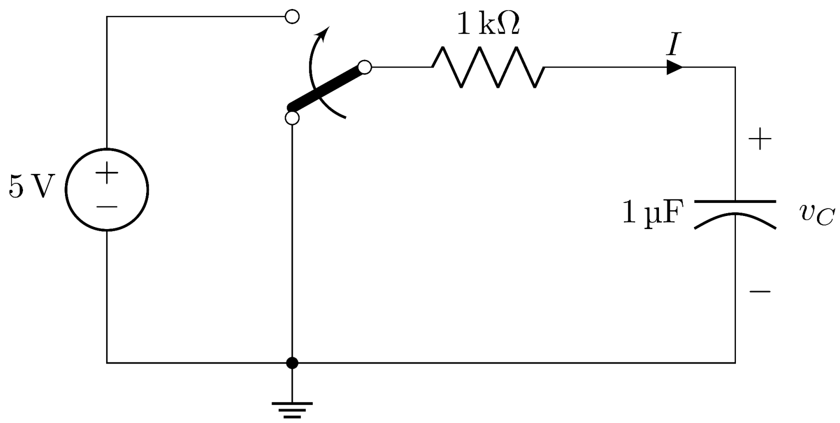


$$C_p = \sum C_n = C_1 + C_2 + \cdots + C_n$$

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.

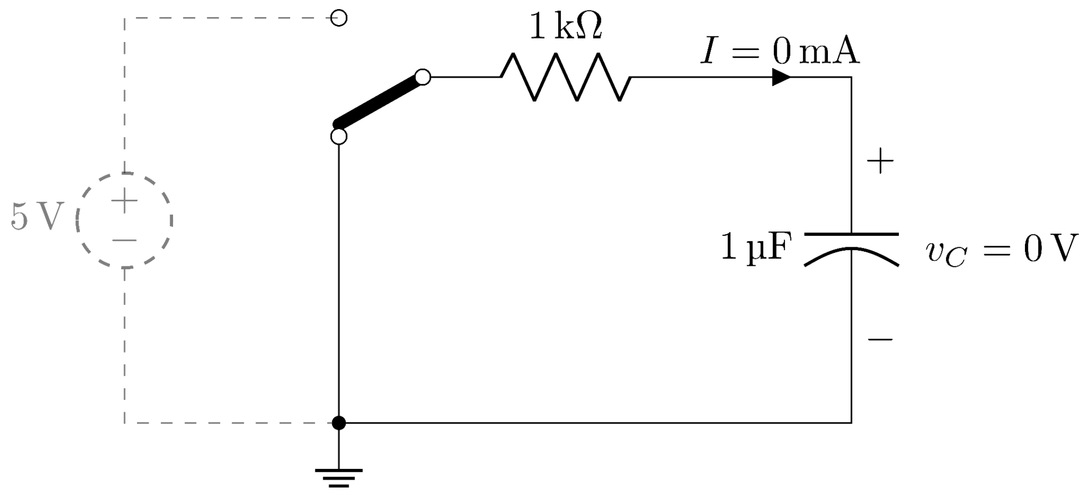
Consider this RC circuit with a switch (arrow indicates the direction of switching):



We can break this circuit into two separate circuits:

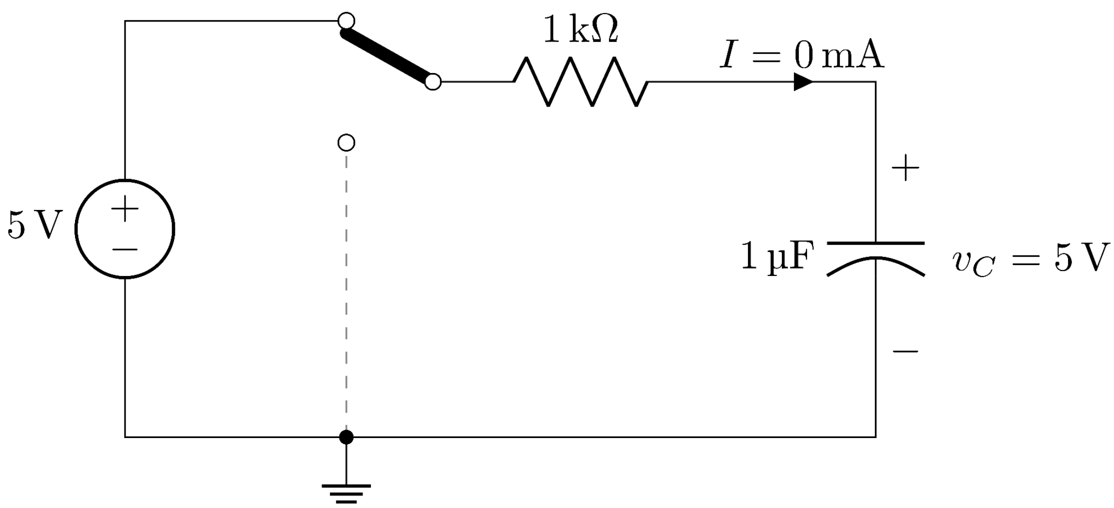
- ➢ Initial circuit
- ➢ Final circuit

The initial position of the switch indicates 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

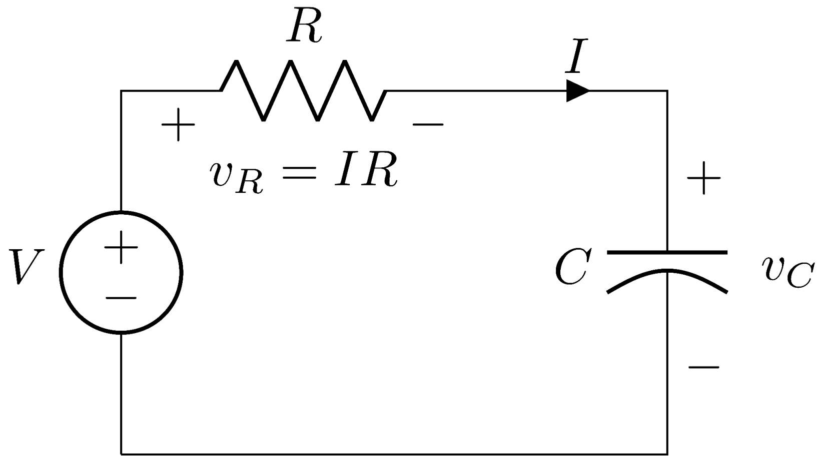
On the other hand, the final position of the switch indicates that the voltage source will now supply voltage. However, **after reaching a steady-state condition, the capacitor will again act like an open circuit.** As a result, the voltage across the capacitor v_C will be 5V.



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,

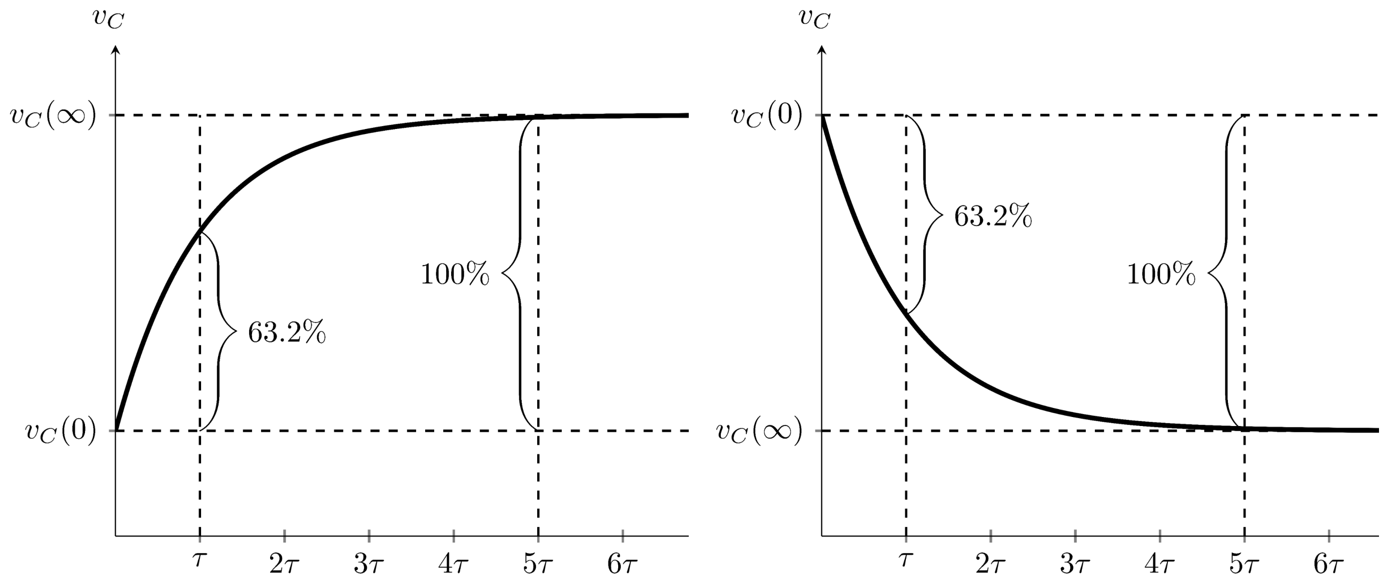
$$v_R + v_C - V = 0.$$
$$\Rightarrow IR + v_C - V = 0$$
$$\Rightarrow \left(C \frac{d}{dt} v_C\right) \cdot R + v_C - V = 0$$
$$\Rightarrow v_C + RC \frac{d}{dt} v_C - V = 0$$
$$\Rightarrow v_C + \tau \frac{d}{dt} v_C - V = 0$$

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 $v_C(0) < v_C(\infty)$, then the RC circuit is said to be in the **charging phase**. And the RC circuit is in the **discharging phase** if $v_C(0) > v_C(\infty)$.



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 $t = \tau$,

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

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

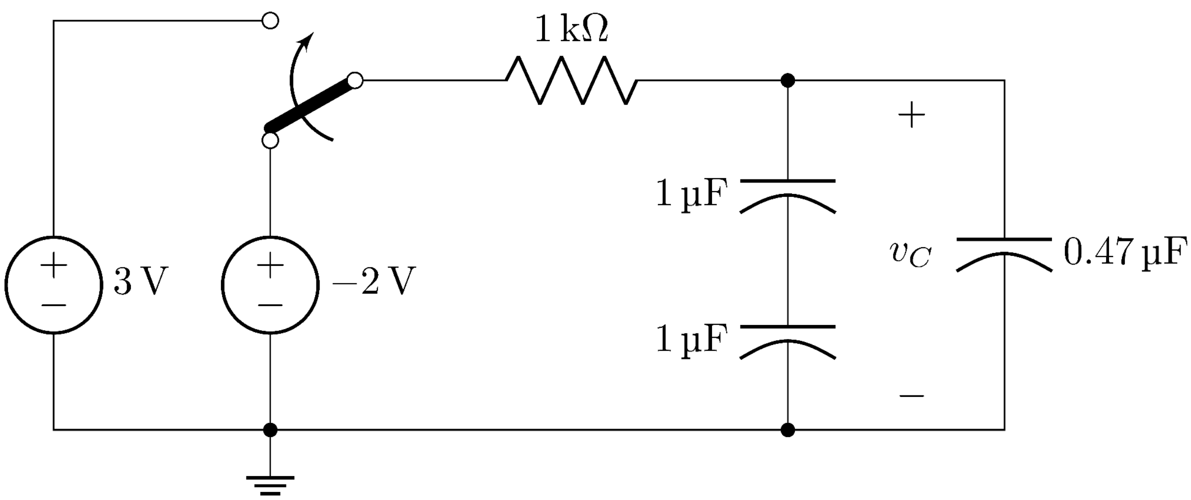
For example, if $\tau = 1ms$, then $1ms$ after switching, the voltage has already reached 63.2% of its way to the final steady-state voltage.

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.**

Procedure

Simulation using LTspice

We will introduce the study of the Transient Behavior in LTspice by simulating the simple circuit shown below (**Circuit 1**). Let us visualize Vc(t) for both the charging (as shown in the circuit) and the discharging phase (switching in the opposite direction).



Circuit 1

An intelligent way to simulate the switching mechanism shown in Circuit 1 is to use a square wave that oscillates between the values of the two sources (3V & -2V) in place of the sources and the switch. That way, despite using a single AC source, it behaves as if it's switching between the two voltages supplied by the sources present in Circuit 1 (3V & -2V). Let us use this method and simulate the circuit step by step as described below:

- ➢ Open a new schematic window by clicking ***File → New Schematic***. Draw the circuit shown below in **Figure 1.**

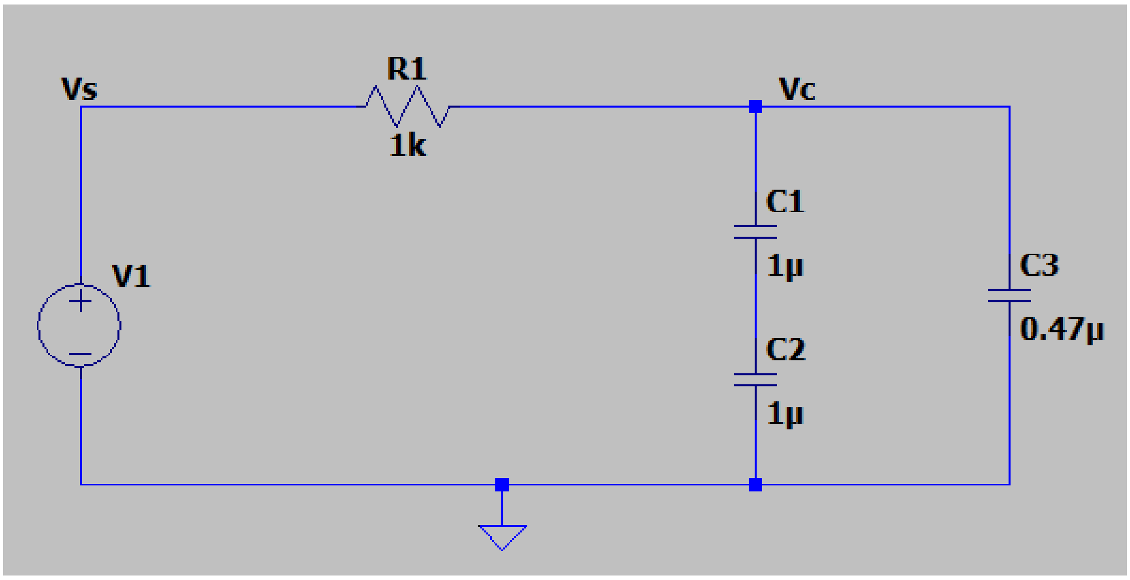
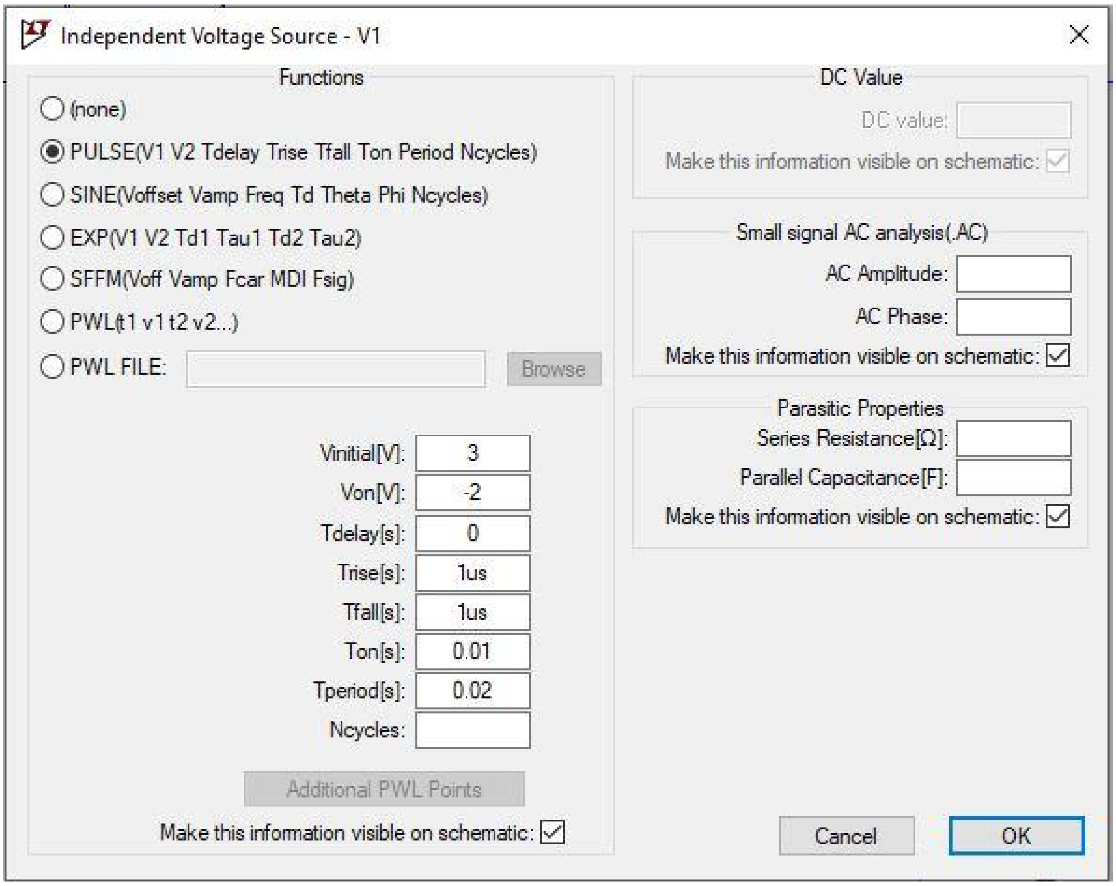


Figure 1

- ➢ We have to modify the **V1** source so that it provides 3V and -2V alternatively in order to mimic the switching action illustrated in **Circuit 1.** We will use the source as a pulsating DC square wave generator. To do so, ***Right-click on the voltage source → Select Advanced → insert the values as below and click OK.*** It will generate a -2V - 3V and **50 Hz** pulsating DC square signal.

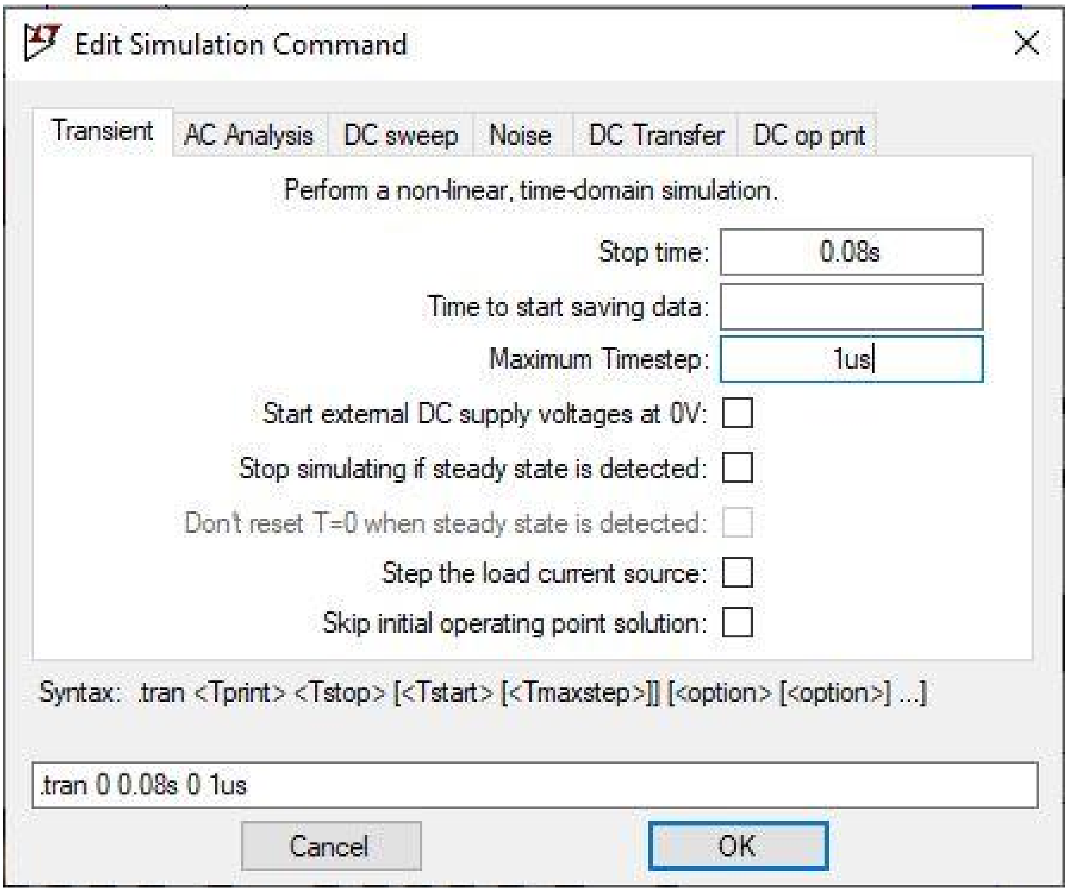


- ➢ To see the responses we have to do ***'Transient Analysis'***. The transient analysis calculates a circuit's response over a period of time.

  To run the 'Transient Analysis', we have to write the analysis command. First, find the ***'Spice Directives'*** option by ***Right-clicking on the schematic → Draft → Spice Directives*** or clicking on the "SPICE Directive" 

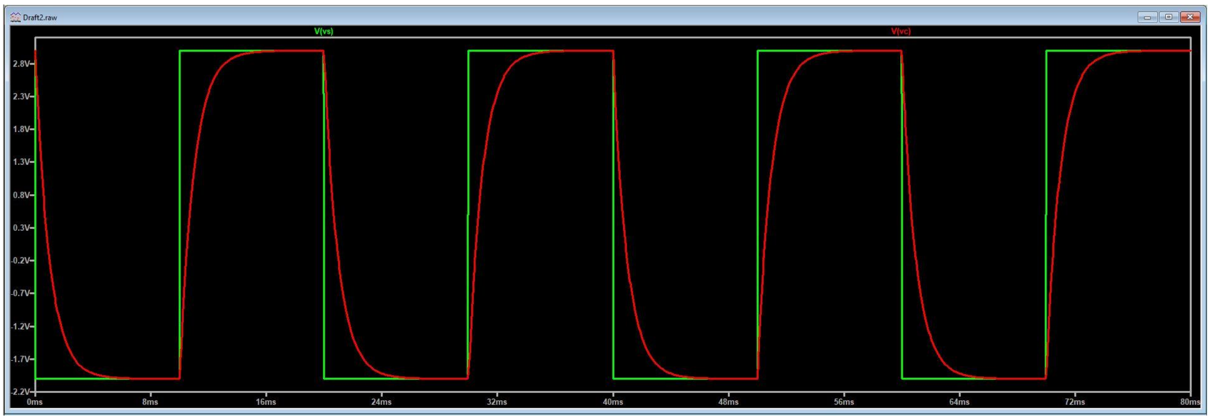
 icon from the toolbar.

- ➢ After clicking the ***'Spice Directives'***, the ***'Edit Text on the Schematic'*** window will appear. Now ***Right-click on the blank space on this window → Select 'Help me Edit' → Analysis Command.*** A window titled ***'Edit Simulation Command'*** will appear. Insert values in the boxes as below and click OK. It will generate a transient analysis command. Place the command somewhere on the schematic. [Notice the '.tran' syntax for transient analysis.]



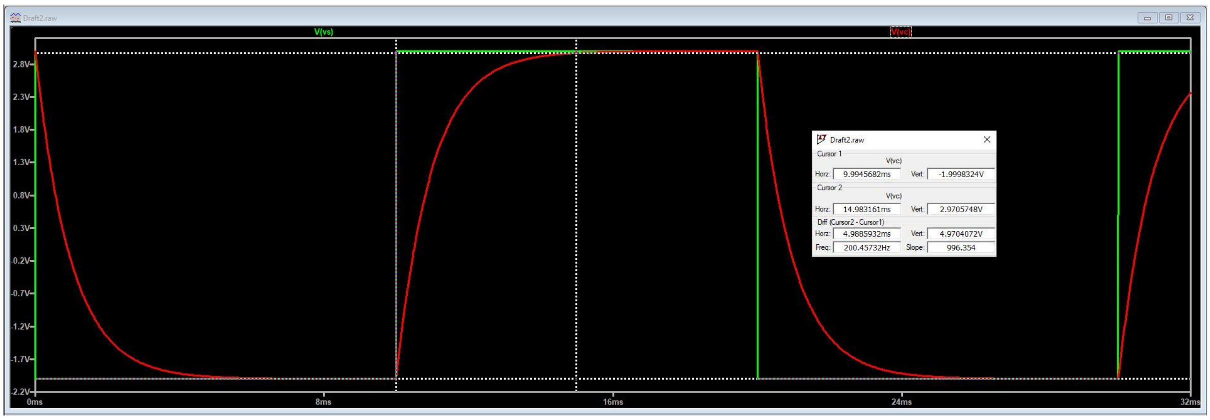
➢ To run the simulation, click ***'Run'***. Find the ***'Run'*** button  from the above toolbar or ***Right-click on the schematic →Run***.

➢ After clicking the ***'Run'*** button a plot window will appear. In this window we can see responses and waveshapes of voltage and currents with respect to time. To see a plot ***Right-click on the plot window → Add trace → Select any voltage or current → OK.***
[We can also add trace by simply using a marker on the schematic. When the run is complete a cursor will appear if we place the mouse cursor on a wire or component of the circuit.]



The axes properties (Range) can be changed by **Right-clicking on the horizontal (x-axis) and the vertical (y-axis).**

- To extract data from a plot/response, use the data cursor. **A cursor for a particular trace will appear by clicking on the name of that trace. One click will produce one cursor, clicking twice will produce two.** The data point of the cursor can be moved by the arrow keys from the keyboard.



- A window will appear on the bottom right corner containing the values corresponding to the cursors. Note that it also shows the difference between the two cursors (data points) for both the vertical and the horizontal axes. Use this to find **Time constant τ.**

- Save the Schematic by clicking ***File → Save as → 'Name.asc'*** and the plots by clicking ***File → Save plot settings → 'Name.plt'*** for future use and analysis.

Lab Work

1. Measure the **Time constant** τ from the plot you just generated.

From the Circuit we simulated, the **Time constant**, τ = | 1.021 ms |

2. Perform similar analysis to visualize the current supplied to the capacitor and observe whether it's a discontinuous graph or not.

3. Observe the shapes of the capacitor voltage & current and also compare the value of the Time Constant to the theoretical value $\tau = RC_{eq}$, and state your opinion on whether your observations match the theory or not.

Here, Ceq= (c1^-1+c2^-1)^-1 +c3
= (1+1)^-1 + 0.47
= 0.97

Theoretically Time constant, T= R*Ceq
= 1*.97
= 0.97ms

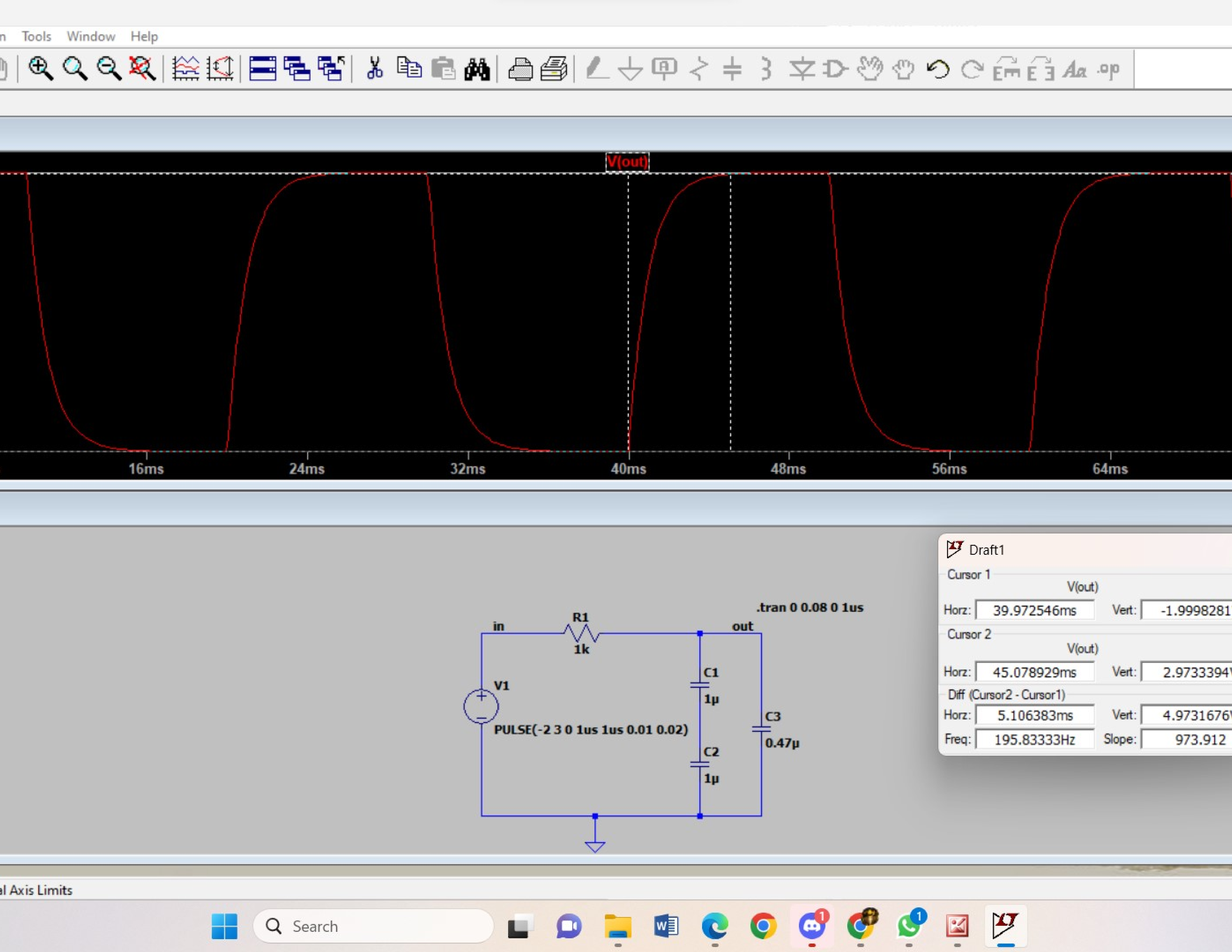
Practically Time constant, T' = 1.021ms

Here, T < T'

So, my observation didn't match the theory, but it's pretty similar value.

Report

1. Answer to questions and Complete the Lab work sections.
2. Save all your .asc and .plt files and make a zip file. You need to submit it with the report.
3. Discussion *[comment on the obtained results and discrepancies]*. Add pages if necessary.


Tools
Window
Help
V(out)
16ms
24ms
32ms
40ms
48ms
56ms
64ms
Draft1
Cursor 1
V(out)
Horz:
39.972546ms
Vert:
-1.9998281
Cursor 2
V(out)
Horz:
45.078929ms
Vert:
2.9733394
Diff (Cursor2 - Cursor1)
Horz:
5.106383ms
Vert:
4.9731676
Freq:
195.83333Hz
Slope:
973.912
.tran 0 0.08 0 1us
in
R1
1k
out
C1
1µ
V1
PULSE(-2 3 0 1us 1us 0.01 0.02)
C3
0.47µ
C2
1µ
al Axis Limits
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