PreLab5 Report

Transient Response of First-Order RC Circuits

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1. Review the section on RC circuit in the textbook, make sure you understand the concepts of transient behavior discussed above.

2. Please note that in order to observe the transient response of the circuit, the period T of the square wave must be long enough to allow the complete charge and discharge of the inductor. Usually T >10τ is appropriate for this purpose.

PART ONE: Time constant

Consider the circuit shown in Figure.1, we have nominal values: R =2kΩ, C = 0.1μF.

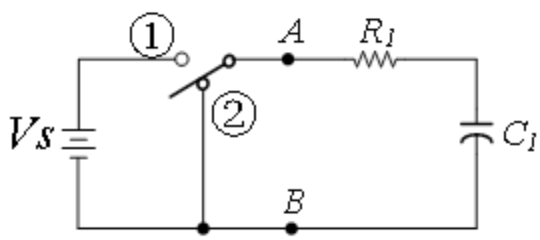


Figure1. First order RC circuit

1. R =2kΩ, C = 0.1μF

1) Calculate the time constant of this circuit , call this time constant τpre-lab1 or τp1. ＿/1pt

$\tau_{p1} = RC = 2\times10^{3}\times0.1\times10^{-6} = 2\times10^{-4}\,s$

2) Charging：t<0, the switch is set to position②，initial value $u_C(0^-)=0$； t=0, the switch is set to position①.

What is the voltage across a capacitor when it is charged @1τ in theory, show your calculations. ＿/2pt

$U_1 = V_s(1-e^{-\frac{t}{\tau}}) = V_s(1-e^{-\frac{\tau}{\tau}}) = V_s(1-\frac{1}{e})$

3) Discharging：t<0, the switch is set to position①，initial value$u_C(0^-) = Vs$；t=0, the switch is set

to position②.

What is the voltage across a capacitor when it is discharged @1τ in theory, show your calculations. __/2pt

$U_2 = V_s e^{-\frac{t}{\tau}} = V_s e^{-\frac{\tau}{\tau}} = V_s e^{-1} = \frac{V_s}{e}$

4) Approximate the time it takes for the capacitor to fully charge or discharge. __/1pt

after five time constant

$5\tau_{p1} = 1\times10^{-3}s$

2. For the first-order RC circuit considered in Fig. 1, introduce a second resistor R_2=3.3kΩ in parallel with resistor R_1=2kΩ.

(1) Find the equivalent resistence for the network of resistors(R_2=3.3kΩ in parallel with resistor R_1=2kΩ). __/1pt

$R_{eq} = R_1 \| R_2 = \frac{R_1 R_2}{R_1+R_2} = \frac{2\times3.3}{2+3.3} = \frac{66}{53} \approx 1.245\,k\Omega$

(2) Calculate the time constant of this circuit , call this time constant τpre-lab2 or τp2. __/1pt

$\tau_{p2} = R_{eq}C = 1.245\times10^3 \times 0.1\times10^{-6} = 1.245\times10^{-4}$

(3) Charging：t<0, the switch is set to position②，initial value $u_C(0^-)=0$； t=0, the switch is set to position①.

What is the voltage across a capacitor when it is charged @1τ in theory, show your calculations. __/2pt

$U_1 = V_s(1-e^{-\frac{t}{\tau}}) = V_s(1-e^{-\frac{\tau}{\tau}}) = V_s(1-\frac{1}{e})$

(4) Discharging：t<0, the switch is set to position①，initial value $u_C(0^-) = Vs$；t=0, the switch is set to position②.

What is the voltage across a capacitor when it is discharged @1τ in theory, show your calculations. __/2pt

$U_2 = V_s e^{-\frac{\tau}{\tau}} = V_s e^{-1} = \frac{V_s}{e}$

(5) Approximate the time it takes for the capacitor to fully charge or discharge. __/1pt

after five time constant

$5\tau_{p2}=6.225\times10^{-4}s$

3. For the first-order RC circuit considered in Fig. 1, introduce a second capacitor C_2 0.22μF in parallel with C_1=0.1μF, R_1=2kΩ.

1) Find the equivalent capacitance for the network of capacitors(C_2 in parallel with C). __/1pt

$C_{eq}=C_1+C_2=0.32\mu F$

2) Calculate the new time constant τpre-lab3 or τp3 of the RC circuit. __/1pt

$\tau_{p3}=RC_{eq}=2\times10^3\times0.32\times10^{-6}=6.4\times10^{-4}$

3) Charging：t<0, the switch is set to position②，initial value $u_C(0^-)=0$； t=0, the switch is set to position①.

What is the voltage across a capacitor when it is charged @1τ in theory, show your calculations. __/2pt

$U_1=V_s(1-e^{-\frac{t}{\tau}})=V_s(1-e^{-\frac{\tau}{\tau}})=V_s(1-\frac{1}{e})$

4) Discharging：t<0, the switch is set to position①，initial value $u_C(0^-)=Vs$；t=0, the switch is set to position②.

What is the voltage across a capacitor when it is discharged @1τ in theory, show your calculations. __/2pt

$U_2=V_se^{-\frac{t}{\tau}}=V_se^{-\frac{\tau}{\tau}}=\frac{V_s}{e}$

5) Approximate the time it takes for the capacitor to fully charge or discharge. __/1pt

after five time constant

$5\tau_{p3}=3.2\times10^{-3}S$

PART TWO: Time Constant Measurement 1

Assume that the initial capacitor voltage is zero. The time constant $\tau = RC$ is one of the most important characteristics of RC circuit. Employ Multisim to find the time constant $\tau = RC$ and plot the transient response of the capacitor voltage.

1. Draw the schematic
1) Capacitor : Basic-> CAP_ELECTROLIT
2) Switch: Basic-> SWITCH ->SPDT.
2. Connect the Oscilloscope's Channel1 to Point A. Connect the Oscilloscope's Channel2 to the upper terminal of the capacitor. There is no need to connect the scope's ground to the circuit ground.

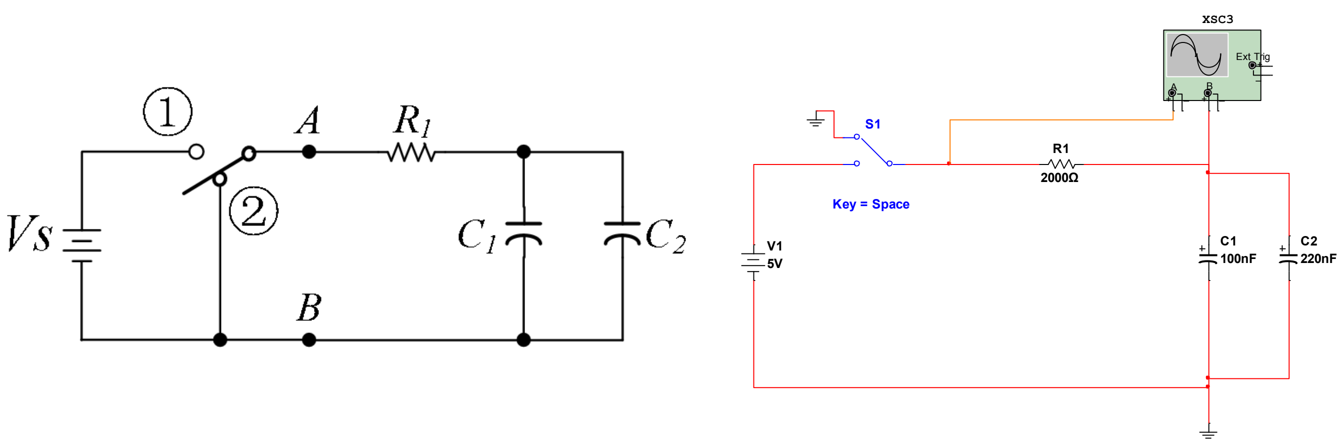
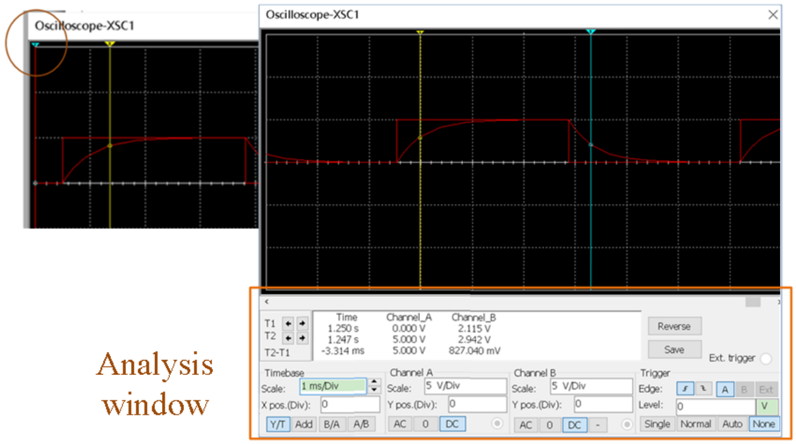


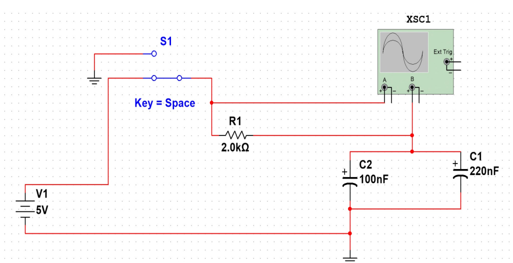
Figure2. First order RC circuit Simulation

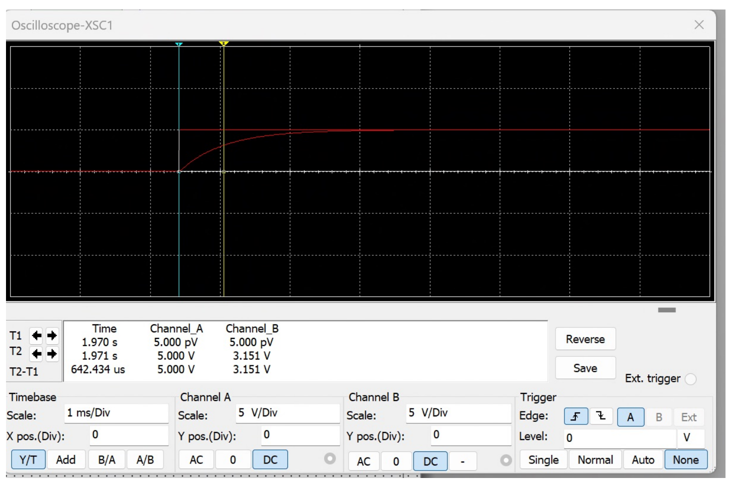
3. Run the simulation and watch the Oscilloscope.
1) Let the switch in position①, which connects R1 to ground.
2) As soon as the trace refreshes on the left hand side of the screen, presses the space bar on the keyboard or select the SPDT and click the left mouse button to change the SPDT from position①to position ②, which will connect the 5V source to the rest of the circuit and charges the capacitor.
3) As soon as the trace refreshes on the left hand side of the screen, change the SPDT from position ② to position ①, which will result in a parallel RC circuit that discharges the capacitor.
4. Two cursors are available, and their default position is on the vertical axis. At the top of the voltage axis you will see a small colored triangle pointing downward. Grab it with your mouse and drag it to the plot area. This data represents the (x,y) coordinates for the point on the plot where the cursor intersects the plotted curve. X represents the time value and Y represents the voltage value. Using these cursors you can extract numerical results from the plot. Note that, for each curve, **the analysis window** also calculates the difference between the X and Y values for the two cursor positions (and it calls these dx and dy). Using this you can make time and voltage difference measurements for any two ponits on either curve.



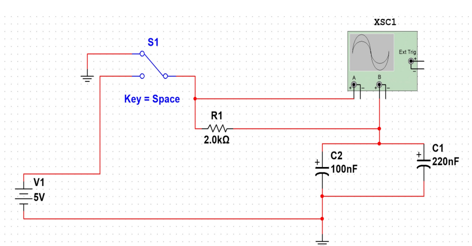
1) Move the two cursors to proper position to measure τ for both charging and discharging from the plot. Capture the waveforms from the Oscilloscope. __/6pt

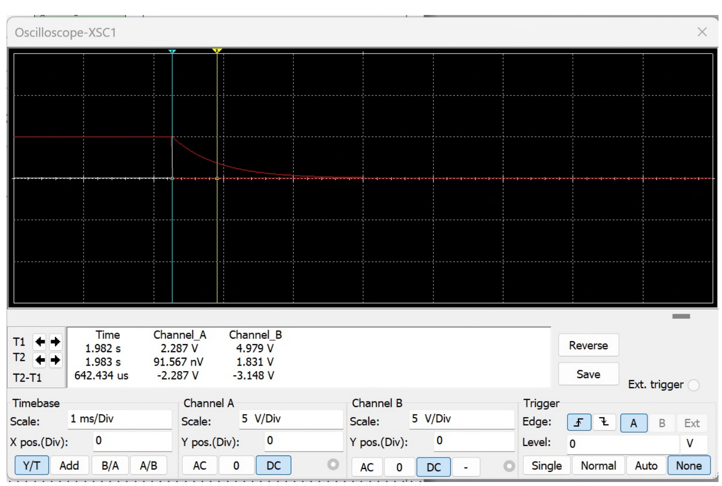
charging





Discharging





2) Get τ for charging and discharging from the simulation results. Compare with your calculation. __/4pt

charging: 642.434×10^{-6} error: $\left|\frac{642.434\times10^{-6} - 64\times10^{-4}}{64\times10^{-4}}\right| \times 100\% \approx 0.38\%$

discharging: 642.434×10^{-6} error: $\left|\frac{642.434\times10^{-6} - 64\times10^{-4}}{64\times10^{-4}}\right| \times 100\% \approx 0.38\%$

Both show that the simulation resulus are very close to the calculate ones.

PART Three: Time Constant Measurement2

As we know, the switch move alternately between positions ① and ②, the voltage across points A and B can be plotted and would be like a square wave left. As a result, the components in the dotted box are analogous to a square-wave generator, which can be produced by a function generator with outputs at points A and B.

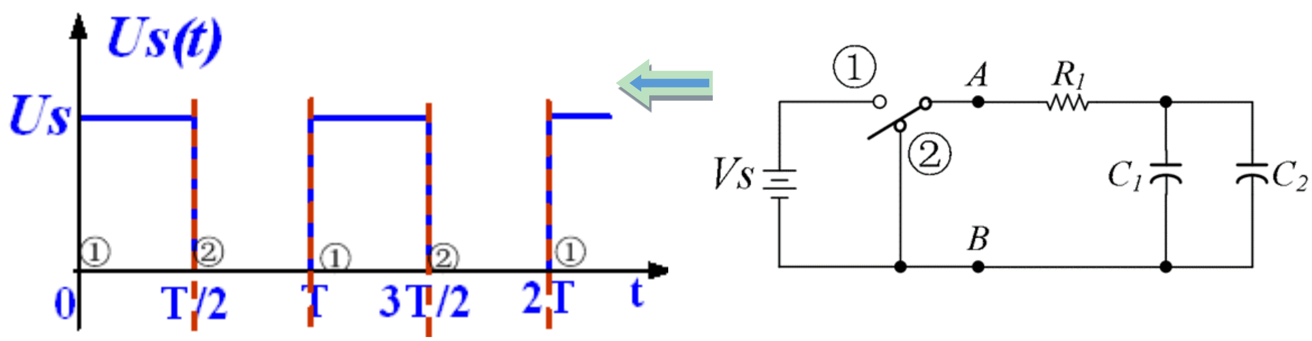


Figure 3.

1. What should be the frequency of the square wave source be in order to clearly display the charge/discharge cycles of the capacitor? Why? __/2pt

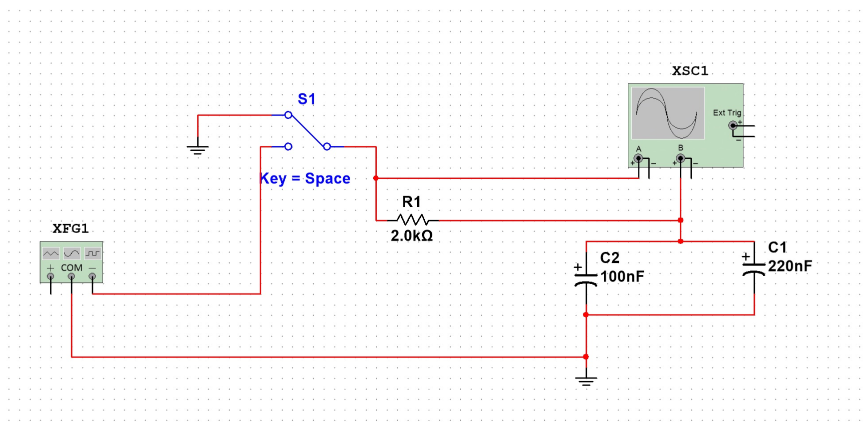
To clearly display the charge/discharge cycles of the capacitor, the voltage is expected to remain constant to act like a square wave. it means that T should satisfy $\frac{T}{2} \geq 5\tau$ (which is the time it takes for a capacitor to fully charge/discharge). thus. $f = \frac{1}{T}$ should be less than $\frac{1}{10\tau}$ (where τ is the time constant)

(in this problem, calculate it should less than $\frac{1}{10\tau} \approx 156Hz$

2. Assume the square wave's minimum voltage of 0V, maximum voltage of 5V, 50% duty cycle and frequency of 150 Hz which is generated by Signal Generator. Note that you may need to manually set the offset to achieve this waveform.

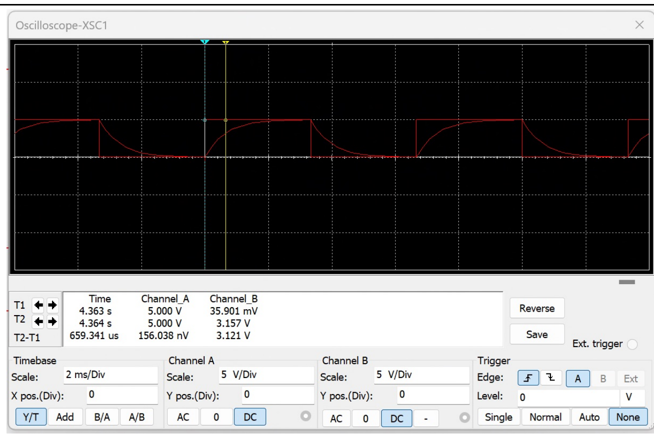
3. Use the oscilloscope to display this waveform on Channel 1 to verify that the square wave is correct. Use Channel 2 of the oscilloscope to display the output voltage over the capacitor.

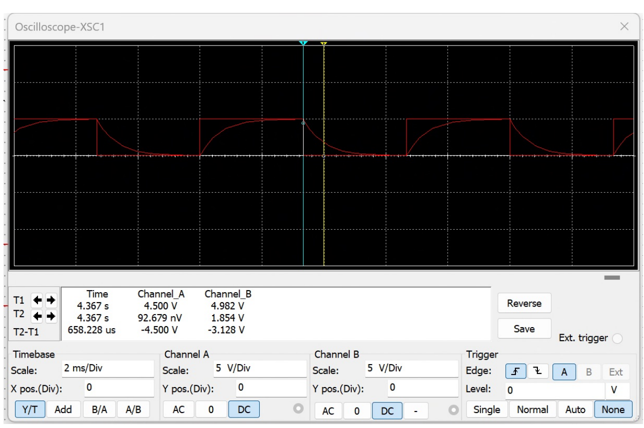
4. Show your schematic. __/4pt



5. Run the simulation and watch the Oscilloscope.

1) Adjust the time base to display 2 complete cycles of the signals. Move the two cursors to proper position to measure τ for charging and discharging from the plot. Capture the waveforms from the Oscilloscope. __/4pt





2) Get τ from the simulation results. Compare with your calculation. __/2pt

charging: 659.341×10^{-6} error: $\left|\frac{659.341 \times 10^{-6} - 6.4 \times 10^{-4}}{6.4 \times 10^{-4}}\right| \times 100\% \approx 2.93\%$

discharging: 658.228×10^{-6} error: $\left|\frac{658.228 \times 10^{-6} - 6.4 \times 10^{-4}}{6.4 \times 10^{-4}}\right| \times 100\% \approx 2.77\%$

which is very close to the calculation.