General Physics II Lab (PHYS-2021)
Experiment ELEC-5:
RC Circuits

Objective:

The manner by which the voltage on a capacitor decreases is studied. The half-life for the decay is measured directly and also calculated using the capacitive time constant.

Theory:

Capacitors are circuit devices that can store charge. The capacitance (size) of the capacitor is a measure of how much charge it can hold for a given voltage.

$$Q = CV_C \tag{1}$$

where C is the capacitance in Farads, Q is the charge in Coulombs, and V_C is the voltage across the capacitor in Volts.
To determine how the charge on a capacitor decays in time, use Kirchhoff's Loop Rule for Figure 1 below.

$$V_o = V_C + V_R \tag{2}$$

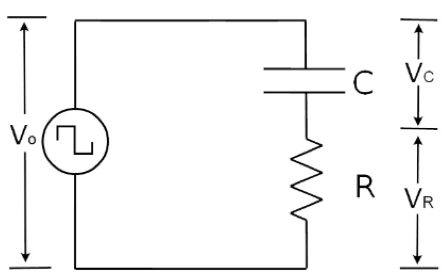

Figure 1: Scope showing the voltage across the capacitor and the output voltage

Solving Equation (1) for the voltage across the capacitor gives

$$V_C = Q/C \tag{3}$$

The voltage across the resistor is given by Ohm's Law:

$$V_R = IR \tag{4}$$

Therefore,

$$V_o = Q/C + IR \tag{5}$$

Since the applied voltage, V_o, is zero when the capacitor is discharging, Equation (5) reduces to

$$Q/C + IR = 0 \tag{6}$$

Since the current is

$$I = \frac{dQ}{dt} \tag{7}$$

Equation (6) becomes the differential equation

$$\frac{dQ}{dt} + \frac{1}{RC}Q = 0 \tag{8}$$

Solving Equation (8) for Q gives

$$Q = Q_{max}e^{-(\frac{t}{RC})} \tag{9}$$

Plugging Q into Equation (2) gives the voltage across the capacitor as a function of time

$$V(t) = V_o e^{-(\frac{t}{RC})} \tag{10}$$

where $V_o = Q_{max}/$C. The rate that voltage across a capacitor (and the charge stored in the capacitor) decreases depends on the resistance and capacitance that are in the circuit. If a capacitor is charged to an initial voltage, V_o, and is allowed to discharge through a resistor, R, the voltage, V, across the capacitor will decrease exponentially.The half-life, $t_{\frac{1}{2}}$ is defined to be the time that it takes for the voltage to decrease by half:

$$V(t_{\frac{1}{2}}) \ = \ V_o/2 \ = \ V_o e^{-(\frac{t_{\frac{1}{2}}}{RC})} \tag{11}$$

Solving for the half-life gives:

$$t_{\frac{1}{2}} \ = \ RC \ ln \ 2 \tag{12}$$

The product RC is called the capacitive time constant and has the units of seconds.

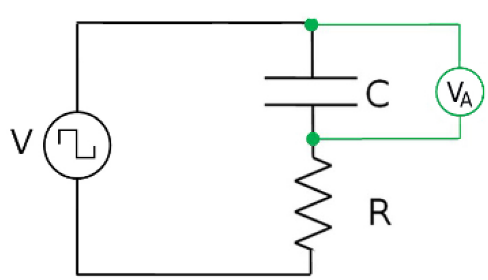

Figure 2: RC Circuit Diagram

Setup

1. Turn ON the Universal Interface (Figure 10) and OPEN PASCO software.
2. Click on Hardware Setup. Click on Channel Analog Input A → Select Voltage Sensor.
3. Click on Hardware Setup. For the Signal Generator #1 → Select Output Voltage Current Sensor.
4. Click on Signal Generator. Set the **Waveform** to Square. Shown in Figure 3.
   → Set the **Signal Generator Frequency** to 350 Hz.
   → Set the **Amplitude** to 2 V.
   → Set the **Voltage Offset** to 2 V.
   NOTE: This will make the square wave all positive with an amplitude of 4V
   → Set the **Signal Generator** on AUTO.
5. Click on the **Pin Icon**  to pin the Signal Generator to the screen.
6. Set the **Mode** to Fast Monitor Mode. Shown in Figure 4.
7. Create a Scope to set up an oscilloscope display.
   → Y-axis (Left side) = **Select Measurement** of Voltage Ch A
   → Click on the  to add new y-axis data to your graph.
   → Y-axis (Right side) = **Select Measurement** of Output Voltage, Ch 01 (V)
   → **Left Click** on the X-axis units to change from (s) to ms.
8. Set the **Sampling Rate** to the maximum allowed to increase the number of points as shown in Figure 4.

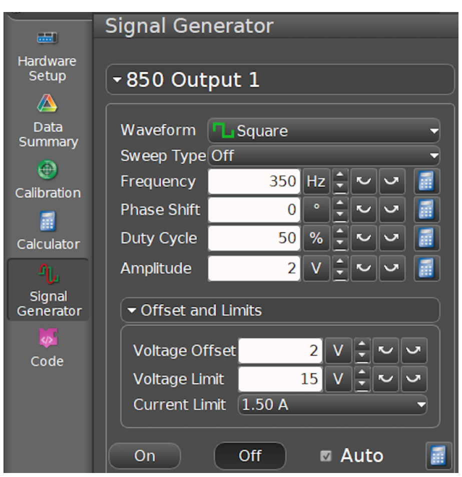

Figure 3: Signal Generator Setup

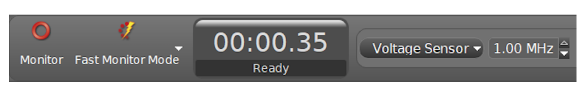

Figure 4: Sampling Rate

Procedure: 3900pF Capacitor, 4V

1. Verify the circuit wires are connected to the 3900 pF Capacitor (Figure 10).
2. Click Monitor and Verify your scope is working correctly like the one shown in Figure 7.
3. Click on the adjust Y-axis Icon () on the graph toolbar to fit the data.
4. Adjust the x-axis scale on the oscilloscope by moving the curser near the x-axis until you get the $\leftrightarrow$ symbol.
5. Right Click and Drag Right until there is a complete cycle as shown in Figure 8.
6. Click Stop when your scope looks similar to Figure 8.
7. Click on Data Summary.
   $\rightarrow$ Right Click on Monitor Run
   $\rightarrow$ Rename the Run "3900 pF"
8. Record the next 4 measurements in the Analysis - 3900 pF Capacitor with output Voltage of 4 V section of your Lab Report.
9. Measure the initial time (t_o) the Voltage starts to decay by Placing the curser on the top of the curve and Left Click.
10. Click on this and a Box with the associated Voltage and Time values at that point along the curve will appear - as shown in Figure 6.
11. Use the arrows to go up or down along the curve to get as close to where you want to measure as possible.
12. Repeat previous step but measure the time it takes for the voltage to decay to half of its maximum ($t_{\frac{1}{2}}$). This time is the half-life.
13. Measure the time it takes for the voltage to decay to one-quarter of its maximum ($2t_{\frac{1}{2}}$).
14. This is two half-lives. Then divide this time by two to find the half-life.
15. Measure the time it takes for the voltage to decay to one-eighth of its maximum ($3t_{\frac{1}{2}}$).
16. This is three half-lives. Then divide this time by three to find the half-life.
17. Print your graph of Voltage vs Time. **Write the Title: "3900 pF Capacitor, 4 V"**
18. Turn it in with your Lab Report.

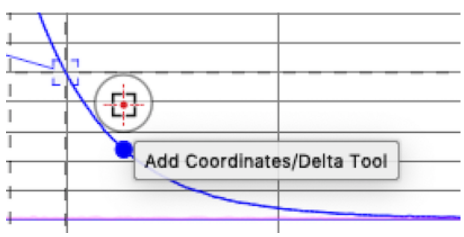

Figure 5: Add Coordinate

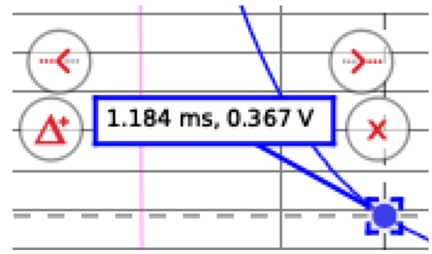

Figure 6: Coordinate Box

Procedure: 3900pF Capacitor, 8V

1. Click on Signal Generator. Set the **Waveform** to Square. Shown in Figure 3.
   → Set the **Amplitude** to 4 V.
   → Set the **Voltage Offset** to 4 V.
   NOTE: This will make the square wave all positive with an amplitude of 8V
2. Click Monitor and Verify your scope is working correctly like the one shown in Figure 7.
3. Click on the adjust Y-axis Icon ( ) on the graph toolbar to fit the data.
4. Adjust the x-axis scale on the oscilloscope by moving the cursor near the x-axis until you get the ↔ symbol.
5. Right Click and Drag Right until there is a complete cycle as shown in Figure 8.
6. Click Stop when your scope looks similar to Figure 8.
7. Click on Data Summary.
   → Right Click on Monitor Run
   → Rename the Run "8 V"
8. Record the next 4 measurements in the Analysis - 3900 pF Capacitor with output Voltage of 8 V section of your Lab Report.
9. Measure the initial time (t_o) the Voltage starts to decay.
10. Measure the time it takes for the voltage to decay to half of its maximum ($t_{\frac{1}{2}}$).
11. Measure the time it takes for the voltage to decay to one-quarter of its maximum ($2t_{\frac{1}{2}}$).
12. Measure the time it takes for the voltage to decay to one-eighth of its maximum ($3t_{\frac{1}{2}}$).
13. Print your graph of Voltage vs Time.
14. **Write the Title: "3900 pF Capacitor, 8 V"**
15. Turn it in with your Lab Report.

Procedure: 560pF Capacitor, 4V

1. Disconnect the wires connected from the 3900 pF capacitor.
2. Connect wires to the 560 pF capacitor.
3. **DO NOT CHANGE THE RESISTOR.**
4. Click on Signal Generator.
   → Set the **Waveform** to Square.
   → Set the **Signal Generator Frequency** to 1800 Hz.
   → Set the **Amplitude** to 2 V.
   → Set the **Voltage Offset** to 2 V.
   NOTE: This will return the square wave all positive with an amplitude of 4V
5. Click Monitor and Verify your scope is working correctly like the one shown in Figure 7.
6. Click on the adjust Y-axis Icon () on the graph toolbar to fit the data.
7. Adjust the x-axis scale on the oscilloscope by moving the curser near the x-axis until you get the ↔ symbol.
8. Right Click and Drag Right until there is a complete cycle as shown in Figure 8.
9. Click Stop when your scope looks similar to Figure 8.
10. Click on Data Summary.
    → Right Click on Monitor Run
    → Rename the Run "8 V"
11. Record the next 4 measurements in the Analysis - 560 pF Capacitor with output Voltage of 4 V section of your Lab Report.
12. Measure the initial time (t_o) the Voltage starts to decay.
13. Measure the time it takes for the voltage to decay to half of its maximum ($t_{\frac{1}{2}}$).
14. Measure the time it takes for the voltage to decay to one-quarter of its maximum ($2t_{\frac{1}{2}}$).
15. Measure the time it takes for the voltage to decay to one-eighth of its maximum ($3t_{\frac{1}{2}}$).
16. Print your graph of Voltage vs Time. **Write the Title: "560 pF Capacitor, 4 V"**
17. Turn it in with your Lab Report.

***** NOTE: Please TURN OFF the Universal Interface when you are finished with the experiment. *****

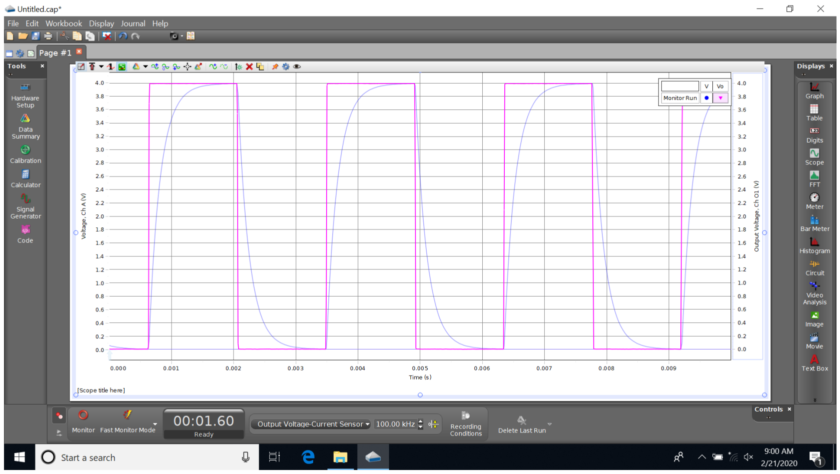

Figure 7: Scope showing the voltage across the capacitor and the output voltage

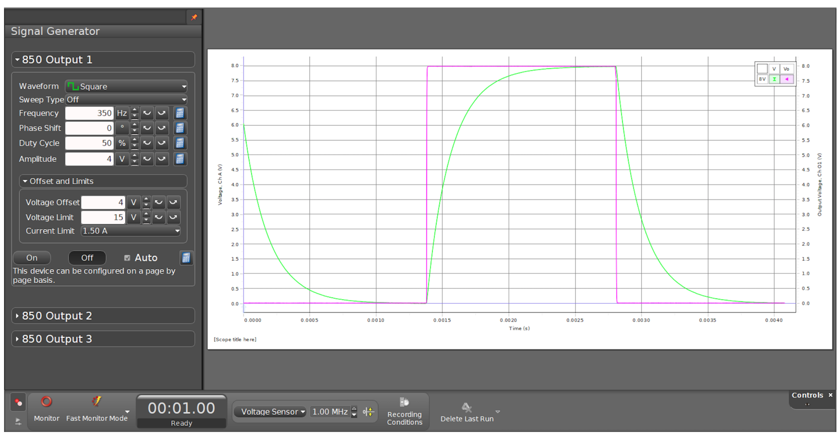

Figure 8: Adjusted scale on the oscilloscope showing a complete cycle.

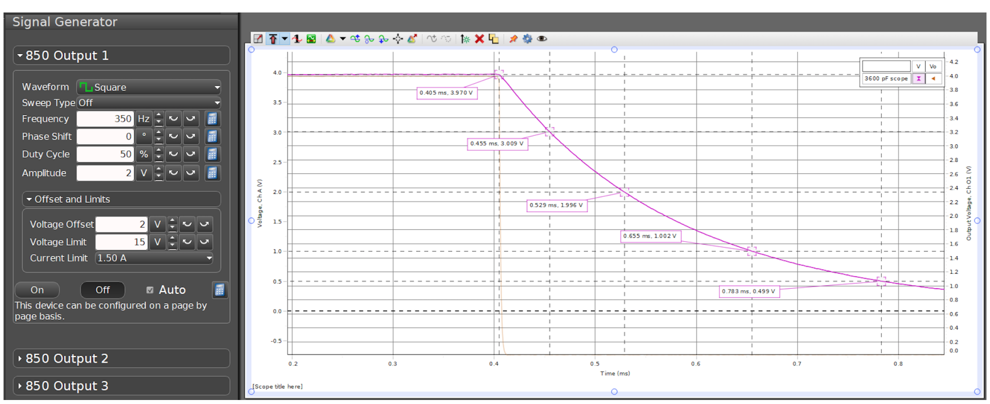

Figure 9: Example: Final scope results showing time measurements for the voltage decay at 100%, 75%, 50%, 25% and 12.5% of its maximum.

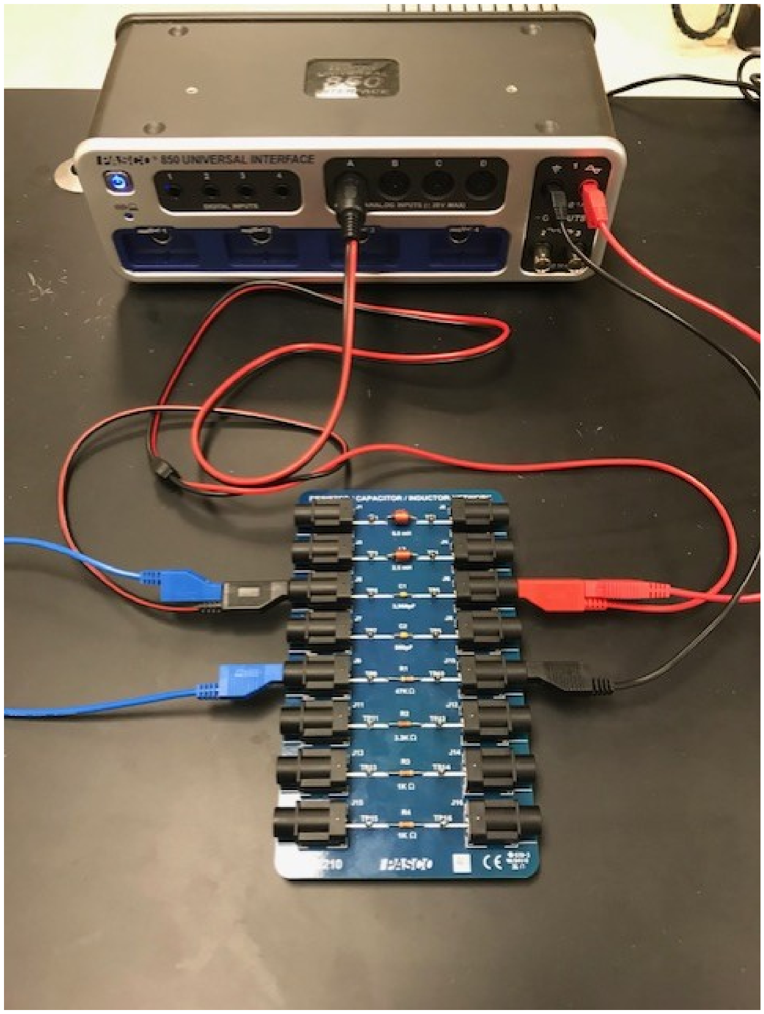

Figure 10: RC Circuit Setup