

RC Circuit (Power amplifier, Voltage Sensor)

Object:

To investigate how the voltage across a capacitor varies as it charges and to find its capacitive time constant.

Apparatus:

Science Workshop, Power Amplifier, Voltage Sensor, (3) Patch Cords, CI-6512 RLC circuit board.

Theory:

When a DC voltage source is connected across an uncharged capacitor, the rate at which the capacitor charges up decrease as time passes. At first, the capacitor is easy to charge because there is very little charge on the plates. But as charge accumulates on the plates, the voltage source must “do more work” to move additional charges onto the plates because the plates already have charge of the same sign on them. As a result, the capacitor charges exponentially, quickly at the beginning and more slowly as the capacitor becomes fully charged. The charge on the plates at any time is given by:

$$q = q_0(1 - e^{-t/\tau})$$

Where q_0 is the maximum charge on the plate and τ is the capacitive time constant ($\tau = RC$, where R is resistance and C is capacitance). NOTE: The stated value of a capacitor may vary by as much as $\pm 20\%$ from the actual value. Taking the extreme limits, notice that when $t = 0$, $q = 0$ which means there is not any charge on the plates initially. Also notice that when t goes to infinity, q goes to q_0 which means it takes an infinite amount of time to completely charge the capacitor.

The time it takes to charge the capacitor to half of full is called the half-life and is related to the time constant in the following way:

$$t_{1/2} = \tau \ln 2$$

In this activity the charge on the capacitor will be measured indirectly by measuring the voltage across the capacitor since these two values are proportional to each other: $q = CV$.

Procedure:

In this activity, the Power Amplifier produces a low frequency square wave (0 to 4 V). This waveform imitates the action of charging and then discharging a capacitor by connecting and then disconnecting a DC voltage source. The Voltage Sensor measures the voltage across the capacitor as it charges and discharges.

The Science Workshop program records and displays the data. You will measure the time for the capacitor to charge to the “half-maximum” voltage. Using the half-life time and the known value of the resistor, you can calculate the capacitance of the capacitor.

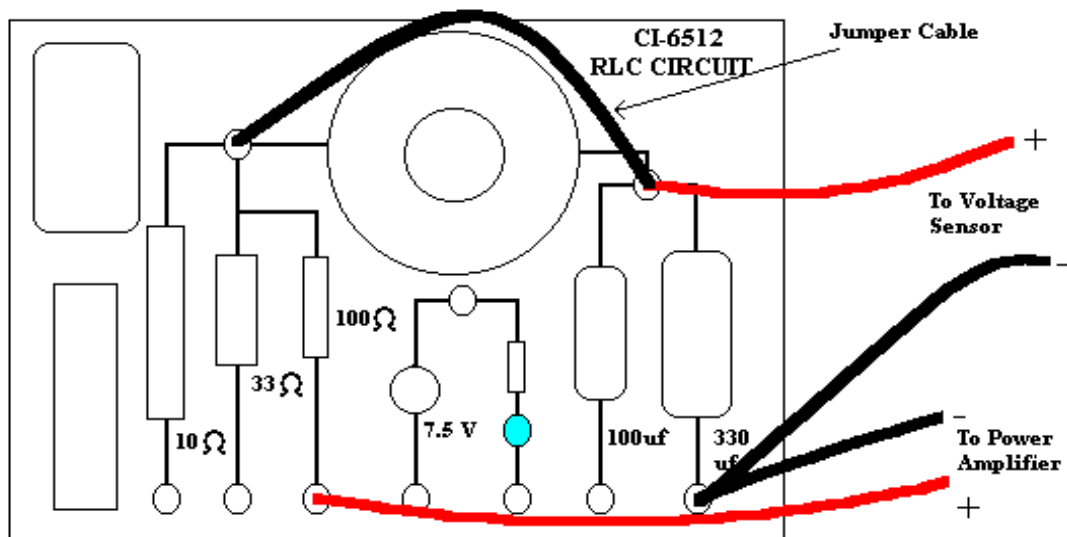
Part I: Computer Setup and Equipment Setup

1. Connect the Science Workshop interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Power Amplifier to Analog Channel A. Connect the Voltage Sensor to Analog Channel B. Plug the power cord into the back of the Power Amplifier and connect the power cord to an appropriate electrical outlet.

3. Open the Science Workshop document titled as shown below:
Windows: P43_RCCL.SWS
4. The Sampling settings for this activity are: Periodic Samples = Fast at 1000 Hz and Stop Condition = Time at 4.00 seconds.
5. The Signal Generator is set to output a 4.00 V, “positive only” square AC Waveform, at 0.40 Hz. It is set to Auto so the Signal Generator will start automatically when you click “start” and stop automatically.
6. Connect a jumper cable to remove the inductor from the circuit.
7. Connect the positive output from the Power Amplifier to the jack just below the 100 Ω resistor.
8. Connect the negative output from the Power Amplifier to the jack just below the 330 μf capacitor.

The circuit now consists of a 100 Ω resistor in series with a 330 μf capacitor.


9. Connect the voltage sensor across the 330 μf capacitor as shown below.




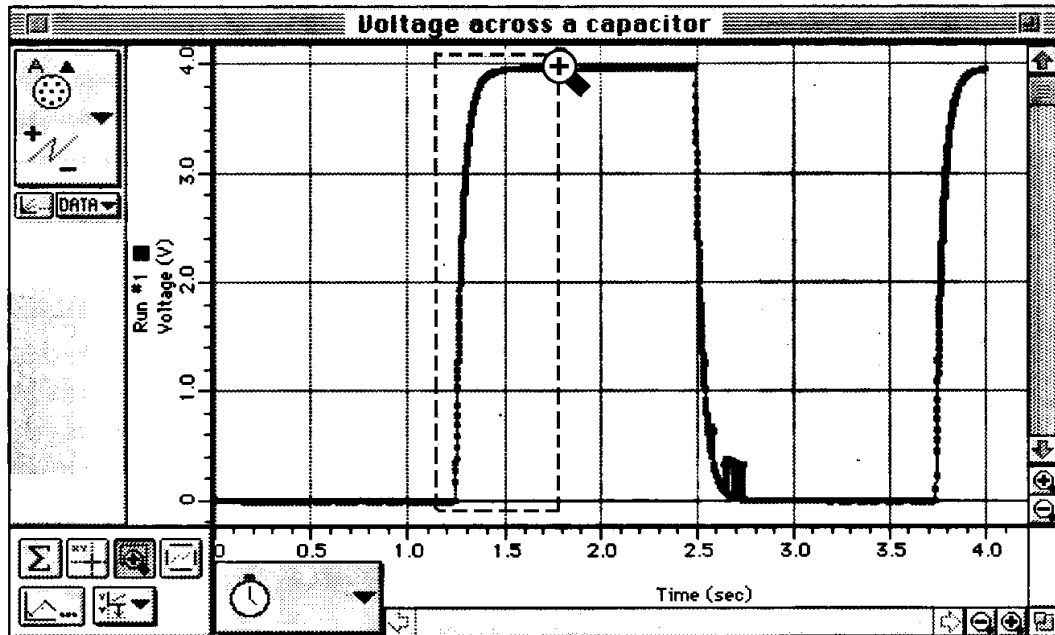
Part II: Data Recording

1. Turn on the power switch on the back of the Power Amplifier.
2. The Signal Generator output will automatically start when data recording begins.
3. Data recording will continue for four seconds and then stop automatically.
4. When data taking is complete, turn off the switch on the back of the Power Amplifier.

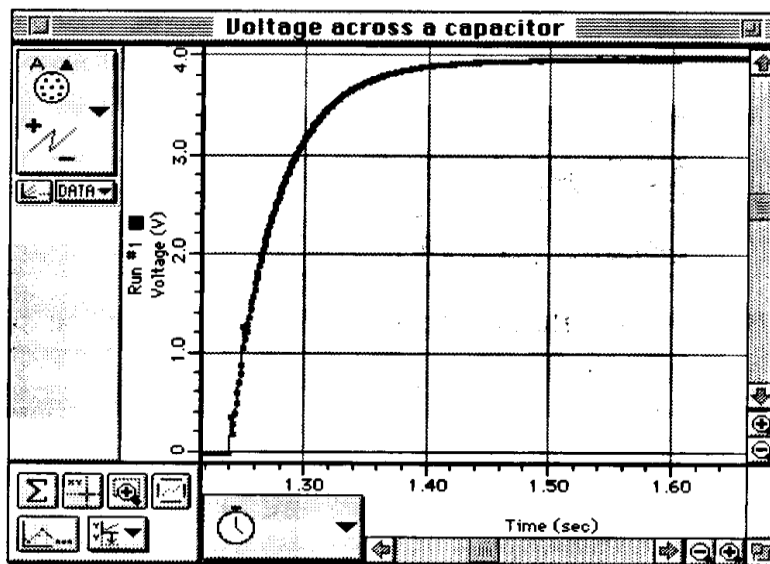
Analyzing The Data:


1. Click the Autoscale button () in the Graph to rescale the Graph to fit the data.

2. Click the Magnifier button (). Use the cursor to click-and-draw a rectangle over a region of the plot of Voltage versus Time that shows the voltage rising from zero volts to the maximum volts.



* This will give you an expanded view of the Voltage versus Time plot for that region.

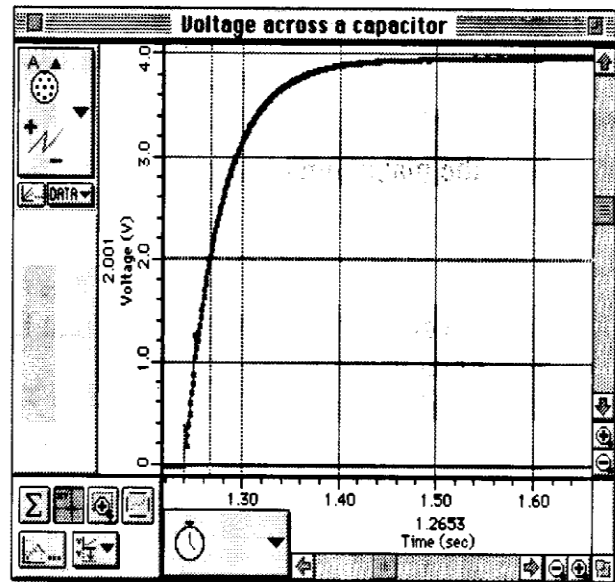
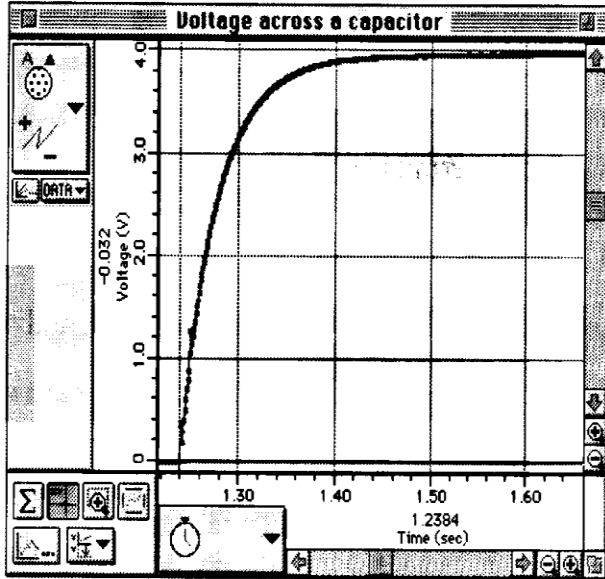


3. Click the Smart Cursor button (). The cursor changes to a cross-hair when you move the cursor into the display area of the Graph.

* The Y-coordinate of the cursor/cross-hair is shown next to the vertical axis.

* The X-coordinate of the cursor/cross-hair is shown next to the horizontal axis.

4. Move the cursor to the point on the plot where the voltage begins to rise. Record the time that is shown in the area below the horizontal axis.



5. Move the Smart Cursor to the point where the voltage is approximately 2.00 volts. Record the new time that is shown in the area below the horizontal axis.
6. Find the difference between the two times and record it as the time to “half-max”, or $t_{1/2}$.

Data:

Beginning time = _____ s

Time to 2.00 V = _____ s

Time to half-max ($t_{1/2}$) = _____ s

1. Use $t_{1/2} = \tau \ln 2 = 0.693RC$ to calculate the capacitance (C) of the capacitor.

Capacitance = _____ farad

2. If a capacitance meter is available, use it to measure the capacitance of the capacitor. Using the percent difference method, compare the measured value to the experimental value. (Remember, the stated value of a capacitor may vary by as much as $\pm 20\%$ from the actual measured value.) If a capacitance meter is not available, use the percent difference method and compare the stated value (e.g., $330\mu\text{F}$) to the experimental value.

Questions:

1. The time to half-maximum voltage is how long it takes the capacitor to charge halfway. Based on your experimental results, how long does it take for the capacitor to charge to 75% of its maximum?
2. After four “half-lives” (i.e., time to half-max), to what percentage of the maximum charge is the capacitor charged?
3. What is the maximum charge for the capacitor in this experiment?
4. What are some factors that could account for the percent difference between the stated and experimental values?