

# RC Circuits and Square Waves

## Equipment Needed:

- |   |           |
|---|-----------|
| 1 RLC Circuit Experiment Board          | Demo Cart |
| 1 Voltage Sensor Assembly               | Demo Cart |
| 1 Multimeter                            | Demo Cart |
| 1 Computer Cart/Interface and Power Amp |           |

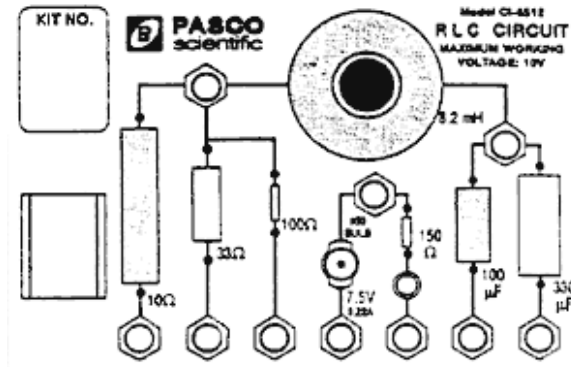


Figure 1: Component Board

Table 1: Component Values by Circuit Board

Ckt Board #	Capacitor( $\mu\text{F}$ )		Inductor(mH)	
	100 $\mu\text{F}$	330 $\mu\text{F}$	without core	with core
1	102.5	330	8.06	20.9
2	99.3	330	7.91	20.3
3	104.5	330	7.92	20.3
4	103.3	330	7.92	20.3
5	104.7	330	8.1	20.5
6	103	330	7.9	20.4

## Purpose

This experiment displays the voltage across the capacitor and the current so that the behavior of a capacitor can be studied.

## Theory

When a DC voltage is applied to a capacitor and a resistor in series charge will start to accumulate in the capacitor. Over time, when the capacitor is fully charged, the maximum charge on the capacitor is given

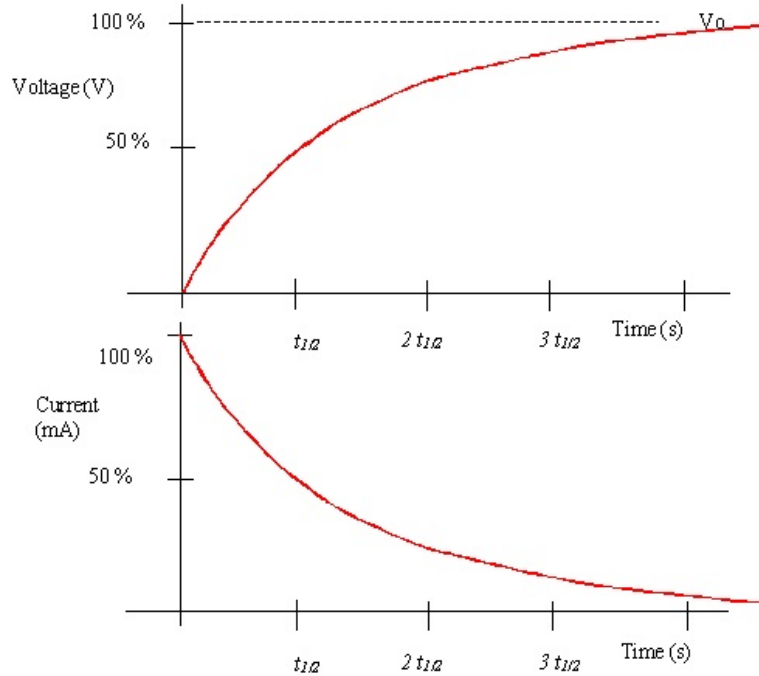


Figure 2: The voltage and the current of a capacitor during the charging process

by:

$$q_{max} = CV_0$$

where  $V_0$  (sometimes written as  $\mathcal{E}$ ) is the applied voltage and  $R$  is the total resistance in the circuit. But it takes time to charge the capacitor. As a function of time, the charge on the capacitor is given by:

$$q(t) = CV_0(1 - e^{-\frac{t}{\tau}})$$

where  $\tau = CR$ . The capacitive time constants is a measure of how long it takes the charge to be established. One time constant is the time it takes for the current to rise to 63% of its maximum value (or fall to 37% of its maximum). The *half life*  $t_{1/2}$ , which is the time for the charge to rise or fall to half its maximum is related to the time constant by:

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

The voltage across the capacitor is given by:

$$V_C = \frac{q}{C} = V_0(1 - e^{-\frac{t}{\tau}})$$

After a time  $t \gg \tau$ ,  $q_{max} = CV_0$  is established and the voltage across the capacitor is equal to the applied voltage,  $V_0$ . The voltage across the resistor is zero. If, after the maximum charge is established, the voltage source is turned off, the charge will then decrease exponentially to zero.

DC Voltage applied:      DC Voltage turned off:

$$\begin{array}{ll}
 q = q_{max}(1 - e^{-\frac{t}{\tau}}) & q = q_{max}e^{-\frac{t}{\tau}} \\
 V_C = V_0(1 - e^{-\frac{t}{\tau}}) & V_C = V_0e^{-\frac{t}{\tau}} \\
 I = \frac{V_0}{R}e^{-\frac{t}{\tau}} & I = -\frac{V_0}{R}e^{-\frac{t}{\tau}}
 \end{array}$$

## Summary

At any time, Kirchoff's Loop Rule applies: The algebraic sum of all the voltages around the series circuit is zero. In other words, the voltage across the resistor plus the voltage across the capacitor will add up to source voltage.

## Procedure

1. Connect the circuit as shown in Figure 3.
2. Connect the DIN plug of the voltage sensor to channel A on the interface box. Connect the banana plugs of the voltage sensor across the capacitor. Make sure the banana plug are not connected where the wires are insulated.

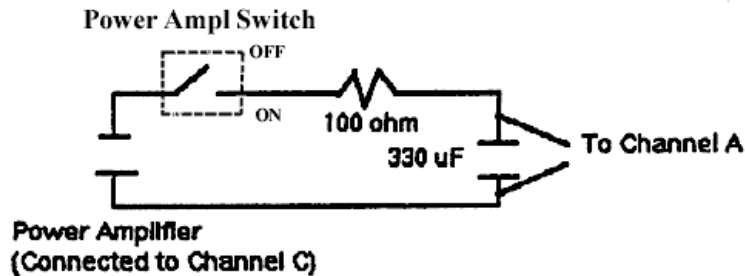


Figure 3: *RC* Circuit

3. Turn on the interface box and computer. Choose the program "Data Studio" on the computer. Click on "Create Experiment" after the program begins.
4. The Experiment Setup window automatically opens. Click on the image of channel A. From the popup list scroll all the way down to select Voltage Sensor and click OK. Under Sampling Rate, choose 4000. This tells the computer how often it should read data during a run.
5. Click on the power output (the rightmost terminal on the image) and a small popup window named Signal Generator should open. Select Square Wave instead of the default Sine Wave. Change the output frequency to 2Hz. You may keep the default amplitude of 5V. You do not have to close the Signal Generator window when you are done, but you may if you wish to do so.
6. Go back to the Experiment Setup window. Click on the Sampling Option... to open another popup window. Click on the tab Automatic Stop, select Time and set it to 1s. Click OK.

7. Close the Experiment Setup window. Anytime you wish to make changes to the setup you can click on Setup on the to left hand corner of the main window.
8. Under Display, you see the item Graph. Double click on it and a Data Source window opens. Click on Voltage, ChA (V) and select OK. A blank graph should open.
9. Under Display, triple click on Graph 1 and change its name to “Capacitor Voltage”.
10. Under Display, double click on graph again, this time select Output Voltage (V) as your data source. Again triple click to rename the graph to “Output Voltage”. Now you are ready for data collection.

## Capacitor Voltage in an $RC$ Circuit

1. Click Start and the experiment will begin to run. It will stop automatically after 1s based on your earlier setup specification.
2. Under Data, double click on Run #1 under Voltage, ChA (V). A Data Properties window opens. Click on the General tab and change Variable Name to “Capacitor Voltage” and click OK.
3. Under Data, double click on Run #1 under Output Voltage (V). A Data Properties window opens. Click on the General tab and change Variable Name to “Output Voltage” and click OK.
4. You should see a graph similar to Figure 4. You should see the voltage decaying from a positive value to a negative value. Half way between the maximum and the minimum voltage is  $V_C = 0$ .
5. Find the capacitive time constant by first measuring the half-life  $t_{1/2}$  on the graph of the voltage versus time.
6. Magnify the decaying part of the curve. Then record the time  $t_1$  at the peak. Then look at the part of the curve where  $V_C = 0$ , measure the time  $t_2$ . The half-life is given by  $t_{1/2} = t_2 - t_1$ . Record your results in Table 2 below.
7. Repeat the experiment two more times with your choice of resistor and capacitor, you may have to change the frequency (between 1Hz to 5Hz) of the square wave to make the charging/discharging curve clear.

Figure 4: Voltage across the capacitor

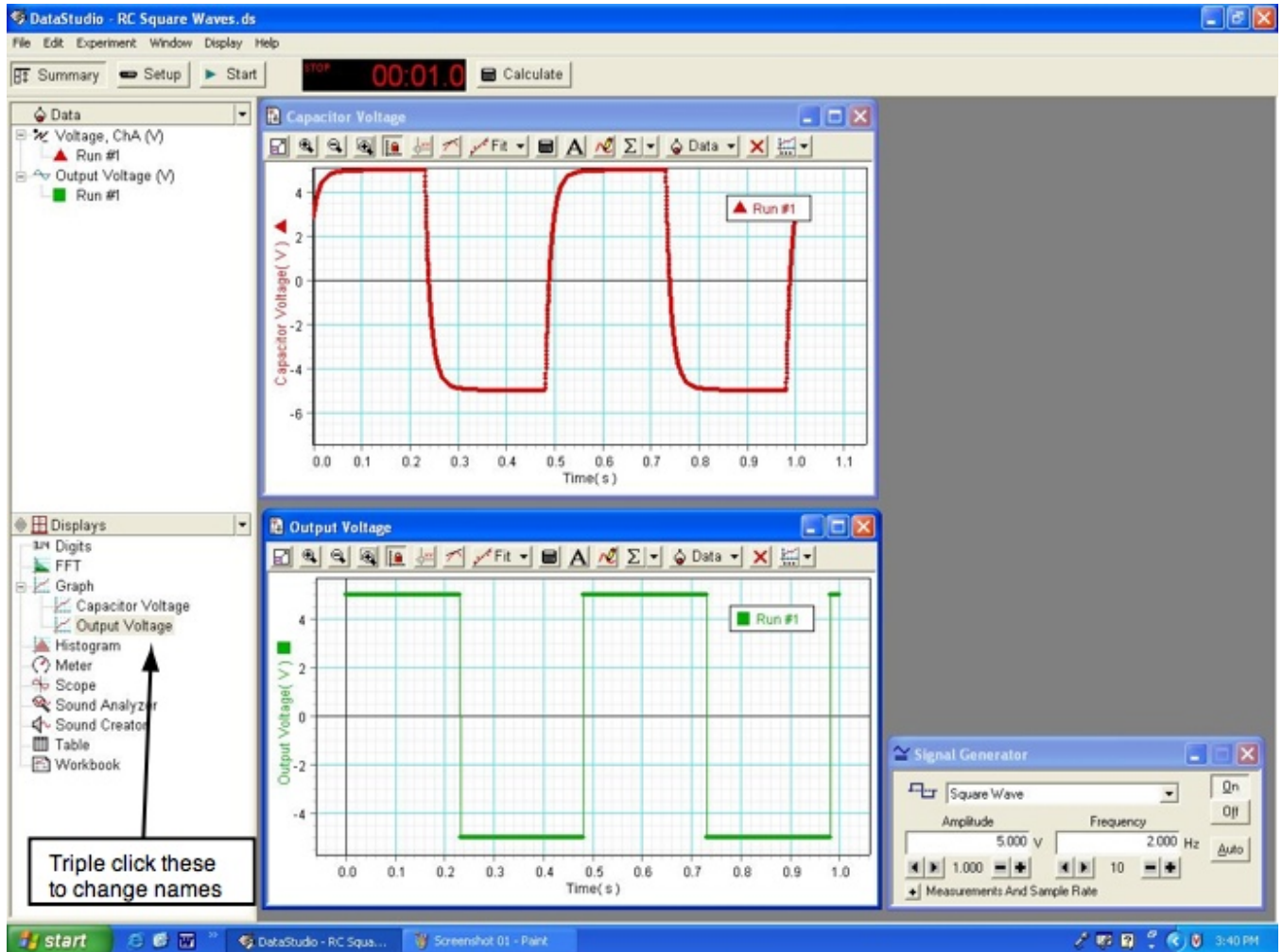


Table 2: Capacitance

	Trial 1	Trial 2	Trial 3
$V_0$			
$R$			
$t_1$			
$t_2$			
$t_{1/2} = t_2 - t_1$			
$\tau_{computer} = \frac{t_{1/2}}{\ln 2}$			
$C_{computer} = \frac{\tau_{computer}}{R}$			
$C_{measured}$			
Percentage Error $C_{computer}$ and $C_{measured}$			

$C_{measured}$  is given in Table 1.