Experiment 14
Time Constants - Series RC Circuit with DC Applied

EL 111 - DC Fundamentals

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Objectives:

For the student to measure current changes in a resistive-capacitive series circuit, then using the measured current to determine resistor and capacitor voltages, next to plot these changes on linear graph paper, and last to verify the experimental results by calculation.

Equipment and parts:

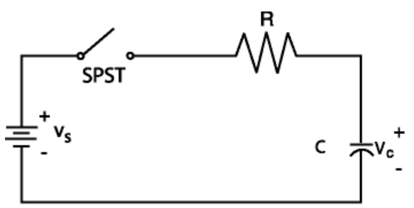
- Meters: Milliammeter or Handheld MM such as the Agilent 971A
- Power Supply: E3631A Triple Output DC power supply
- Resistor: 16 kΩ
- Capacitor: 7,500 µF, 35 V or 50 V (electrolytic)
- Misc: Stopwatch, clock or watch (with second hand); Alligator Lead

> ***Note to Instructor:*** *Source voltage V_S, R and C are chosen to give a maximum current just under 2.000 mA, and a time constant of about 2 minutes. Other values of R, C and V_S may be used, as needed, depending on the equipment and components available.*

Information:

RC time constant circuits are used extensively in electronics for timing (setting oscillator frequencies, adjusting delays, blinking lights, etc.). It is necessary to understand how RC circuits behave in order to analyze and design timing circuits.

In the circuit below with the switch open, the capacitor is initially uncharged, and so has a voltage, vc, equal to 0 volts. When the single-pole single-throw (SPST) switch is closed, current begins to flow, and the capacitor begins to accumulate stored charge. Since Q=CV, as stored charge (Q) increases, so too does the capacitor voltage (vc) increase. However, the growth of capacitor voltage is not linear; in fact, it's called an exponential growth. The formula which gives the instantaneous voltage across the capacitor as a function of time, is:



$$v_C = V_S\left(1 - e^{(-t/\tau)}\right)$$

This formula describes ***exponential growth***, in which the capacitor voltage is initially 0 volts, and grows to a value of $\mathbf{V_S}$ after enough time has gone by. It is important to understand each term in this formula in order to be able to use it as a tool.

The use of the above formula in any RC circuit is only possible if the symbols in the equation are fully understood. The following definitions describe each of these symbols:

$\mathbf{V_S}$ = The maximum possible voltage change that will occur in the circuit during a time lapse of five time constants. For the voltage versus time graph shown below, V_S is 100 volts. (In the experiment you will do, V_S is 30 V.

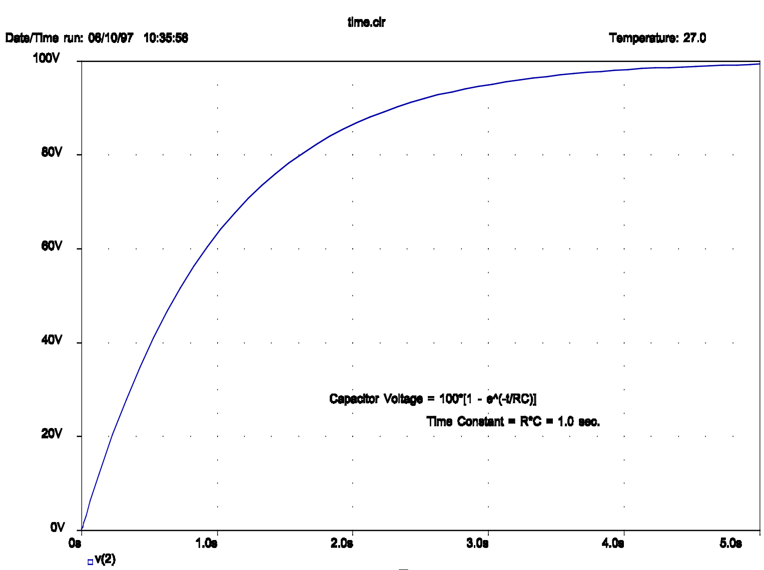
t = The lapsed time in seconds that the circuit voltages and currents have been changing. For the voltage versus time graph shown below, t is in seconds.

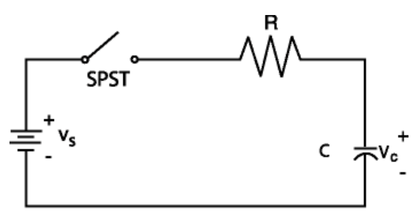
τ = The **time constant** of the circuit, and the symbol is the lower-case Greek letter TAU. τ is the product of R and C (τ = RC) in ohms and farads, and the unit of τ is seconds. R is the total resistance in series with the capacitor, and C is the total capacitance of the circuit.

$\mathbf{v_C}$ = The capacitor voltage at any instant of time after the switch closes.

e = The base of natural logarithms, a constant which equals about 2.7183.

Figure 1 below is a graph of the capacitor voltage in a circuit where the time constant, τ, is 1.0 second, and $\mathbf{V_S}$ is 100 volts. Notice that after about 5 seconds (i.e. 5 τ) the capacitor voltage has grown **from** 0 volts **to** 100 volts, and the capacitor voltage is 100 volts and appears to have stopped changing. This is a condition called "**steady-state**". While in theory it takes an infinite time for "steady-state" conditions to be reached, in practical terms, after five time constants using practical lab instruments it is nearly impossible to measure any changes occurring.

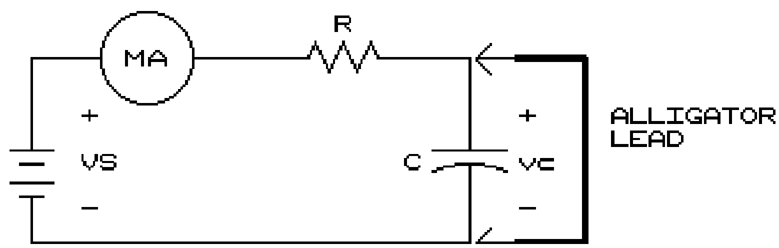




Graph of capacitor voltage (vc) versus time

Procedure:

1. Construct the circuit shown below. Let R = 16 kΩ, C = 7,500 μF (35 V or 50 V electrolytic), V_S = 30 V, and use an alligator lead jumper as the short circuit across the capacitor.



2. Record the initial current reading of the milliammeter; it should be closed to "full-scale" for a digital meter on the 2 mA range (I = [30 V/16 kΩ]). Express the current in units of μA.

Initial current = __________ μA

Write the above initial current value in on the table on page 5, in the row for t = 0.0 seconds, for both Trial One and Trial Two.

3. Since it takes five times constants for a capacitor to fully charge, calculate one time constant and five time constants for this circuit; if necessary, change your data table to ensure that data is taken for no less than five time constants.

$$1\tau = RC =$$

$$5\tau = 5(RC) =$$

Now get ready for some serious sustained data taking! This is best done with a partner, but can be done successfully by one person. You will need a watch, (preferably a stopwatch), or an analog wall clock with a second hand. The instant you remove the alligator jumper, the current (which *had been* flowing through the jumper) flows through the capacitor. This is time = 0, and you will begin recording data every 0.5 minute (30 seconds) after that instant.

4. Every thirty seconds, record the current under the **Trial One** column, until that column is filled, on the data table on page 5 of this experiment.

5. Now repeat steps 3 and 4, because obtaining accurate, repeatable readings when the current is changing is difficult. The results of **Trial One** and **Trial Two** will then be averaged. **Be sure to replace the alligator jumper before starting Trial Two**. There will be a significant spark the moment you put the jumper across the capacitor, resulting from the rapid discharge of the energy stored in the capacitor, which brings its voltage back to 0 volts.

6. Average the currents (Trial One and Trial Two) for each row in the data table, and enter that average current in the table.

7. At each time in the table, using the average current at that time, calculate the resistor voltage, using V_R = I(R); this is Ohm's Law. Be sure to used the measured value of R.

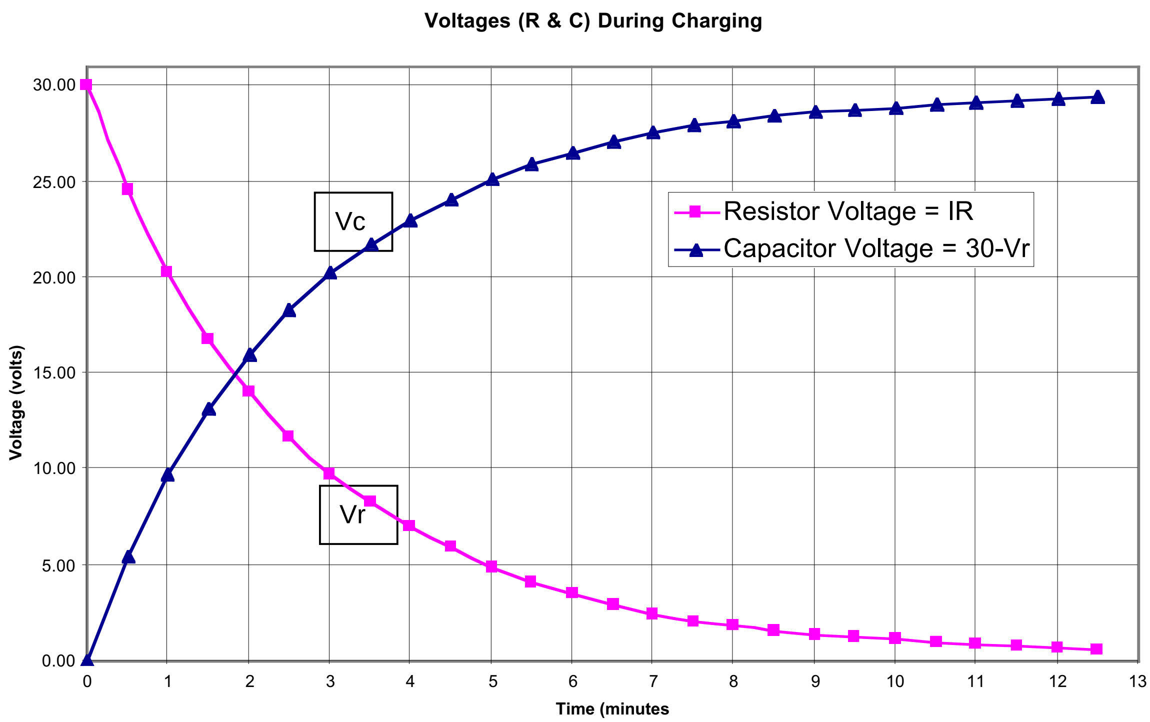
8. Now, for each time in the table, using the calculated resistor voltage, calculate the capacitor voltage using $V_C = (V_S - V_R)$. Be sure to used the measured value of R. This is just Kirchhoff's Voltage Law applied: the sum of the resistor voltage and the capacitor voltage must equal the source voltage.

9. **It's plotting time!** Now you are going to construct a single graph, with two curves (dependent variables) on it. You will plot **v_R vs. time**, and **v_C vs. time**. In setting up the axes of your graph, note that the time axis should be in **minutes**. Also, realize that:

   - the resistor voltage starts at V_S and **exponentially decays** to nearly 0 volts.
   - the capacitor voltage starts at 0 volts and **exponentially grows** to nearly V_S volts.
   - because of this, only one vertical (y, ordinate or dependent) axis is needed.
   - a full sheet of commerical graph paper must be used, data point indicators are required on all plotted points, and a French curve must be used to construct the two curves.

On the next page is a sample graph, to help you in constructing your own. The time axis on it goes out a bit longer than the 11 seconds specified for your experiment.

When your graph is done, it should look something like the following graph made with Micosoft Excel (except that yours will be done by hand, and will look lots neater ☺):



Notice that Vc starts at 0 volts, and rises exponentially to 30 volts (the supply voltage). Vr begins at 30 volts, and exponentially decays to 0 volts.

Time	Current			Resistor Voltage	Capacitor Voltage
(sec)	Trial One (μA)	Trial Two (μA)	Average (μA)	(V)	(V)
0.0					
0.5					
1.0					
1.5					
2.0					
2.5					
3.0					
3.5					
4.0					
4.5					
5.0					
5.5					
6.0					
6.5					
7.0					
7.5					
8.0					
8.5					
9.0					
8.5					
9.0					
9.5					
10.0					
10.5					
11.0					

10. After the graphs have been completed, do the following:

a. Describe the capacitor voltage behavior from 0 through 5τ, in terms of initial and final voltage magnitude, linearity and rate of change.

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b. Describe the resistor voltage behavior from 0 through 5τ, in terms of initial and final voltage magnitude, linearity and rate of change.

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c. To how many volts has v_C charged in one time constant? ____________________

d. To what % has the capacitor charged to at this point? ____________________

e. Using the equation in the information section of this experiment, show the calculation of v_C for a time equal to one time constant.

f. How many volts are across the resistor at the end of one time constant? ____________

What % is this of the total possible voltage change? ____________________

g. Read from the graphs the values of the capacitor and resistor voltage at 4 minutes.

V_R = ____________ V_C = ____________

h. Calculate the resistor and the capacitor voltage at 4 minutes.

v_C =

v_R =

i. From the results of g and h above, what do you conclude about the accuracy of your graphs?

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