RC Time Constants

Experiment

Objective:

In this experiment you will demonstrate how variations in the value of resistance and capacitance in and RC circuit effect the charge time of the capacitor. You'll build a test circuit using a solderless circuitboard and experiment with various combinations of resistance and capacitance. Using a stopwatch, you will measure the voltage across the capacitor at one second intervals up until the capacitor is fully charged. Plugging the time hacks into a spread sheet, you'll then model a performance curve of your experiment and compare it to the calculated baseline value in the model.

Required Materials:

Digital Voltmeter
Solderless Circuitboard
Decade Resistance Box
SPST Switch
4.7uF, 10uF, 100uF, and 1000uF Electrolytice Capacitors
Aligator Lead
Stopwatch
PC running Microsoft Excel.

Theory:

Connecting an external source of electromotive force (emf… or voltage), such as a battery or a power supply across the capacitor, will transfer charge to the plates of the capacitor until the voltage across the capacitor equals the applied emf. If the applied emf is suddenly removed while the two plates of the capacitor are connected by an external circuit, electrons will flow from the negative plate of the capacitor to the positive plate through the circuit (very much like water flowing downhill).

The discharging capacitor acts as a time-dependent source of emf (V(t)) … or a tempory battery. It supplies a current (I(t) = V(t)/R) through the resistor. It's just like a battery, except that there is no active chemical process to maintain the difference in potential across it. V(t) finally vanishes when there is no longer any excess charge on either plate. It can take quite a long time for the capacitor to completely discharge. The smaller the capacitor voltage, the more slowly the charge leaves the capacitor plates. In other words, the rate at which the charge leaves the capacitor is proportional to the voltage across the capacitor.

$$Q = VC$$

The equation above shows that the voltage will decrease at the same rate as the charge, so the discharge of capacitor voltage is an example of a phenomenon common in nature, where the rate at which a quantity changes is proportional to the magnitude of the quantity at any particular instant. With calculus, it is easy to show that this kind of a relationship between a quantity and its rate of change means that the quantity depends "exponentially" on time. Two mathematical versions of the relationship between capacitor voltage and time while the capacitor is discharging are:

$$V_T = Vo^{\,e-t/\tau}$$

$$\ln\left(\frac{V(t)}{Vo}\right) = -\frac{t}{\tau}$$

where t is the time in seconds measured from the time when V is equal to V0, and e (» 2.71828) is the base of the natural logarithms. The quantity τ is called the time constant of the circuit and is equal to the product of the resistance and the capacitance:

$$\tau = RC$$

Note that t is expressed in seconds since the quantity in the exponent must be dimensionless. The time constant is the amount of time it takes for the capacitor to charge / discharge to 36.8% of its initial value, because when t = τ,

$$V_T = Vo^{\,e-t/\tau}$$

becomes:

$$Vt = V_O e^{-1} \approx 0.368 V_O$$

Problem 1 A circuit like the one in Figure 1 has a total capacitance of 15.0 μF and a total resistance of 512 kΩ.

(a) What is the time constant of the circuit in seconds?
(b) If the voltage on the capacitor is 10.0 V before connecting it to the resistor, how long will it take after connecting the capacitor to the resistor for the voltage to drop to 3.68 V?

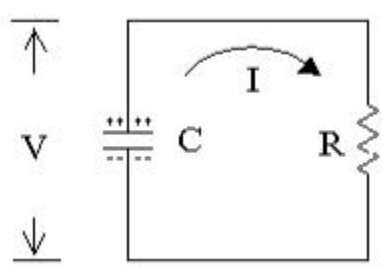

Figure 1 Simple RC Circuit

The equation below gives the time dependence of the capacitor voltage during discharge. The time dependence when the capacitor is charging is different, and is given by

$$V(t) = V_{app}\left(1 - e^{-t/\tau}\right)$$

Where Vapp is the applied (charging) potential, and **τ** is the time constant.

General Formula

If all capacitors started with a charge of zero (0) volts, the formulas above would be all you needed to solve for the charge time of an RC circuit. In the real world, a capacitor may have a starting voltage not equal to zero, and then again may not have voltage applied to it for a long enough period of time to charge fully to the supply voltage. In order to accommodate the many types of situations that may occur when charging or discharging a capacitor in a DC circuit, the following general formula is used:

$$Vc = Vi + Vd(1 - e^{-t/\tau})$$

Problem 2. Using Eq (2a) or (2b), determine algebraically how much time measured in time constants (t) it will take to discharge a capacitor in an RC circuit to 1% of its initial voltage V0, when V = 0.01V0.

Problem 3. Using Eq. (5), determine algebraically how much time it will take in terms of time constants to charge a capacitor in an RC circuit to 99% of the applied potential Vapp, when V = 0.99Vapp.

Procedure:

1. ( ) Open the Excel Model for RC Time Constants – Experiment Sheet.
2. ( ) Select standard RC values for a full charge lasting more than 15 seconds.
3. ( ) Construct the circuit in Figure 2. on a solderless circuit board with the selected RC.

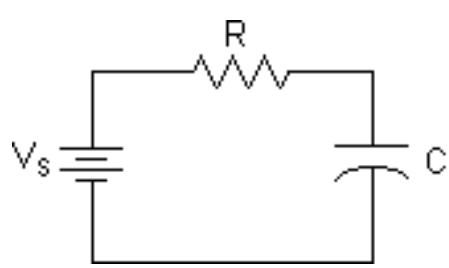

Figure 2 Test Circuit

4. ( ) Adjust Vs to precisely 10vdc.
5. ( ) Connect a digital voltmeter across the capacitor observing polarity.
6. ( ) Make sure the SPST switch is open.
7. ( ) Temporarily connect the aligator lead shorting out the capacitor and the remove it.

You are going to measure the charge time of the capacitor at 1 volt increments. You will need a stopwatch using the “split” or “lap” button to measure and record the time when the voltmeter reads 1V, 2V, and so on until the voltmeter reads 9.5 volts. You will notice that neither the spread sheet model nor the test circuit actually reaches the 10 vdc applied voltage.

8. ( ) With the capacitor fully discharged, close the switch starting the trials.
9. ( ) Record the values and then enter them into the spread sheet under Trial 1.
10. ( ) Completely discharge the capacitor as you did in step 7.
11. ( ) Repeat steps 8 through 10 to complete Trails 2 and 3.

The spread sheet model will chart the results of your experiment plotting an exponential curve over the calculated value. They should be similar. If not, check your experiment and try again.

Conclusion:

Changing the value of the resistor or capacitor in an RC circuit changes the time constant and therefore the charge and discharge time of the capacitor. The charge rate is exponential rather than linear. RC circuits are used as electronic filters and oscillators. Understanding, calculating, and measuring time constants is necessary to determine flaws in communication circuitry as well as in the design oscillator and filter circuits.