RC Circuits and The Oscilloscope

Objective

In this experiment, the time constant of an RC circuit will be measured experimentally and compared with the theoretical expression for it. Students will also become familiar with using the oscilloscope to make voltage measurements.

Theory

If a circuit is composed of both resistors and capacitors, the current flowing in the circuit and the charge on the capacitors no longer remains independent of time. The case we will consider is a capacitor, initially charged, connected in series to a resistor and a switch which is initially open. A circuit diagram of this case is shown in Figure 1.

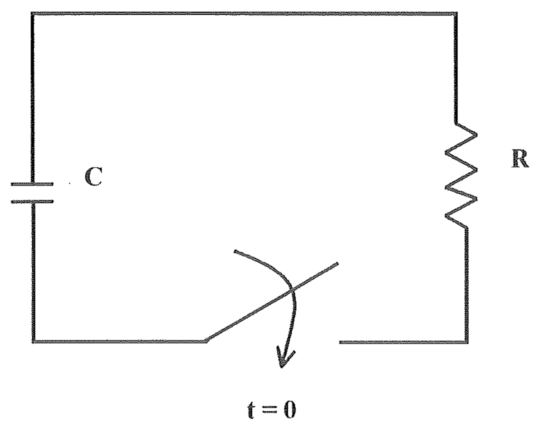

Figure 1: Discharging Capacitor Case Circuit Diagram

In this case, when the switch is closed, the capacitor discharges causing current to flow in the circuit. The energy stored in the capacitor is dissipated by the heating of the resistor. The voltage, current, and charge dissipate exponentially in time. These processes are represented mathematically by the following set of equations,

$$Q(t) = CV_0 e^{-t/\tau} \quad (1)$$
$$I(t) = \frac{V_0}{R} e^{-t/\tau} \quad (2)$$
$$V_C(t) = V_0 e^{-t/\tau} \quad (3)$$
$$V_R(t) = V_0 e^{-t/\tau}. \quad (4)$$

In these equations, Q is the charge on the capacitor as a function of time, C is the capacitance of the capacitor, t is the time increment, I is the current in the circuit, V_C is the voltage across the capacitor, and V_R is the voltage across the resistor. The variable τ is the time constant of the circuit. It governs the rate for which things can things happen in the circuit. If τ is small, things happen quickly in the circuit, meaning voltage builds up quickly on the capacitor and the current falls rapidly. Mathematically, the time constant is the product of the value of the resistance and the capacitance,

$$\tau = RC.$$

Since we are using a time varying signal, we will observe both the charging and discharging nature of the capacitor. In this experiment, the time constant, τ, for a discharging RC circuit will be measured using an oscilloscope. From Equation 4, the voltage across the capacitor is equal to e^{-1} when the time is equal to the time constant. Numerically, e^{-1} can be approximated, to within a 2% difference, by the fraction $^3/_8$,

$$V_C(t) = V_0 e^{-t/\tau} \longrightarrow \frac{V_C(t=\tau)}{V_0} = e^{-1} \approx \frac{3}{8}. \qquad (5)$$

In other words, when a time interval equaling the time constant has passed, the voltage across the capacitor is $\frac{3}{8}$ of the initial voltage. The oscilloscope will be used to measure how long it takes for the voltage to fall to this fraction of the initial voltage. The time constant for various circuit combinations of resistor and capacitors will be measured experimentally. A comparison between theoretical and experimental values of the time constant will be determined after recording appropriate measurements of the analyzed circuits.

Procedure and Data Analysis

Oscilloscope Exercises

In this series of exercises, various simple measurements will be made in order for you to get acquainted with the oscilloscope.

Period of Sinusoidal Voltage Measurement

In this section, students will learn how to make time measurements using the oscilloscope by measuring the period of a sinusoidal voltage source.

1. Connect the Function Generator to the power strip on the breadboard. Connect the oscilloscope as you would connect a Voltmeter, in order to measure the voltage as a function of time.

2. Switch the Function Generator "ON." Change the "Frequency" setting of the function generator to 100.00 Hz. Note, the frequency displayed is the frequency of the output voltage.

3. Adjust the "AMPLITUDE" control on the Function Generator so that the "Pk-Pk" measurement is between 2.50 V and 3.50 V.

5. Turn the oscilloscope "On". Set the **VOLTS/DIV** to 1.00 V. Adjust the **SECONDS/DIV** setting until a standing wave appears on your screen.

6. Record the "FREQUENCY" value from the Function Generator on your data sheet. Calculate the period from this value using the equation and record the result on your data sheet.

$$T = \frac{1}{f} \qquad (6)$$

7. Record the period of oscillation value from the oscilloscope on your data sheet.
8. Adjust the frequency of the Function Generator to 2000 Hz. Repeat steps 1 through 7.
9. Switch the waveform from a Sinusoidal Wave to a Square Wave. Repeat steps 1 through 7 again.
10. Turn off the Function Generator.

RC Time Constants

In this section, the oscilloscope will be used to measure the time constant of RC circuits; circuits containing *resistors* and *capacitors* are used in series and parallel arrangement to measure time constants.

1. Use a multimeter to measure the values of a 10 $k\Omega$ resistor. The color code values are *NOT* significant for this experiment. Record the measured value on your data table.

2. Combine the 10 $k\Omega$ resistor and the 0.01 μF capacitor in a series circuit with the function generator. Refer to the circuit diagram in Figure 2. Connect the oscilloscope so that it measures the voltage drop across the capacitor. ***Be careful that the Function Generator ground is connected to the Oscilloscope ground.***

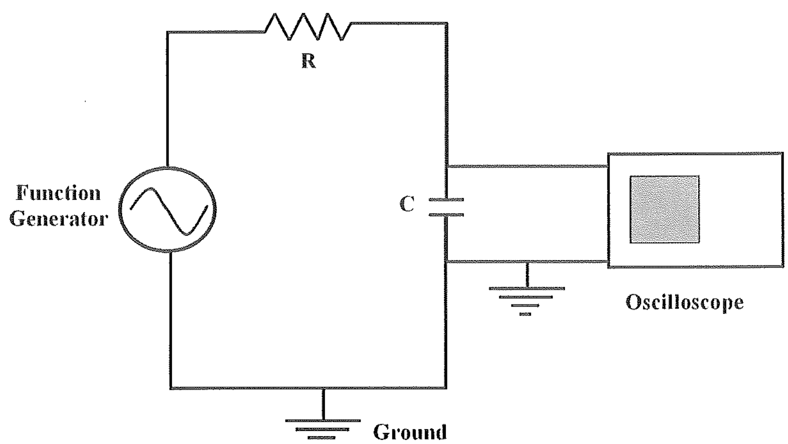

Figure 3: Circuit Diagram for RC Circuit with Oscilloscope

3. Have the TA check your circuit before you turn on the Function Generator. Change the "Frequency" control to 1000 Hz. Change the "WAVEFORM" selection to the square wave pattern.

4. Adjust the "AMPLITUDE" control on the Function Generator so that the "Pk-Pk" measurement 4 Volts.

5. Create a standing wave pattern by adjusting the **SEC/DIV** control. Refer to Figure 3.

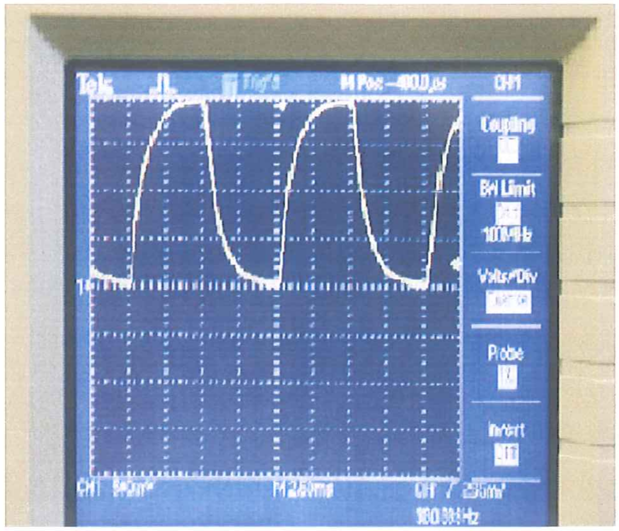

Figure 3: Trace of Voltage Drop Across Capacitor of RC Circuit

6. Measure and record the time constant τ corresponding to when the initial voltage has decayed to 3/8 of the initial voltage. You will first need to determine the time-scale. This value is centered at the bottom of the display. The experimental time constant is determined from the number of divisions along the horizontal. Record this value on your data sheet.

$$\tau_{exp} = \frac{numberofdivisions}{5}(time\ scale\ value) \tag{7}$$

7. Calculate the theoretical value of the time constant using measured values of resis-tance and capacitance. Record this on your data sheet.

$$\tau_{theo} = RC. \tag{8}$$

8. Calculate the percent difference between the experimental and theoretical values for the time constant. Record this on your data sheet.