LAB 7
RC Circuits

OBJECTIVES

1. Analyze the transient behavior of a series RC circuit.
2. Determine the RC response to a square-wave input voltage.
3. Predict and measure the time constant τ_C of an RC circuit.
4. Experimentally calculate the capacitance of an unknown capacitor.

EQUIPMENT

Capstone (Signal Generator & Voltage Sensors), 1000 μF capacitor, 0.22 μF capacitor, capacitor of unknown capacitance, 35.7 kΩ resistor, decade resistor, breadboard, wires, DMM, stop watch, power supply.

THEORY

When a *dc* voltage source is connected across an uncharged capacitor, the rate at which the capacitor charges up decreases 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 voltage of the capacitor has two different responses – a charging phase and a discharging phase:

$$V_C(t) = \begin{cases} \varepsilon\left(1 - e^{-t/\tau_C}\right) & \text{Charging phase} \\ \varepsilon\, e^{-t/\tau_C} & \text{Discharging phase} \end{cases}$$

where ε is source voltage and $\tau_C = RC$ is the time constant. Because of the series nature of the RC circuit, during the charging phase, the sum of the voltage drops across the capacitor and the resistor must equal the voltage supplied by the power supply:

$$V_C + V_R = \varepsilon \quad \text{Charging phase}$$

PROCEDURE

Part 1A: Stop Watch Analysis of Charging RC Circuit

(a) *Use the DMM to measure the actual capacitance and resistance of the 1000 μF capacitor and the 35.7 kΩ resistor.* Use the DMM to set the output voltage of the power supply to 10.0 V.

(b) Construct an RC circuit consisting of a 1000 μF capacitor in series with a 35.7 kΩ resistor. Also include a DMM to measure the voltage across the capacitor.

(c) *Calculate the theoretical time constant,* $(\tau_C)_{\text{thy}}$, *of the RC circuit using the actual values of C and R.*

(d) Turn on the power supply and use a stopwatch to *record the voltage across the capacitor at 5.0 s intervals until the capacitor is fully charged (after about 5 or 6 time constants). Plot the voltage across the capacitor as a function of time using either Excel or Google Sheets*

(e) *Determine the approximate time constant from the voltage versus time data and compare it with the theoretical time constant using a precent difference. How do they compare?*

Part 1B: Capstone Analysis of Charging RC Circuit

(f) Use the DMM to set the output voltage of the power supply to 5.0 V.

(g) Construct an RC circuit consisting of a 1000 μF capacitor in series with a 35.7 kΩ resistor. Use two voltage sensors and Capstone to measure the voltage across the resistor and the voltage across the capacitor.

(h) Turn on the power supply and *plot the voltage across the capacitor and the voltage across the resistor as a function of time on the same graph*. Continue to take data for at least 5 time constants.

(i) *Determine the time constant* $(\tau_C)_{\text{expt}}$ *from the voltage versus time plots. Compare* $(\tau_C)_{\text{expt}}$ *with the theoretical time constant* $(\tau_C)_{\text{thy}}$ *from Part (1c) using a percent difference. How do they compare?*

(j) *Measure the voltage across the capacitor and the voltage across the resistor at* $t = \tau_C, 2\tau_C, 3\tau_C, 4\tau_C,$ *and* $5\tau_C$. *At each time, calculate* $V_C + V_R$. *Does* $V_C + V_R = \varepsilon$ *at each time? Why or why not?*

Part 2: Oscilloscope Analysis of a Charging RC Circuit

In this part of the experiment, we will use Capstone to output a low frequency "positive-only" square wave (0 to 5 V). This waveform imitates the action of charging and then discharging a capacitor by connecting and then disconnecting a *dc* voltage source.

(a) Use a DMM to set the resistance of the decade resistor to 200 Ω.

(b) Construct the series RC circuit consisting of a 0.22 μF capacitor in series with the decade resistor. Use the Capstone output as your power supply and set the Signal Generator to produce a 5 V "positive square wave" with a frequency of 500 Hz.

(c) Use one Voltage Sensor to observe the voltage across the capacitor (V_C) and another Voltage Sensor to measure the output voltage from Capstone (V). Use Capstone to display both the V_C and V vs. time on the same plot.

(d) *Calculate the theoretical values for the voltage across the capacitor at $t = 1\tau_C$, $3\tau_C$, and $5\tau_C$.*

(e) Use the built-in analysis tools to display to find the capacitor's voltage for $t = \tau_C$, $3\tau_C$, and $5\tau_C$. *Record your data in a table. Compare the experimental and theoretical values for the voltage across the capacitor at each time using a percent difference. How do they compare?*

(f) For each of the following modifications, first predict how the V_C waveform will change, *then make the modification and compare the observed waveforms with your predictions:* (a) decrease the *amplitude* of the signal generator output, (b) increase the *frequency* of the signal generator output, and (c) increase the *resistance* of the decade resistor.

Part 3: Calculating the Capacitance of an Unknown Capacitor

(a) Use the DMM to set the output voltage of the power supply to 5.0 V.

(b) Construct an RC circuit consisting of a capacitor (with unknown capacitance) in series with a 35.7 kΩ resistor. Use two voltage sensors and Capstone to measure the voltage across the resistor and the voltage across capacitor.

(c) Turn on the power supply and *plot the voltage across the capacitor and the resistor as a function of time on the same graph.* Continue to take data until the capacitor is fully charged (after about 5 or 6 time constants).

(d) Measure the voltage across the capacitor and the voltage across the resistor at 3 different times. At each time, calculate $V_C + V_R$. Does $V_C + V_R = \varepsilon$ at each time? Why or why not?

(e) From the curve of the voltage across the capacitor as a function of time, *measure the time constant of the RC circuit. From τ_C, calculate the capacitance of the capacitor.*