LAB 20. RC CIRCUITS

Problem

How does a capacitor's votage change as it charges and discharges?

How can we model actual RC circuits?

Equipment

DC Power supply, breadboard, switch, large capacitor, connector wires, resistors, multimeter, timer

Background

A capacitor in series with a resistor charges and discharges as a decaying exponential. If the capacitor's starting voltage is V_1 and the voltage across the capacitor + resistor is switched to V_2 at time $t = 0$, the capacitor's voltage V decays as $V = V_2 + (V_1 - V_2)\, e^{-t/\tau}$, where τ is the time constant of the system.

Activity

Repeat the charging and discharging experiments at least twice for good statistics. Ideally, examine at least two capacitors, each combined in series separately with at least two different resistors. If time is short (isn't it always?), you may run the charging experiments with just one Capacitor-Resistor combination, and run discharges only with the others.

Charging the capacitor

1. Measure and record the resistance of the resistor. Read and record the nominal capacitance of the capacitor.
2. Discharge the capacitor by shorting it. Set up a circuit so that the capacitor is in series with a resistor and the switch. **If the capacitor is polarized, make sure that it is connected so that its (+) terminal is at higher potential than its (−) terminal**. When you are ready to begin, turn on the DC power supply and verify its voltage with the voltmeter. Then set up the voltmeter to measure the voltage across the resistor.
3. Close the switch. At the same time, start the timer. Every five seconds, record the voltmeter reading. It may be helpful to observe the decay informally a few times to get an idea of the time interval you should allow between measurements.
4. Continue until the voltage reading is no more than 10% of its original reading.
5. When you are finished, short the capacitor to discharge it.

Charging the Capacitor again

1. Setup and run this the same as the previous activity, but this time monitor the voltage across the *capacitor*.

Discharging the capacitor

1. Set up the circuit so that the capacitor is in series with the resistor and switch. Connect the DC power source to the capacitor (**positive to positive, negative to negative**) and power up the capacitor. Verify that the capacitor is charged.
2. Set up the voltmeter to measure the voltage across the resistor.
3. Disconnect the power source from the capacitor.
4. Switch from charging to discharging the capacitor. At the same time, start the timer. Every five seconds, record the voltmeter reading.
5. Continue until the voltage reading is no more than 10% of its original reading.
6. When you are finished, short the capacitor to discharge it.

Other things to consider

Does the capacitor "leak," that is, do charges equilibrate through the capacitor itself, without linking the terminals to a circuit? If so, how can you determine that it is happening? How can you characterize and model this?

Is the voltmeter infinitely resistive, or does it allow some current to flow? If it does allow current to flow, how could we detect and model that?

How will the voltage across a capacitor behave if the capacitor is connected in series or parallel with another capacitor?

Data Processing

Transform your (V, t) data from V_R of the charging experiments and V_C of the discharging experiments to (ln V, t). Use a linear fit of the transformed data to find the time constant τ from each experiment. From these time constants and other information you have collected about the system, estimate the capacitance of the capacitors.). (What would you need to do to model V_C from a charging experiment?) Carry out any other analysis necessary to explain the data.

Lab Report

Report your observations and findings in a written report with sentences and paragraphs.

Abstract

Identify the circuits, your measurements, and what information you obtained from the measurements.

Purpose

What concepts are you intended to learn in this activity?

Theory

Here you get to explain how RC circuits theoretically should behave. This is also a good place to explain how non-ideal behaviors of components, such as current through the voltmeter and leakage of a capacitor, might affect the measurements.

Experimental

Identify the appearance and nominal capacitance of each capacitor you use. Identify the make and model of your multimeter. Explain briefly how you performed each type of experiment. Include circuit diagrams for each experimental circuit you used, showing all components including the meter.

Observations and data

Report the measured resistances. Show the plots of observed V (vertical axis) vs. time (horizontal axis). Also show plots of the transformed data— ln(V) vs. t—for the decreasing voltages, with their straight-line fits. Report the fit parameters—slope and intercept—for the best-fit lines.

Analysis and discussion

Explain the ln (V) plots and how you used them to estimate capacitances. Discuss the estimates of capacitance, including how different estimates for the same capacitor agree with each other and with the nominal capacitance. Discuss any possible measurement errors, and assess how well your mathematical model matches the measured behavior of the circuits.

Conclusion

Are you able to find reliable estimates of capacitances in this experiment? Does the model adequately describe the circuits?