Resistance and Capacitance in a DC Circuit

Objective

The purpose of this activity is to empirically observe the behavior of the current through a capacitor within an RC circuit.

Materials

1. Analog leads to Pasco Interface
2. Banana-to-banana wires
3. Fluke Digital Multimeter
4. Large aluminum component box
5. Pasco 850 Interface

Introduction

Consider the circuit in Figure 1. If the switch is placed in position 1, the circuit is complete and includes the battery. At this point, current flows through the resistor and capacitor. The capacitor acts like a charge reservoir. It can hold an amount of charge $Q_{saturation} = CV$, where C is the capacitance and V is the voltage across the source. As the current flows through the capacitor, the charge builds up in the capacitor. As the amount of charge in the capacitor approaches $Q_{saturation}$, the capacitor will have less room for additional charge, so the current will become less and less. If one were to keep the switch in position 1 for a long enough time, the capacitor would become (nearly) fully charged and the current would (nearly) cease to flow. In this case, the current is proportional to how much charge the capacitor can still accept—i.e., I $\propto$ $(Q_{saturation} - Q)$.

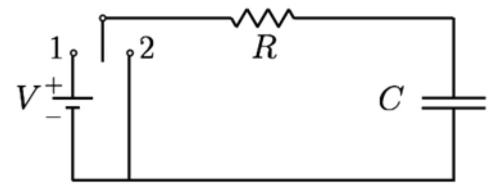


Figure 1

Now, suppose the capacitor is fully charged and the switch is placed in position 2. The capacitor will discharge through the resistor. At first, the capacitor will readily release its charge through the resistor—i.e., the current will be relatively high. As time progresses, the capacitor will have less charge to give away; consequently, the current will decrease over time. In this case, the current is proportional to the charge in the capacitor—i.e., $I \propto Q$.

Current is the instantaneous flow-rate of charge. In any situation where the instantaneous rate of change of a variable is directly proportional to the variable itself (like both cases above), the functional form (of the dependence on the independent variable) is an exponential curve. Therefore, the current will decay exponentially as a function of time in both cases above.

All exponential decays have a characteristic “half-life”. The half-life is the time that it takes for the

dependent variable to be reduced by a factor of 2 (half the original value). For both cases above the half-life is $t_{1/2} = RC\,ln(2)$ $t_{1/2} = RC\,ln(2)$, where R is the resistance of the resistor. For example, if the current is 1 amp at $t = 0$, it will be 0.5 amps at some time $t = t_{1/2}$ later, 0.25 amps at $t = t_{1/2}$ later, etc...
The potential across the resistor will always be proportional to the current. So, everything discussed above for current should work for voltage in the circuit above.

Procedure

You will be measuring two RC decay half- lives. The first will be long enough to measure using a multimeter and a stopwatch. The second half-life will be one that more typically would appear in electronic circuits and will require a voltage sensor and a signal generator, both of which will be provided by the Pasco 850 Interface.

Part 1

1. Open Pasco Capstone on the desktop of your lab computer.
2. In the "Tools" windows panel on the left side of the screen, click on "Hardware Setup". Click on the yellow circle around analog "Channel A" and select "Voltage Sensor". On the top far right of the interface, click on the yellow circle and select "Output Voltage-Current Sensor".
3. Click on "Signal Generator" in the "Tools" window panel. Select "850 Output 1" and change the "Waveform" to "DC".
4. Set the DC Voltage to 2.00 V and click "On".
5. In the "Displays" window panel to your right, double click on "Graph". Change the quantity being measured on the y-axis by clicking "Select Measurement" and choosing "Voltage, Ch A". Double -click on "Table"; change the measurement on the first column to "Time" and the second column to "Voltage, Ch A".
6. Insert a red banana-banana wire into the far-right jack on the interface (Output 1). This will be the positive (+) terminal of the voltage source.
7. Insert a black banana-banana wire into the ground jack immediately adjacent to the positive terminal. This will be the ground terminal of the voltage source. For now, we're finished setting up the interface.
8. Set up the circuit shown in Figure 3a on page 4. You're now ready to make measurements of the half-life of the RC circuit.
9. We intend to visually monitor the time and voltage every 15 seconds for 5 minutes. Therefore, be sure to set your sample rate to 15 seconds in the "Controls" panel at the bottom of your screen (circled portion in the image below using the arrow keys). Then click "Record".

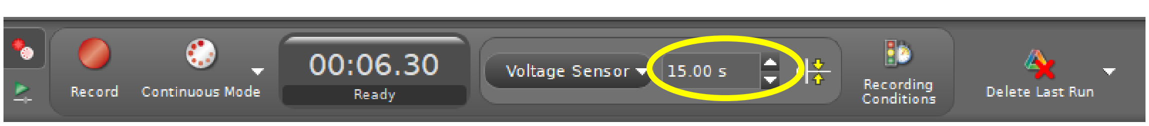


Figure 2*: "Controls" Panel*

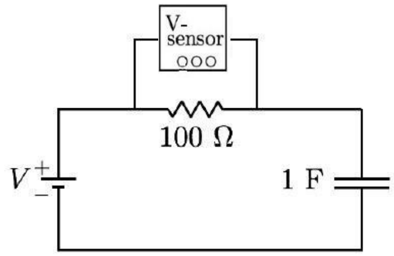
10. (Read and understand this entire step before you begin this step!) Remove the wire from the positive terminal of the interface, and immediately plug it into the negative side of the capacitor, shorting the circuit[1], and immediately start recording the time and voltage every 15 seconds (again) for 5 minutes.
11. Plot the data from steps 9 and 10 on separate plots. Find an experimental half-life from both plots.
12. Measure the resistance of R with a multimeter (disconnect the resistor from the circuit first!). Using this measured resistance and your measured half-life (from step #11) get an experimental value for capacitance of C. The manufacturer claims that the capacitance of this capacitor is 1 F (with a 20% tolerance). Does your result support with this claim?

Part 2

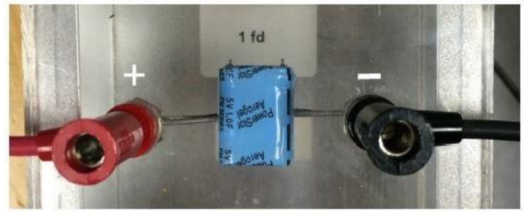
In this part you'll be using a square wave to act like the battery and a switch from Part 1. To the capacitor, the input voltage will appear to be continually switched from position 1 to position 2.

1. For this part of the experiment, we also need the interface to record the voltage across the capacitor. To include this, click on Analog Channel A in "Hardware Setup" and select "Voltage Sensor".
2. Set up the circuit as illustrated in Figure 3c (on page 4).
3. In the Signal Generator window panel, change the signal generator from "DC" to "Positive Square Wave".
4. Set the amplitude to 5.000 V. Set the frequency such that the period of the square wave is significantly longer than your expected RC decay half-life. Why is a longer period important? (*Ensure the sampling frequency is large enough.*)
5. In the Displays window panel, double-click "Scope", choose "Voltage, ChA (V)"as the quantity to be measured on the y-axis.
6. Click "Record". If the parameters are all set well, then the trace of the Voltage on the screen will be fairly stable and stationary. (*Make sure you adjust your voltage per division to monitor the wave effectively*)
7. Determine the half-life from the oscilloscope trace. Compare this to your calculated value.

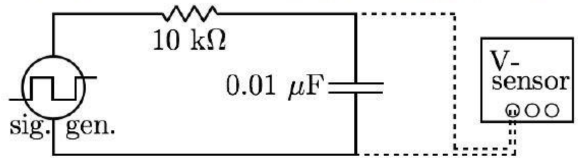
[1] In this context, "short" means that you'll remove the voltage source from the circuit, essentially moving the switch in Figure 1 (on page 1) from position 1 to position 2 by connecting the wire (that was connecting the capacitor to the voltage source) directly to the capacitor. This forms a loop between the resistor and capacitor.



(a) For Part 1



(b) Polarity of 1 F capacitor for Part 1



(c) For Part 2

Figure 3: *(a) The voltmeter should measure the voltage across the resistor (Caution: The 1 F capacitor is polarity specific, so it won't work properly if connected incorrectly; see (b) for the correct polarity.) (c) The connections for the voltage sensor (which will serve as an oscilloscope) are shown as dotted only to aid the reader in not confusing them as part of the circuit, and the signal generator should be set to produce a square wave.*

Last Modified: May 28, 2019