

Experiment 7: RC Circuits

Introduction

Capacitors are used in timing circuits in many devices. The time that your dome lights inside your car stay on after you turn off your cars ignition at night is one example of how a capacitor can be used to maintain the lighting long enough for you to remove the keys and collect your things before exiting. The value we use to characterize these kinds of circuits is given by the time constant defined as: $\tau = RC$, where R is the circuit resistance (your dome light in this case) and C is the capacitance, in Farads (F). In this lab, we will measure the time constant of different capacitors in two situations - one where the time constant is several seconds long, and the other for time constants on the order of several milliseconds long. Consider the following RC circuit (figure 1). It contains a source of power (either DC or AC), a resistor R, and of course a capacitor C. If at time $t = 0$ the Switch A is closed (Switch B remains open), charges will begin to build up in the capacitor. These charges do not accumulate within the capacitor instantaneously due to the “resistance” provided by the resistors. The potential difference across the capacitor can be expressed as

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

where $\tau = RC$, and V_o is the maximum potential difference across the capacitor. After a sufficiently long time (much larger than the time constant), if Switch A is opened while Switch B is closed, the capacitor will discharge all of its accumulated charges. The potential difference across the capacitor for this process can be expressed as

$$V(t) = V_o e^{-t/\tau} \quad (2)$$

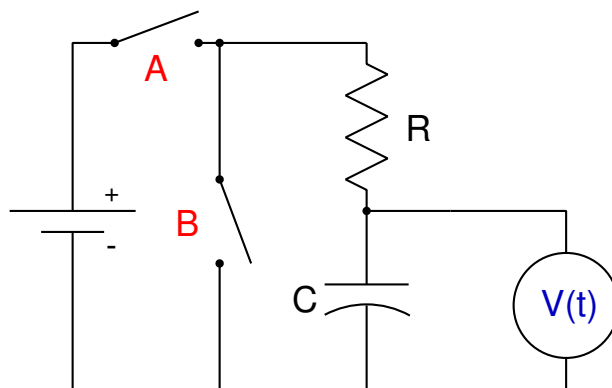


Figure 1: Circuit for RC charge-discharge measurement where $V(t)$ is the sensor used to measure the potential difference across the capacitor as a function of time.

The time dependence of the potential difference $V(t)$ for the charging and discharging process is shown in Figure 2. The time constant can be determined by observing either the charging or discharging process. For the charging process, τ is equal to the time for $V(t)$ to reach 63% of its “final” value. For the discharging process, τ is equal to the time for $V(t)$ to fall 63% from its initial value. These values can actually be measured at any time during the charging or discharging cycle, as long as one waits long enough for the capacitor voltage to increase or decrease by 63% of a measured value. If one can capture the voltage passing 9V during a discharge cycle, then one only needs to measure the time it takes for the voltage to decrease by 5.7V to 3.3V (a 63% decrease). You will practice this latter approach with the next exercise.

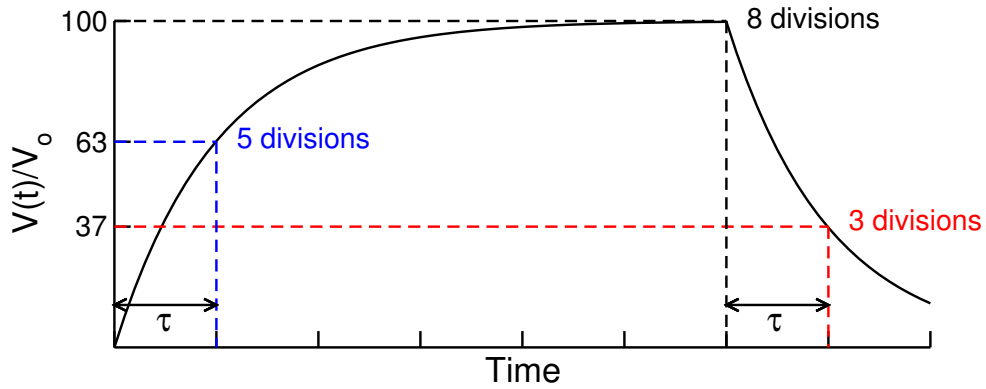


Figure 2: Potential difference across a capacitor in an RC circuit as a function of time.

Part 1 - Measurement of a Long Time Constant:

In this experiment, you will measure $V(t)$ across the capacitor as it discharges. First measure the capacitance of the large capacitor provided using a capacitance meter (the nominal value is $47 \mu\text{F}$). Then put on safety glasses, and construct the circuit as shown in Figure 3, making sure the electrolytic capacitor is connected with correct polarity. The act of connecting or disconnecting the wire between the battery and breadboard functions as the switch. To monitor the voltage use a voltage sensor connected to the 850 Universal Interface. Notice that when the capacitor is connected to the battery, current will flow until the capacitor is completely charged. When the battery is disconnected, the capacitor discharges through the voltage sensor, and interface. The interface contains an internal resistor R_i , which acts as the “load” resistor for the circuit. In other words, the resistor in the 850 Universal Interface is the R in the RC circuit. The internal resistor is given as $R_i = 1 \text{ M}\Omega$. Use the Capstone software to set up a display containing a two column table, and select voltage in the first column, and time in the second column. Then find the controls tab near the bottom of the window, and adjust the sample rate for the voltage sensor to 1 Hz (1 measurement per second).

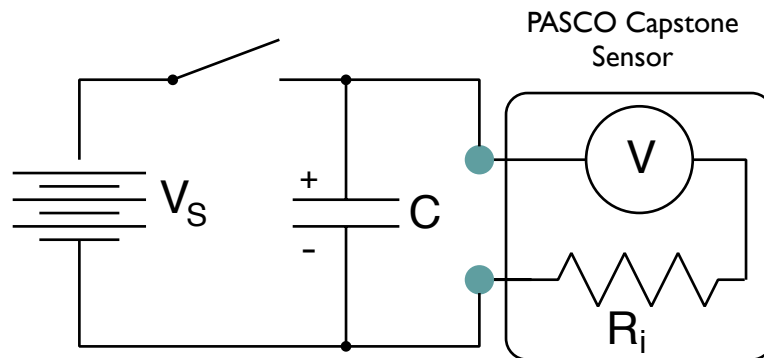


Figure 3: Setup for RC circuit with large capacitor and a resistor (R_i) from inside the voltage sensor.

Charge the capacitor by connecting it to a 9 Volt battery. This should take only a few milliseconds for the voltage reading to go beyond 9V since there is almost zero resistance between the battery and the capacitor. Disconnect the battery and click the Record button in the control tab, when the voltmeter reads exactly 9 V (i.e. $V_o = 9V$) record the time from the second column of the table on your data sheet. Then record subsequent times for voltages from 8.0 V- 2.0 V in one volt increments, subtracting to find the elapsed times. Recharge the capacitor and repeat as often as necessary. Create a two-column data table. The first column for $V(t)$ and the second column for elapsed time. Be sure to record the values of capacitance and resistance (C and R) for use later.

Answer the following questions in your lab report:

1. Equation 2 can be written as $\ln V(t) = \ln V_o - t/\tau$. This means that if we plot $\ln V(t)$ versus t , the slope will correspond to $-1/\tau$. Find the natural logarithm of $V(t)$ from your data and plot $\ln V(t)$ versus t .
2. Find the slope of the best-fit line and thus obtain the experimentally measured value of the time constant. Compare the time constant obtained from this slope with the predicted value of τ using $\tau = RC$ and the values of R_i and C obtained previously.

Part 2 - Measurement of a Short Time Constant

In this part, we measure the short time constant of another RC circuit by continuously charging and discharging the capacitor. We accomplish this by connecting the RC combination to a power supply (function generator) producing a square wave voltage pattern as shown in Figure 4. During the period when the applied voltage is V , the capacitor is charging, whereas during the period when the applied voltage is $-V$, the capacitor is discharging. Since these charging and discharging processes occur very rapidly, a convenient way to study these processes is using the oscilloscope since time scales are now milliseconds rather than seconds.

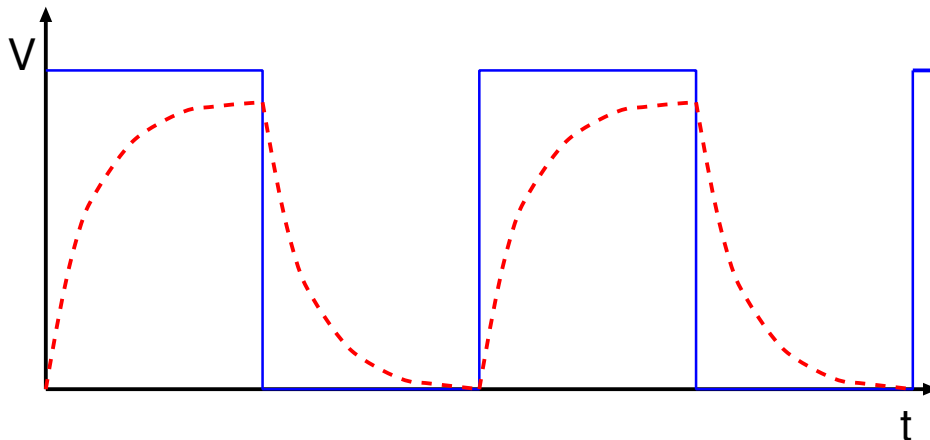


Figure 4: Square wave applied to RC circuit in blue and voltage across capacitor in dashed red vs. time.

Part 2 Procedure:

1. Using the Capacimeter and an Ohmmeter, find the capacitance and resistance of the small capacitor and the resistor given for this part (nominal values 10 nF and 12 k Ω , respectively). Connect the RC circuit as shown in Figure 5. Make sure you connect the input of the oscilloscopes CH1 to the point between the capacitor and resistor in the circuit.

- Switch on the function generator and set it to 900 Hz. Turn on the digital oscilloscope and adjust the vertical and horizontal positioning knob, the time/div scale, and the V/div scale for Channel 1 until you obtain the charging/discharging trace. Press the autoset button on the upper right of the oscilloscope if it takes you more than a few minutes to get a display. Expand the trace and adjust the amplitude of the function generators square wave amplitude so that it extends across the whole 8 divisions of the screen, only making visible one or two complete periods of the square wave. The screen on your oscilloscope should look similar to the dashed line of Figure 4.
- Now record the time (t) it takes for the voltage of the capacitor to reach 63% of the highest voltage. Similarly, record the time when the discharging voltage decreases 63% from its highest voltage. These two values should be roughly identical. Find the average and use this as the experimental time constant.
- Plot the oscilloscope trace and include it in your laboratory report. Illustrate in your sketch how you obtained the time constant and the values you used.
- Monitor the voltage applied from the function generator using the oscilloscope probe and any other provided cables (via Ch 2). Use the autoset function on the oscilloscope and see if you can reproduce the display shown in Figure 4. This will require moving one of the channels vertically to align it with the other channel. The amplitudes should match. Switch to 4.0 kHz for the frequency of the function generator and note what happens to the voltage across the capacitor.

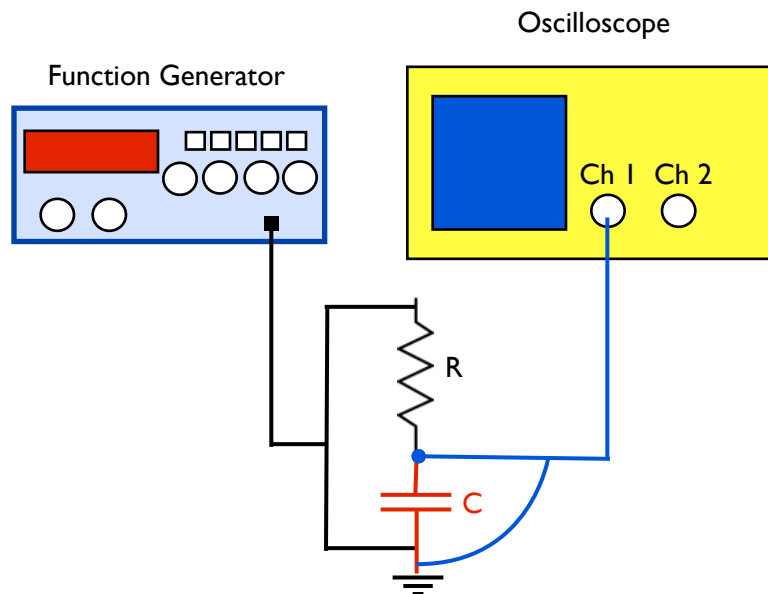


Figure 5: Setup for measurement of fast time constant.

Answer the following questions in your lab report:

- Compare your measured value with the product of RC obtained from the individual values of R and C measured earlier and equation $\tau = RC$.
- Using Equation 2, show the mathematical reasoning behind why the time constant, τ , represents a 63% decrease in the initial voltage for a discharging capacitor.