PS3: Capacitors

Thursday, February 25, 2021 4:18 PM

PS3-CapsRC circuits

PSet 3: Capacitors and RC circuits

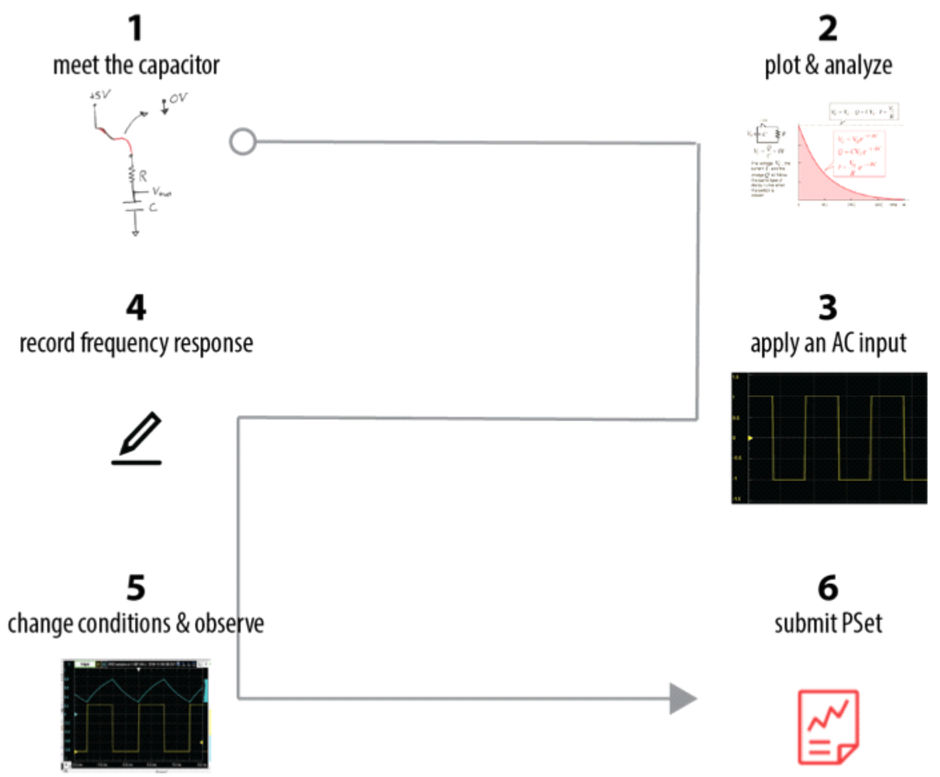
In this week's lab, we will start to use capacitors and learn about their wonders.

Goal: To observe how capacitors respond to direct current (DC) voltage inputs and an alternating current (AC) voltage square wave input.

Learning objectives

- Recognize that a capacitor stores charge;
- Graph the voltage change *across* and current *through* a capacitor as it charges;
- Use Wavegen to produce a square-wave AC signal of a specific frequency and amplitude;
- Compare the measured V(t) with the theoretical capacitor response;
- Calculate the approximate time constant, τ, of an RC circuit;
- Plot the voltage drop *across* a capacitor with changes in the square-wave input frequency

Visual Summary

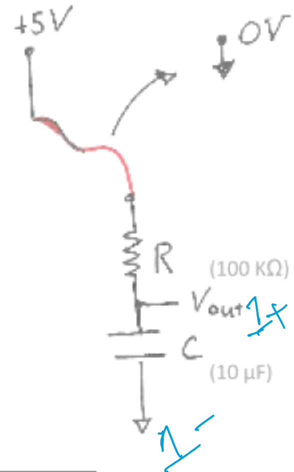


1. Meet the capacitor

In this part, you'll build a circuit that looks like a voltage divider with a capacitor substituted for the bottom resistor. In this circuit, R = 100 kΩ and the C=10 µF. You will see what happens to V_{out} when you put voltage in and then "drain" it by connecting V_{in} to ground.

Build the circuit below, using a wire

This squiggly line is a long-ish loose wire that you'll use to switch to 0 Volts.



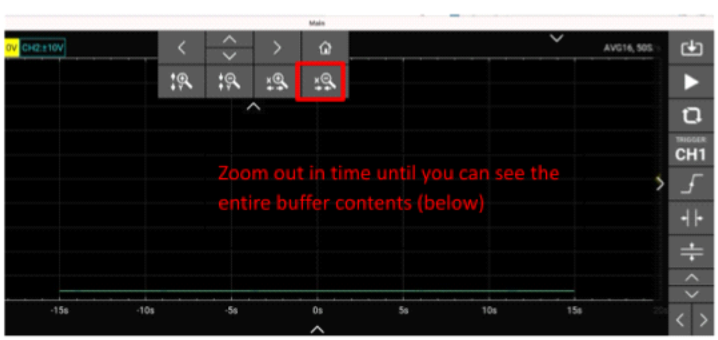
Set up your scope so that it uses Channel 1 to measure the ΔV *across* the capacitor.

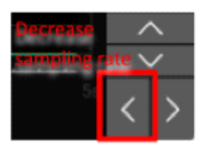
Where should the 1+ and 1- probes connect?

Prepare to the scope settings to monitor what happens over time when you switch from 5V to 0V input. It will take about 5-10 seconds.

First, set to single sweep ( ) rather than repeat ( ). The data will fill a single buffer.

Note: The memory buffer is fixed in size, so you should decrease the sampling rate (fewer samples/second) to accommodate 10 seconds of data collection.





Start the scope( ) and by hand,

quickly move the wire at +5V to ground. Watch the voltage *across* the capacitor change with time. We call this behavior "discharging." Record your observations on the PSet worksheet (page 8)

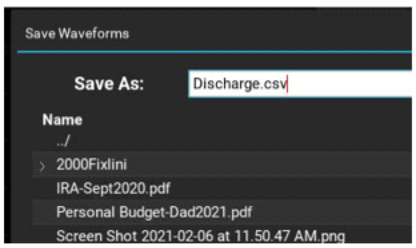
What is physically happening during the dis- charging?

Next, you will record the change in ΔV_{cap} during charging. If your capacitor has fully discharged, Ch1 should indicate V_{out}=0.

Disconnect the input wire from Ground.

Now we are going to monitor what happens when you connect V_{in} to 5 V.

Start the scope (single) sweep and plug the V_{in} wire to the +5 V rail of your breadboard. Save this plot.



Make sure you add ".csv" as a file extension.

AND, we are now going to take some measurements off of this plot using the scope tools.

2. Plot & analyze

The plot of V_{out}=V(t) is theorized to adhere to $V(t) = V(\infty)\cdot(1 - e^{-\frac{t}{\tau}})$ (p. 35, text*). In this section, you will use the Scope tools to determine the value of $V(\infty)$ and τ. Then you'll plot the measured V(t) with the analytical (i.e., theoretical) V(t).

*in the text, V(∞)=1 and τ =1.

$V(t) = V(\infty)$. We don't have t=∞, but we have a large enough t that $V_{out} \approx V(\infty)$

Determine V(∞) from your experimental data, using the scope measuring tools.

4.8V

How can you tell if t(time) is large enough that V(t)→V(∞)?

Hits an asymptote

(Hint: What should happens to the exponential term when t gets really large?)

Now we need to use the same tool to find the value of τ. What is V_∞ in your case? Using this value, you can determine τ from $V(t) = V(\infty)\cdot(1 - e^{\frac{-t}{\tau}})$.

$\tau = 0.97$

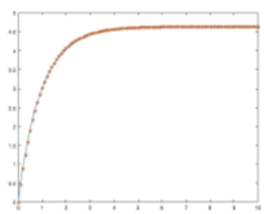
When t= tau, what will be V_{out} for your circuit? 3.03V

$RC = 10^5\Omega \cdot 10^{-5}F = 1s$

Record your measured values of V(∞) and τ on the PSet worksheet (p. 8).

Plot and compare the measured V_{out} and theoretical V(t) for the charging capacitor.

Your theoretical charging curve is likely to fit well to the experimental data, although the voltage might be off a bit due to the internal impedance of the O-scope.



Here is a tiny, unreadable graph to illustrate that the theory "", fits to the blue line of measured data.*

As a reminder, here is the circuit before you began charging the capacitor:

From our text, we know that the equation for the current *through* the capacitor is $I_{cap}(t) = C\cdot\frac{dV}{dt}$, where V is the voltage drop *across* the capacitor. In our case, $V = V_{out} - 0V = V_o$.

As always, the units of measure are important. 1 Amp = 1 Farad Volt/second

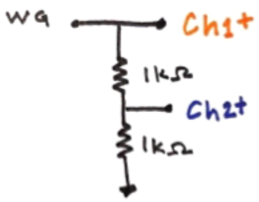
What is the equation for current through the resistor, $I_{resistor}$? $I = V/R$

On the same graph, plot the currents through the resistor and capacitor. Use $V_{measured}(t)$ for the resistor and $V_{theory}(t)$ for the capacitor.

Please return the 10 μF capacitors to their proper bins.

3. Apply an AC input

Now we are going to see how capacitors respond to voltages that alternate in time (Alternating Current, or AC inputs). As a comparison, let's first build a voltage divider circuit and test V_{out} with an AC V_{in}.

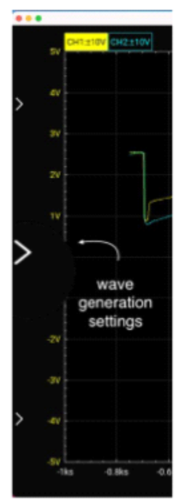


Use WG (Wave Generator) as the

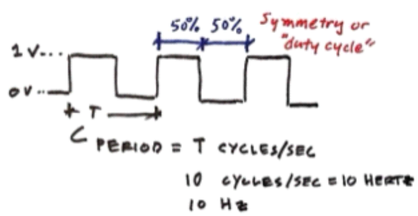
Use scope Ch1+ to monitor V_{in};

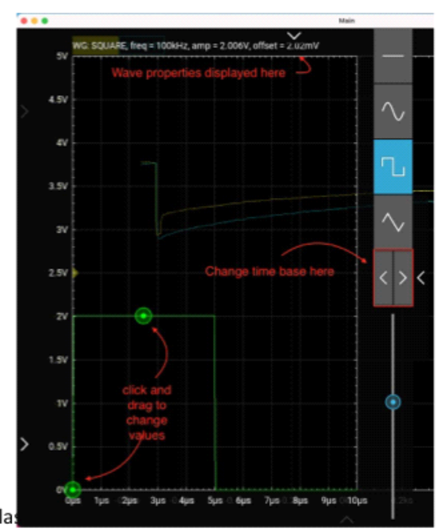
Use scope Ch2+ to monitor the V dropped *across* the bottom resistor.

What should you connect Ch1- and Ch2- to?



Set up the wave generator to get the following signal (at WG on the O-scope):





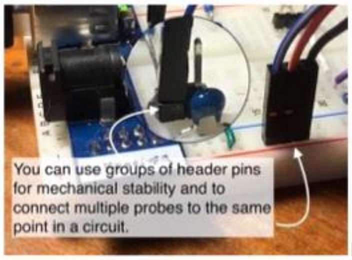
‣Run with continuous cycling ()

You should see the voltage response of several cycles. If not, let's troubleshoot:

Are the Voltage signals off screen (y axis)?
What time scale (x-axis) will a square wave?

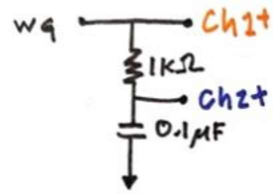
When you have several cycles in the display, sketch and label the Vin and V_{out} signals on the worksheet.

What?



Here is a tip on using groups of header pins for stability.

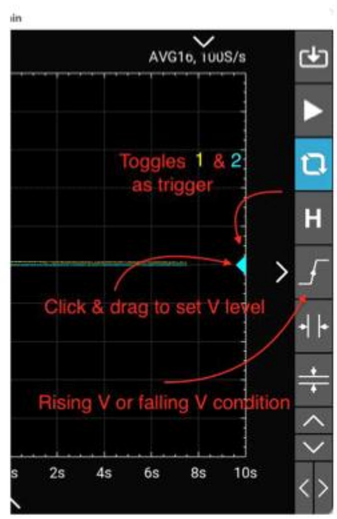
Now, replace the bottom resistor with the capacitor as shown here in this RC circuit:



Apply the same WG signal and sketch the response on your worksheet.

♬

If the signal is scrolling by on the screen, you can fix the data to the t=0 point by specifying



Trigger conditions: This will set a "trigger" to the 0 point on the time axis.

What data source (Channel 1/Channel 2)?

What condition (rising/falling)?

What voltage level of the condition?

4. Record the frequency response

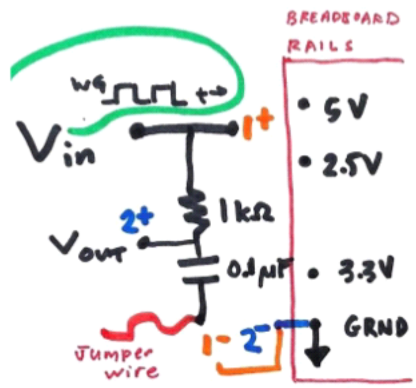
Increase the frequency of the input wave and monitor the qualitative changes in Vout. Note that as you increase the frequency, you'll also have to increase your sampling rate. In your worksheet, sketch the response at 10 Hz, 1, kHz, 10 kHz and 100 kHz.

Comment in the worksheet on the ways the capacitor response to frequency changes is similar to or different from the response you got from Part I.

Change the V_{in} to 2 V. Observe the change in V_{out} for Vin frequencies (10 Hz to 100 kHz). What is the difference in V_{out} compared to V_{in} is 1 V. Record your observations on the worksheet.

5. Change the conditions & observe

Now we are going to see the effect of changing the reference point for the RC circuit (i.e., the leg of the capacitor). Let's get ready by putting a jumper wire in the circuit as shown to the right.



Repeat the sweep of frequencies (10 Hz to 100 kHz) and record your observations.

6. Submit PSet

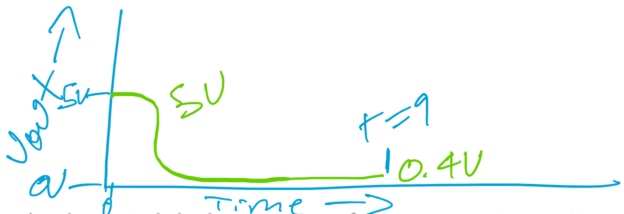
Deliverables:

For this assignment, you turn in the worksheet and the plots you were requested to make. Create plots with clear axis labels with units. The plot should be well labeled. This is not a lab report, so just the plots.

PSet 3 Worksheet

1. Meet the capacitor

Sketch what you observed of $V_{out}(t)$ upon moving the V_{in} = +5V → 0V. In this rough sketch, label the axes, and the V(t=0s) and V(t=9s) second values.



The theoretical discharging curve for an RC circuit is $V(t) = V(0)\cdot e^{-\frac{t}{RC}}$. How did your observed V(t) deviate from this idealized exponential decay and why?

It flattened out at 0.4V, I'm not sure why

2. Plot and Analyze

$V(\infty)_{measured}$ = 4.8 Volts   approximate $\tau_{measured}$ = 0.97 sec

Compute RC for your circuit,   RC = 1 sec.

Theoretically, RC= τ . Compare the RC for your circuit to the experimental τ

They're very close, which is great

Include the following plots for the charging capacitor

1. V(t) for the charging capacitor with $V(t)_{theory}$,
2. I(t) for the resistor with I(t) for the capacitor

Comment on plot 2:

It's very noisy, and I'm not sure why. I tried a rolling average, and it helped a bit but not significantly without averaging together like 15 points. The current through the capacitor is *waaaay* less than the current through the resistor.

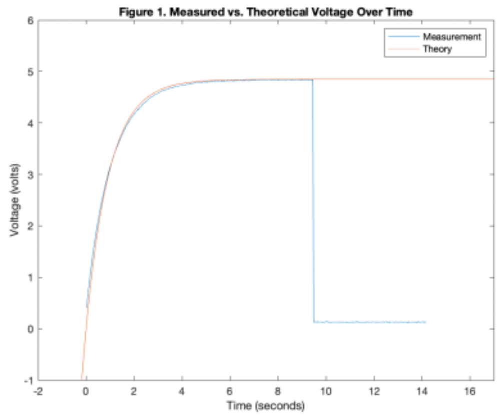


Figure 1. Measured vs. Theoretical Voltage Over Time
Measurement
Theory
Voltage (volts)
Time (seconds)

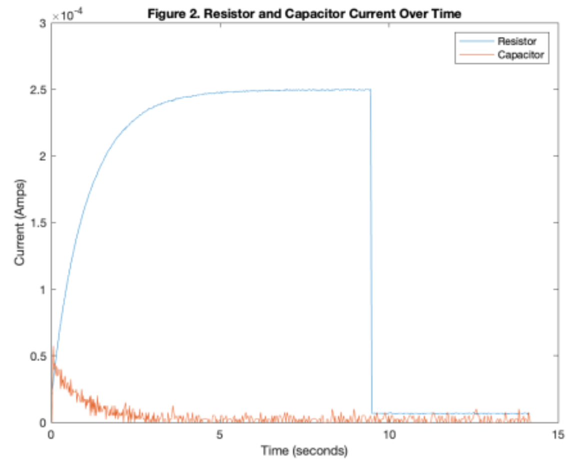
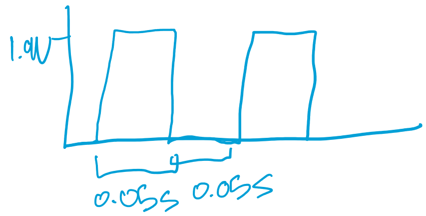
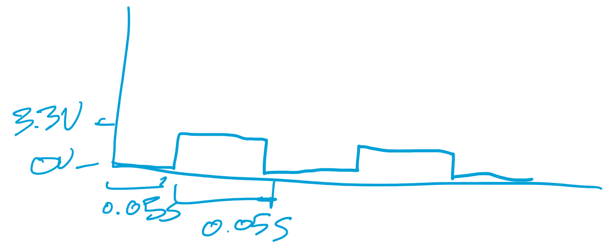


Figure 2. Resistor and Capacitor Current Over Time
Resistor
Capacitor
Current (Amps)
Time (seconds)

3. Apply an AC Signal

Sketch and label a cycle for the voltage divider.	Sketch and label a cycle for the RC circuit.





4. Record the frequency response

Sketch and label of a cycle of the Vin and V_{out} for the RC circuit at these frequencies:

10 Hz	1 kHz	10 kHz	100 kHz

What trends do you notice in the V_{out} as the frequency is swept from 10 Hz to 100 kHz?

The pattern changes significantly, as the cap no longer has time to discharge between cycles

What trends do you notice in the V_{out} for the same 10 Hz to 100 kHz sweep for V_{in}=2.0 V?

My oscope was very buggy so I couldn't test this. (I emailed Brad)

5. Change the conditions and observe

How does the reference voltage (0V, 2.5V, 3.3V or 5V) affect V_{out} ?

Assuming I did this right, it had no impact, which was unexpected. I double-checked my connections

This RC circuit is considered a filter for the input signal. Would you call it a high-(frequency)pass or a low-(frequency)pass filter? Why?

Low-pass, b/c it lets lower freqs thru and blocks higher ones