PSet 4: Capacitors and RC circuits

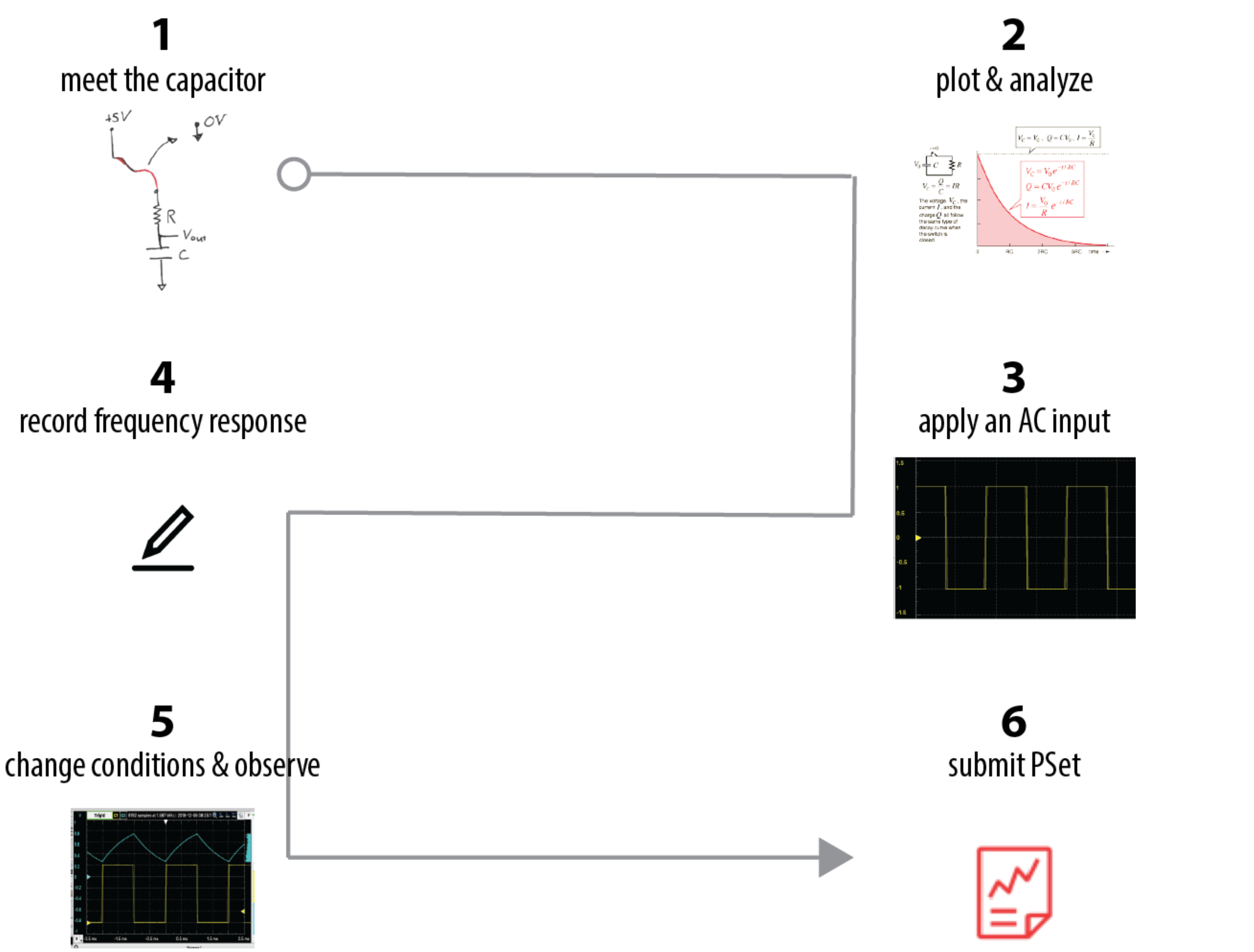
In this week's lab, we will start to use capacitors and learn about their wonders.

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

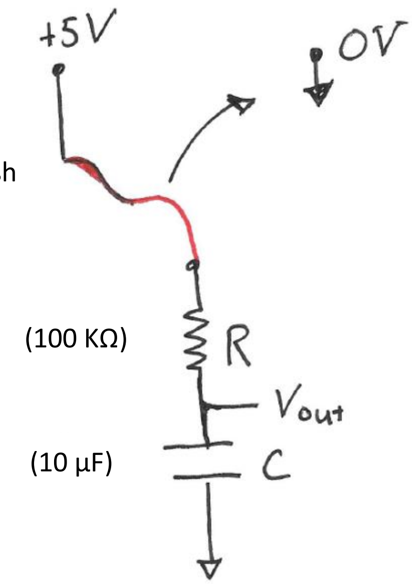
Visual Summary



1. Meet the capacitor

Build the circuit below, using a wire

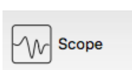
This squiggly line is a long-ish loose wire that you'll use to switch to 0 Volts.



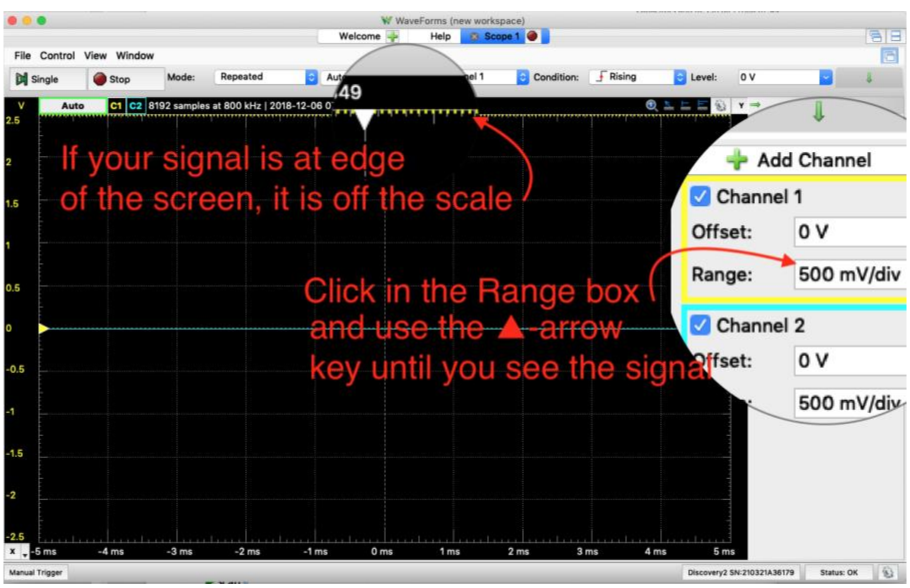
Make sure the AD shares the same **Ground** as your circuit & computer.

Set up the AD so that it uses Chanel 1 to measure the ΔV *across* the capacitor.

Where should the Ch1+ and Ch1- probes connect?

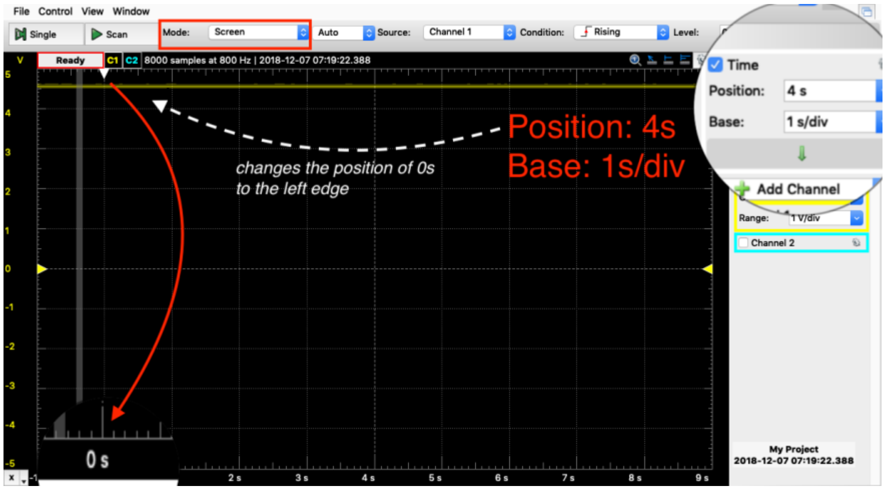
Add 

, ▶ Run. Use the tips in the graph below to find your signal.



Prepare to monitor what happens over time when you switch from 5V to 0V input:

Set **Mode:** Screen, Change the Time>**Base:** 1 s/div, Time>Position: 4s



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?

Now, 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.

When the cursor scope gets to 0 s, plug the V_{in} wire to the +5 V rail of your breadboard. Stop it when it gets to 9 s and save this plot.

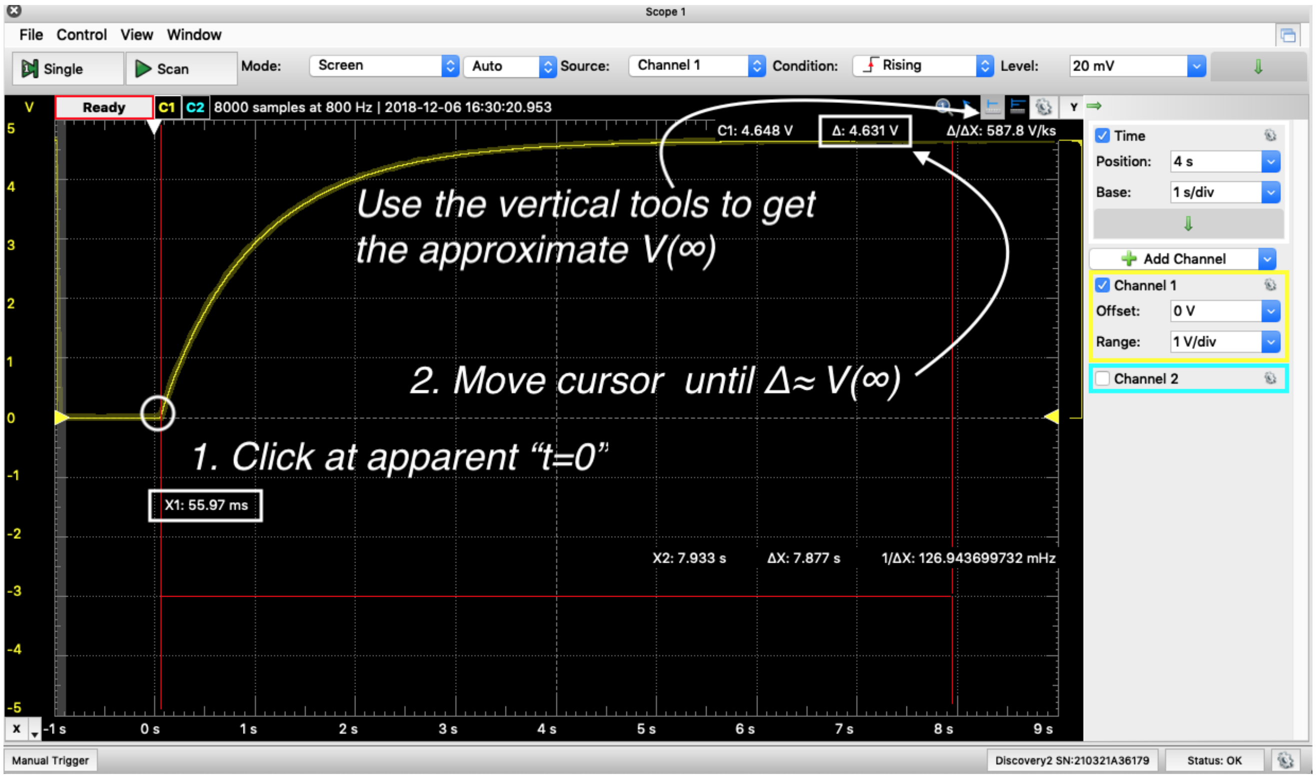
2. Plot & analyze

The plot of V(t) is theorized to adhere to $V(t) = V(\infty) \cdot (1 - e^{-t/\tau})$ (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.

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

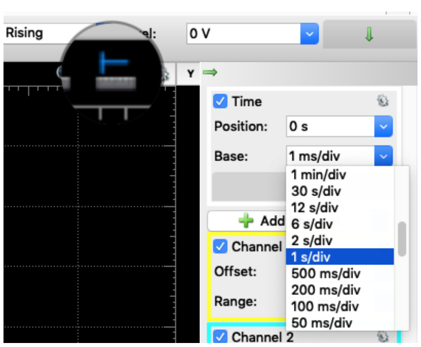
How can you tell if t(time) is large enough that V(t)→V(∞)?



Now we need to use the same tool to find the value of τ. In this case, the t=0 starts at X1~59 ms, V(∞)≈4.63 V. We can determine τ from $V(\tau) = 4.63V \cdot (1 - e^{-t/\tau})$.

When t=τ, what will be V_{out} for your circuit?

Use the vertical tool to determine τ from your data.



Left click on the tool,

With the cursor, point to and left click (and release) on the apparent V(t=0)=0 position. This is the point at which V_{in}=+5V.

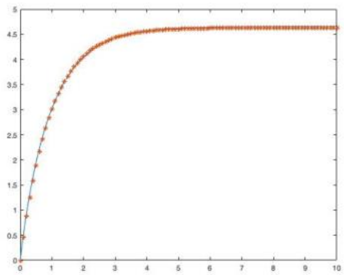
Move the cursor to the right until the Channel 1+ value (C1), Δ = V(t=τ). At this point, ΔX = τ.

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

Plot and compare the measured and theoretical V(t) for the charging capacitor.

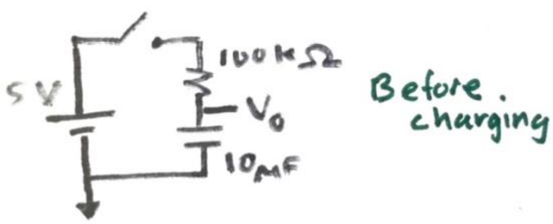
For a quick guide on using MatLab for these plots, see isim.olin.edu, Class 6.

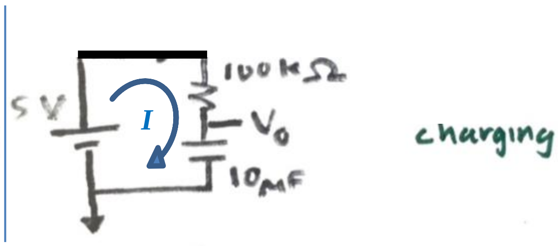
Your theoretical charging curve is likely to fit well to the experimental data.



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, $I_{resistor}$?

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 AC inputs. Build the circuit below and connect the AD.

Use Wavegen 1 as the V_input

Use Scope Ch1 to monitor V_input;

Use Scope Ch2 to monitor the V dropped *across* the capacitor.

The Discovery and circuit should share a ground.

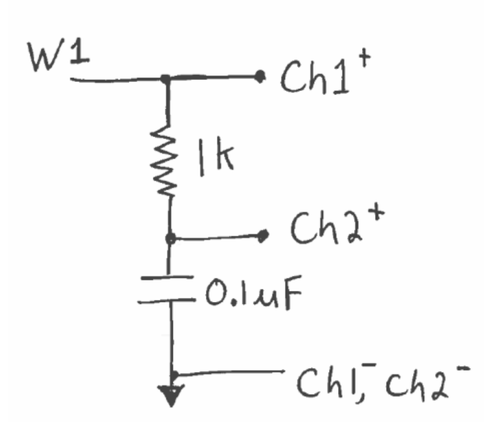
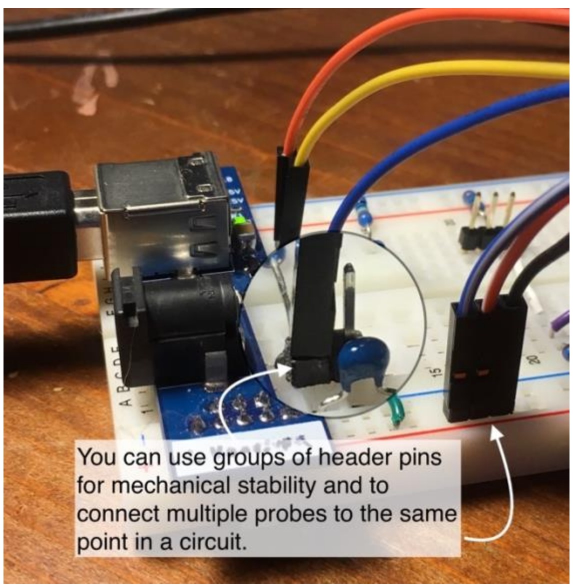


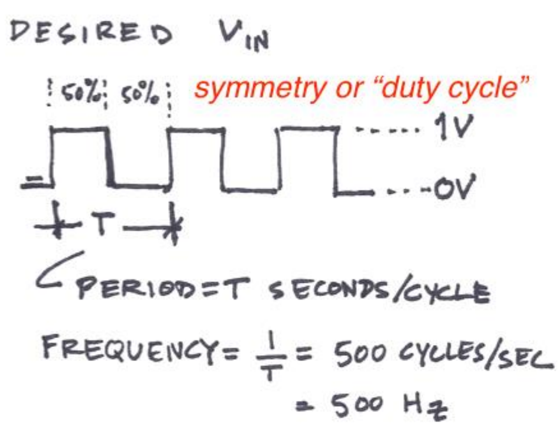
Figure 1: Simple RC circuit for part 2 of the lab.

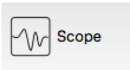
You should have nothing from the Analog Discovery connected to the 5 Volt power rail on your breadboard.



Use 

to create the desired V_{in} and then ▶ Run

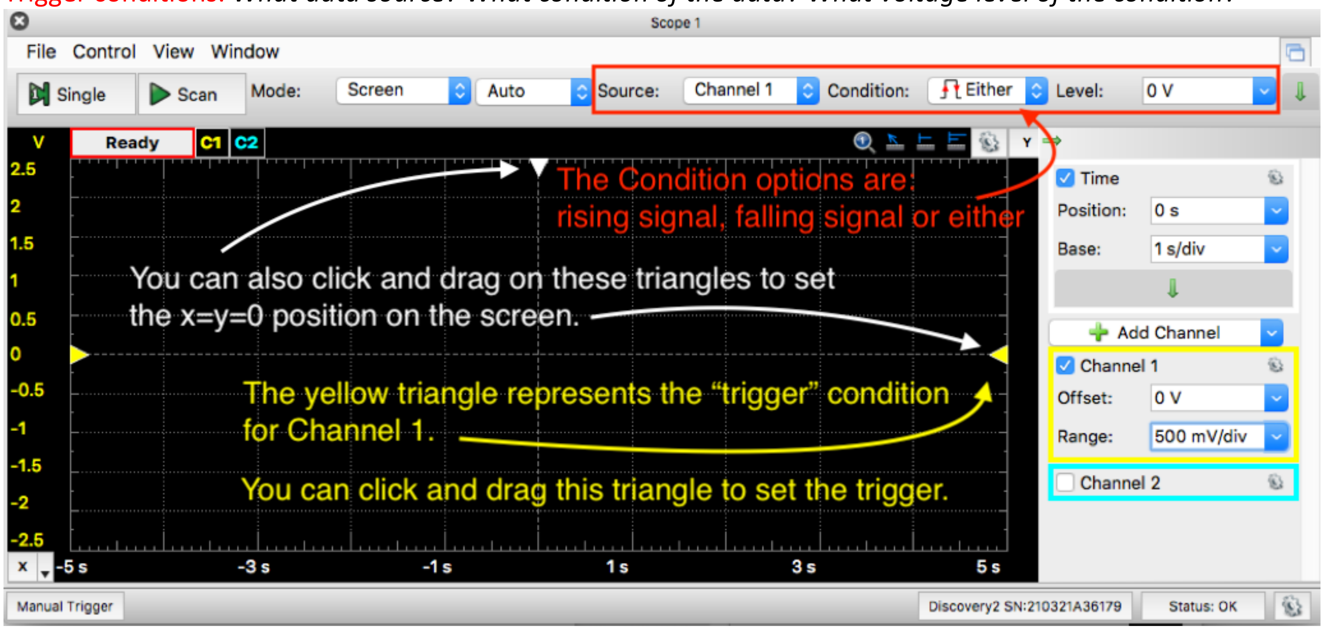




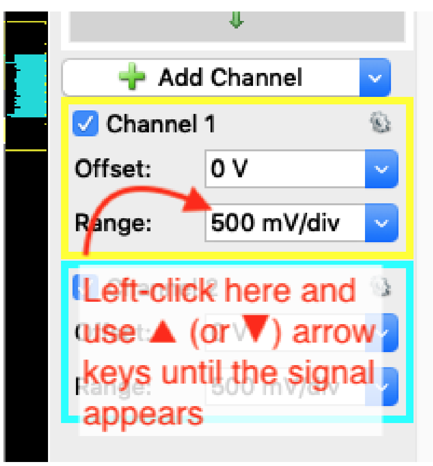
▶ Run. You should see the voltage response of several cycles. If not, let's troubleshoot:

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

Trigger conditions: *What data source? What condition of the data? What voltage level of the condition?*



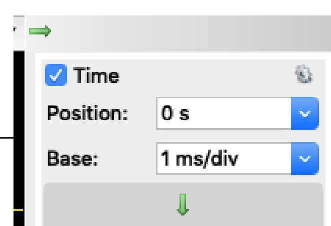
Are the Voltage signals off screen?



Let's call this

Arrow-stepping

This process will help you in trouble-shooting



Can you see the waveform?

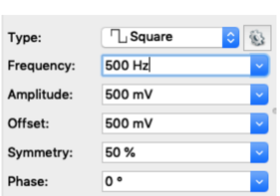
If not, you can arrow-step to stretch/compress the Time Base:

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.

4. Record the frequency response

You'll need to work with both Scope and Wavegen:

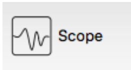
In the Wavegen, left-click in the Frequency: box.



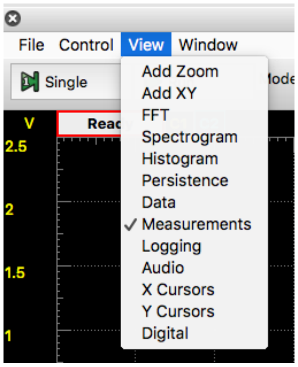
Use ▲ arrow key to step up to 1.5 kHz ("Arrow-stepping") and notice what happens.

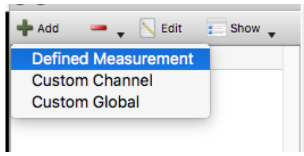
Now, try adjusting the frequency up and down using "Arrow-stepping" to observe what happens to the output signal as frequency increases.

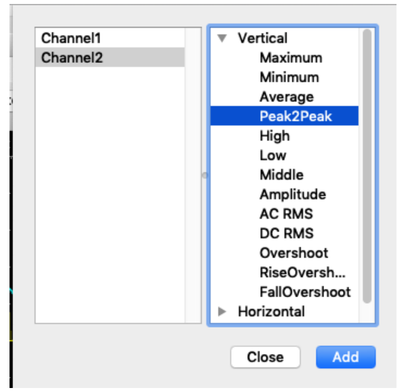
The behavior you observe should be the similar as in Figure 3.9 of the book.

In 

, View>Measurements, Add Defined Measurement, Channel 2>Vertical> Peak2Peak.



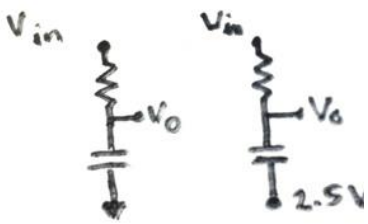




Now adjust the V_in frequency using "Arrow-stepping", from 100 Hz to 200 kHz. Notice and record the voltage drop over the capacitor in the PSet worksheet (Column 1, table, p. 11).

5. Change the conditions & observe

Now change the input signal to be a square wave with 1 V amplitude, centered at 0V (PSet Worksheet table, Column 2, p. 11). Record the voltage drop over the capacitor at the different frequencies.



Now change the reference for the capacitor from Ground to 2.5 V.

Repeat the sweep of frequencies and record the values in the PSet Worksheet table, Column 3.

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 $V(t) = V(0) \cdot e^{-t/RC}$. How did your observed V(t) deviate from this idealized exponential decay and why?

2. Plot and Analyze

$V(\infty)_{measured}$ = ________________ Volts   approximate $\tau_{measured}$ = ____________sec

Compute RC for your circuit,   RC = _______________sec.

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

Include the following plots for the charging capacitor:

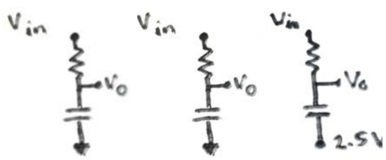
1. V(t) for the charging capacitor with $V(t)_{theory}$,
2. I(t) for the resistor with I(t) for the capacitor

Comment on plot 2:

3. Apply an AC Signal

Comment in the worksheet on the ways this response is similar to or different from the response you got from Part I. *Sketching and labeling a single cycle can help explain.*

4. Change frequency & 5. Response



Conditions:	V_{in}= 0 – 1 V	V_{in}= -1 to 1V	V_{in} = -1 to 1V
V_{in} freq (Hz)	ΔV over capacitor (volts)		
100			
200			
500			
1 k			
2 k			
5 k			
10 k			
20 k			
50 k			
100 k			
200 k			

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?

What trends do you notice in the ΔV of the capacitor as the frequency is increased?

How does changing V_{in} affect the trend of ΔV(freq)?

How does the reference voltage (0V or 2.5V) affect $\lim_{f\to\infty} V_{out}$?

How the $\overline{V_{in}}$, $(the\ mean\ input\ voltage)$ affect the $\lim_{f\to\infty} V_{out}$?