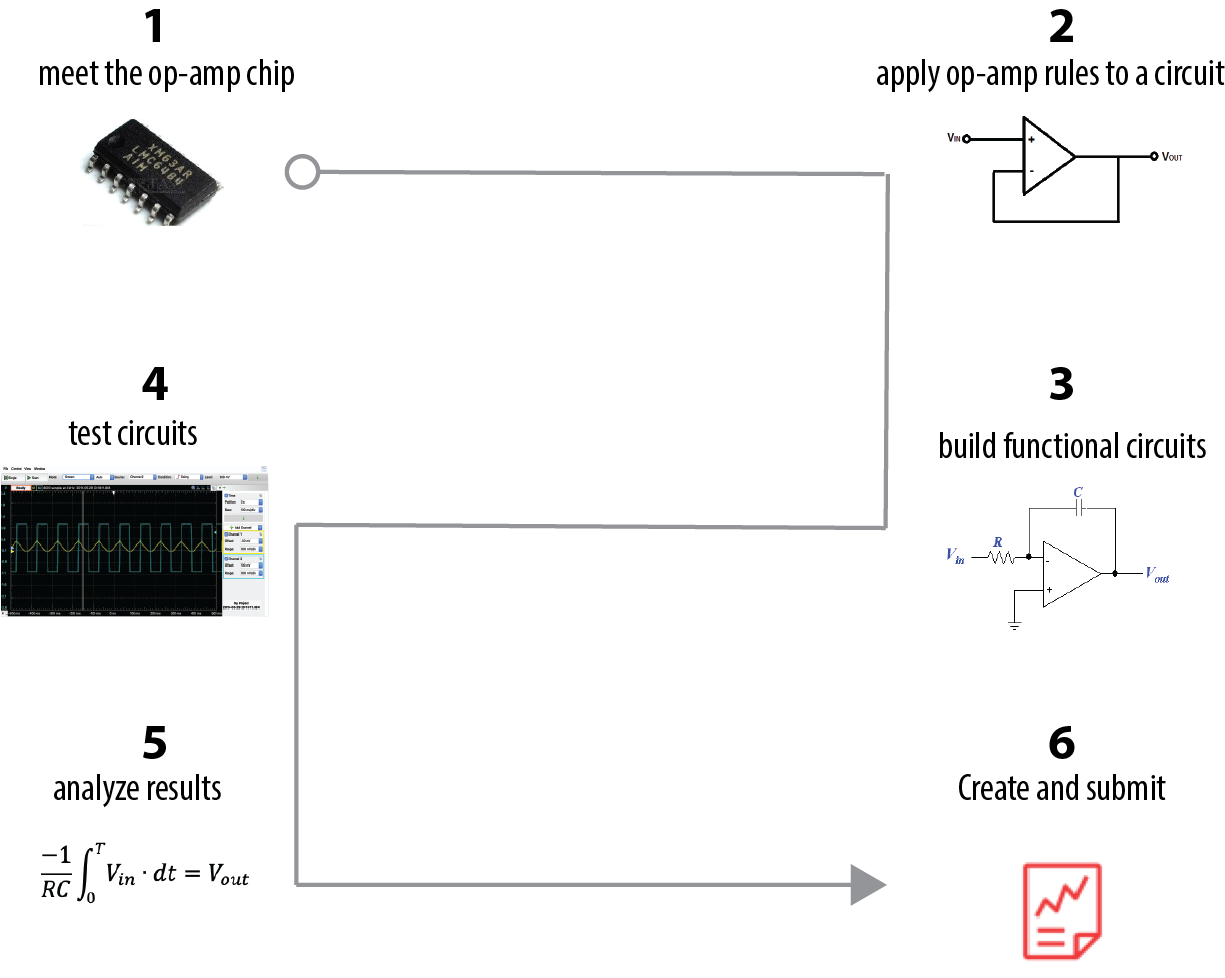
**Lab: Controlling Current with Op-Amps**

Goals: 1. Configure an op-amp as a buffer. 2. Use negative feedback of an op-amp to create a current source; Challenge: Verify the theoretical characteristics of a capacitor and a light-emitting diode using a controlled current.

Learning objectives

* Apply the operational principles of op-amps to a feedback circuit;
* Derive a mathematical relationship between Vout and Vin for a simple op-amp feedback circuit;
* Demonstrate the use of an op-amp in a circuit as fixed current source;



1. **Meet the op-amp chip**

We will be using the [LMC6484](http://www.ti.com/lit/ds/symlink/lmc6484.pdf)A op-amp chip which has the pin configuration schematic pictured to the right:

This schematic omits information. For example, all four of the op-amps are connected to and , which can be a range of values, according to the specification sheet from the above link.***For this lab, connect to +5V, and*  *to ground.***

An expanded, but simplified view of a single op-amp would look something like this:

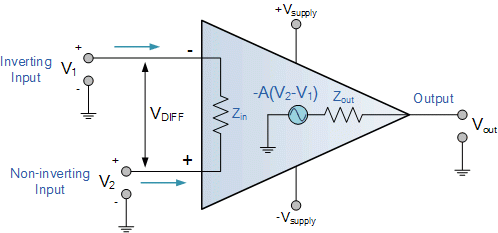
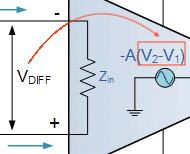
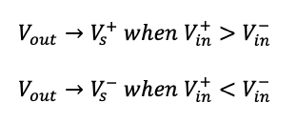
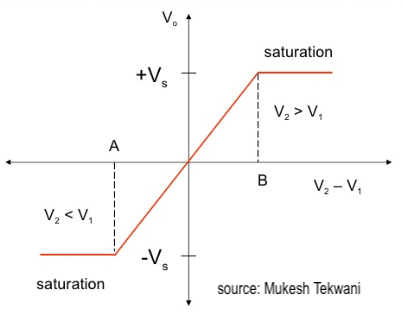


Image adapted from: <https://www.electronics-tutorials.ws/opamp/opamp_1.html>

This expanded version helps us remember that the op-amp has an internal current source that enables it to push and pull electrons (i.e., supply ±*I* ) to the output pin, which it does in response to its differential voltage input, (VDIFF). 

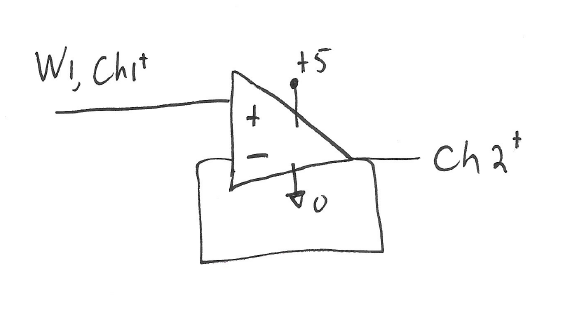
The Zin (internal impedance, see Problem Set 3) is so large that we assume that the input currents are negligible. We also assume that Vout instantaneously responds to the inputs. 

If you’re interested, you can check the specification sheet ([LMC6484](http://www.ti.com/lit/ds/symlink/lmc6484.pdf)A) to see details of this internal current supply, such as gain (A), the maximum current that it can push and pull at the output, and that the range of Vout is When we use op-amps, we often “ignore” their internal components and their limitations—*when you run into trouble with an op-amp performance, the trouble is likely to be traceable to these internal limitations.* 



1. **Build and test a buffer**

Use that same spec sheet to build a “Single-ended unity gain buffer” (Spec Sheet, p. 1), with 5V=. The 0.1μF capacitor mentioned in the spec sheet on the eliminates noise; you can skip it. A “buffer” is something that prevents one thing from affecting another: *friendship can be a buffer against loneliness.*



Using our principles of **op-amps with** **feedback**,

I+= I -≈0, V+=V-

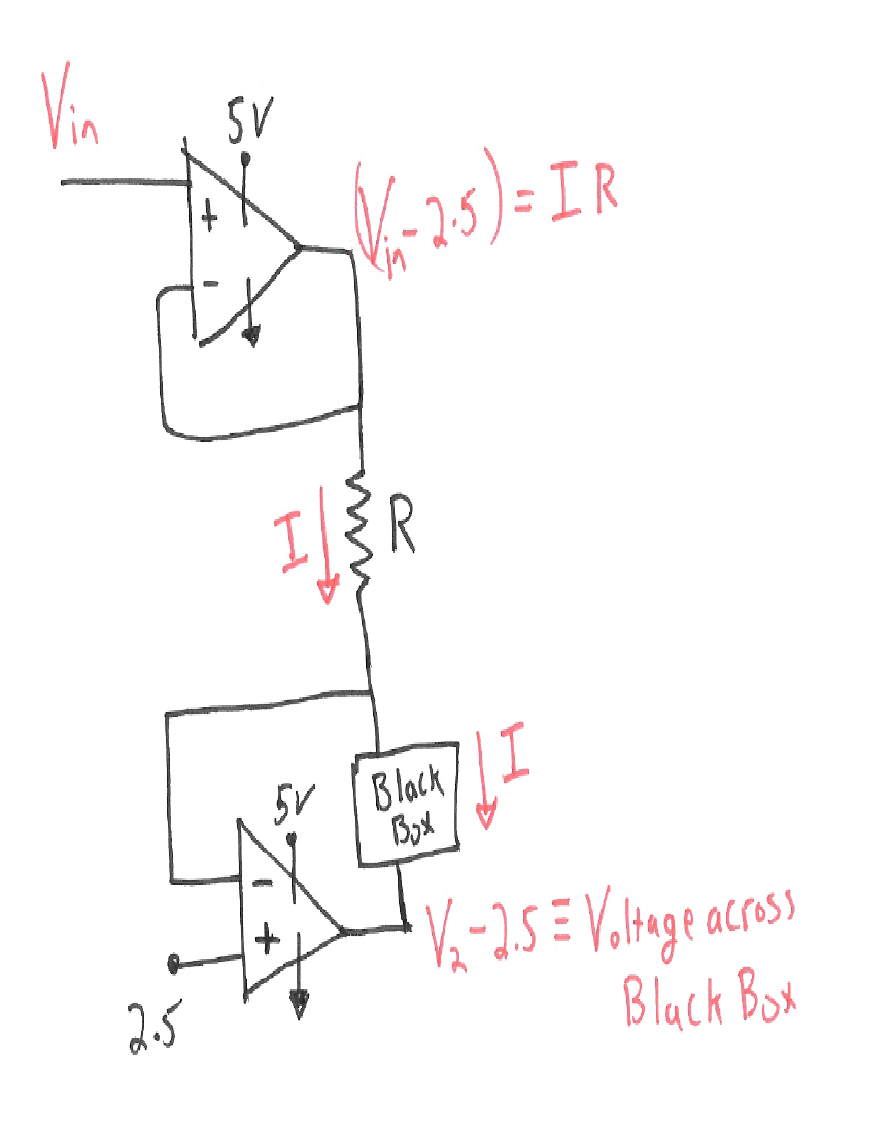
derive the expected relationship between Vout (Ch2+ in the diagram above) and Vin (Ch1+)





1. **Build a current source using op Amps**

A useful circuit for exploring the relationship between voltage and current is shown in Figure 1. Please build this circuit, using any resistor or a small capacitor for the “black box.”



**Figure 1: Generic source current, measure voltage circuit.**

First, let’s try to understand this general circuit using our rules when op-amps are wired in **negative feedback**:

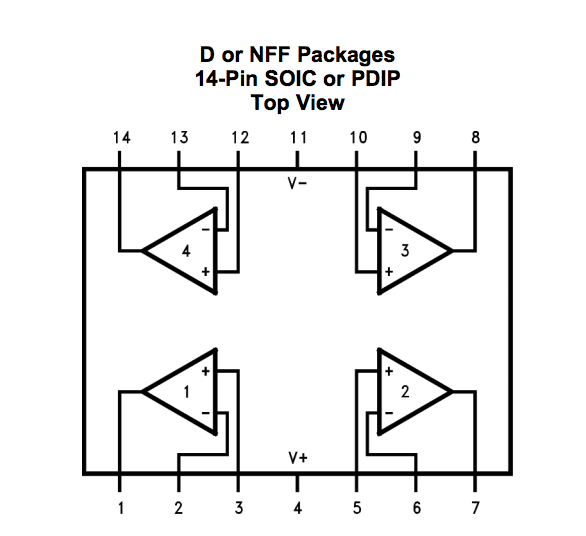








By controlling and selecting an appropriate value of **R**, we can control —we’ve made a current source!

1. **Test the source with a capacitor**
2. Build the circuit shown Figure 2a) using the [LMC6484](http://www.ti.com/lit/ds/symlink/lmc6484.pdf)A chip which has the pin configuration pictured in Figure 2b). You might want to redraw 2a) using 2b) before you build it.

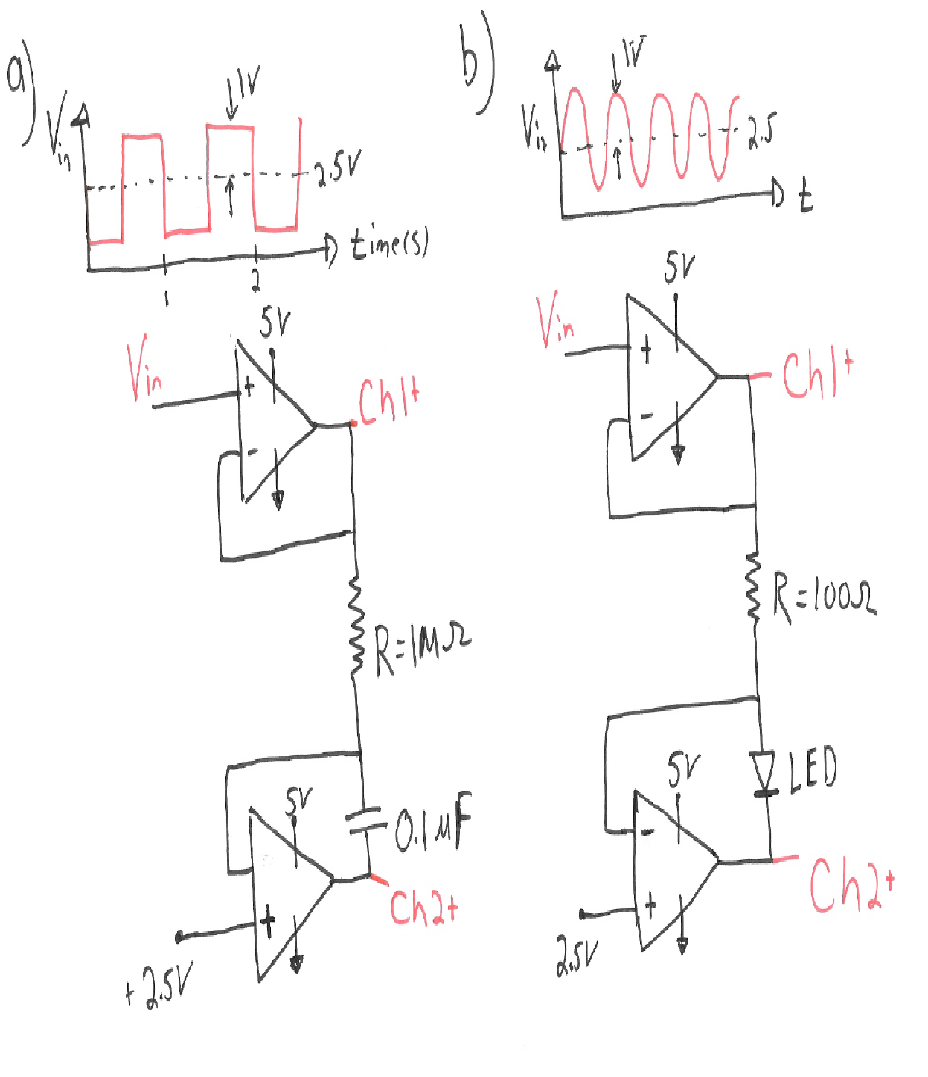
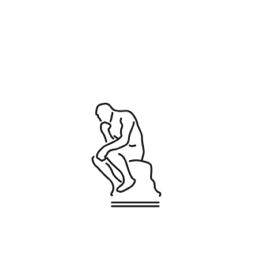
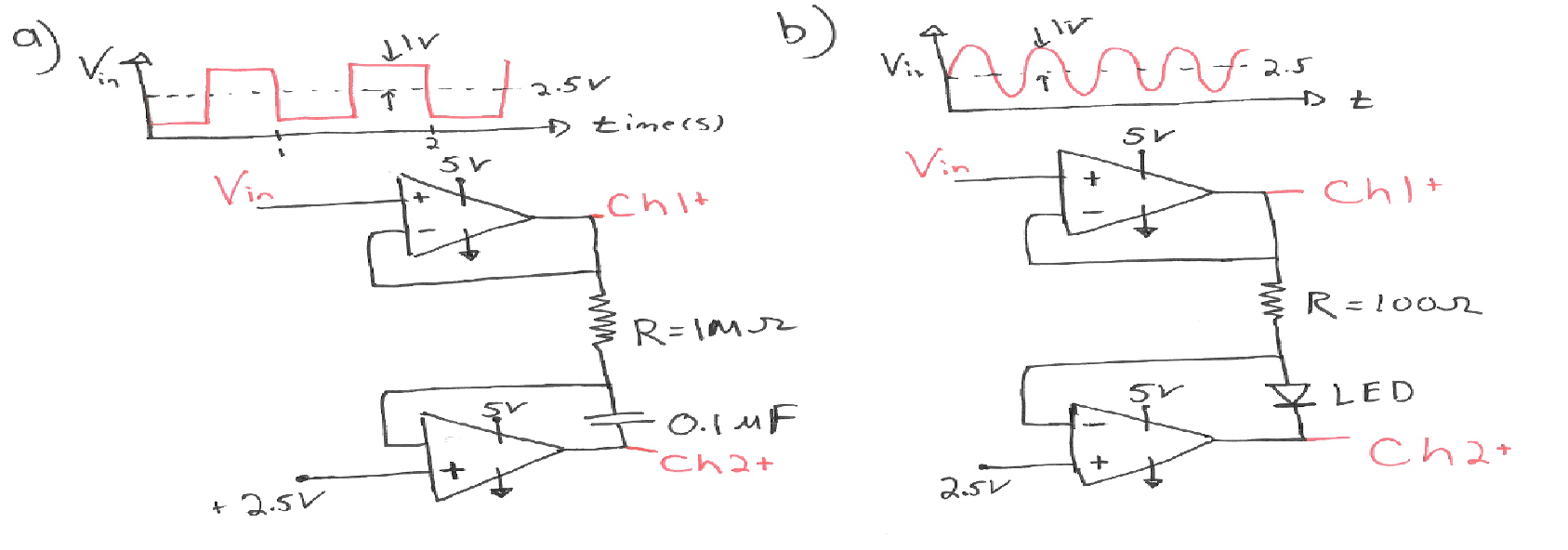
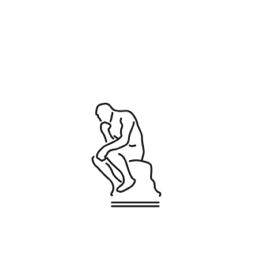
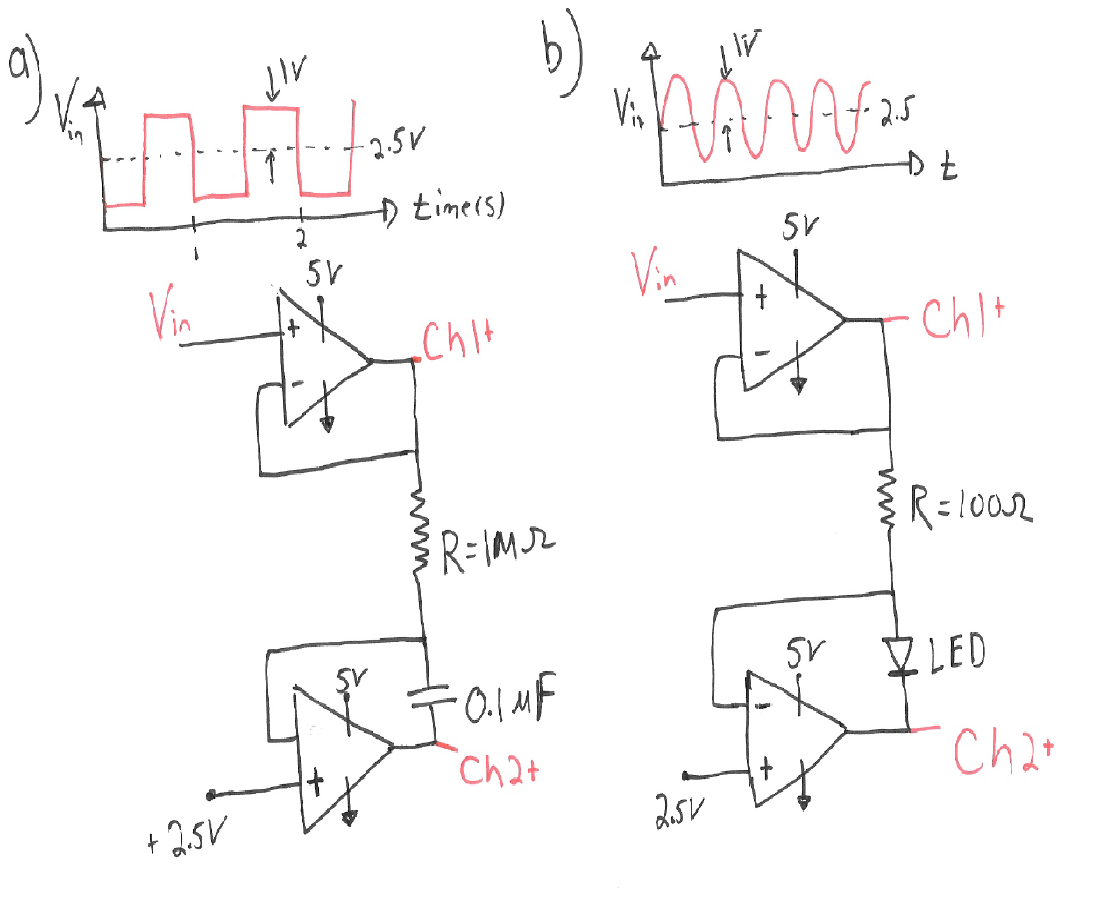


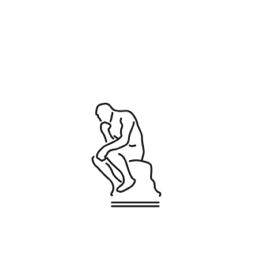
Figure 2. a) Circuit to test the capacitor performance, b) Pin configuration of LMC6484A chip.

1. Connect the Analog Discovery to the circuit; Set Wavegen using the Vin signal of Figure 2a).



1. Assess the expected voltage across the capacitor:

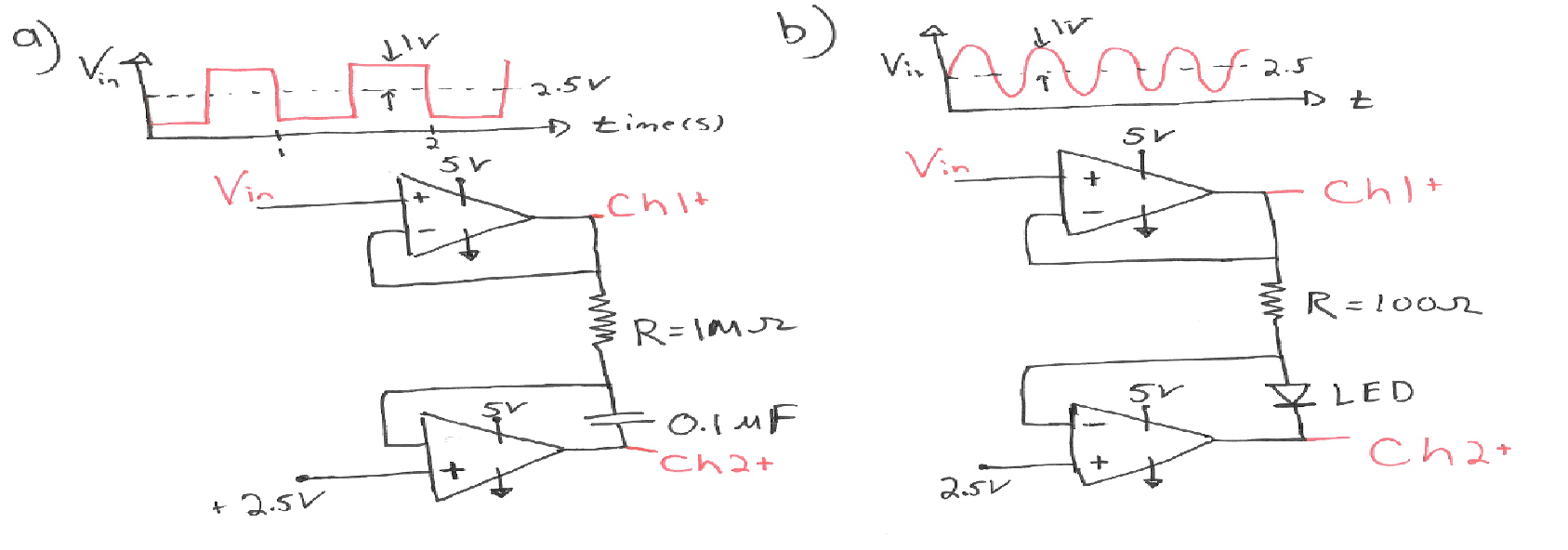




To see if you’re getting the output that you expect, we’ll have to recall that

,

where *c* is the capacitance of the capacitor and is the change in voltage across the capacitor with time.

Let’s rearrange this equation and integrate:

Remember V/R=I. And since the voltage is constant during the ½ cycle, we can take the current out of the integral,

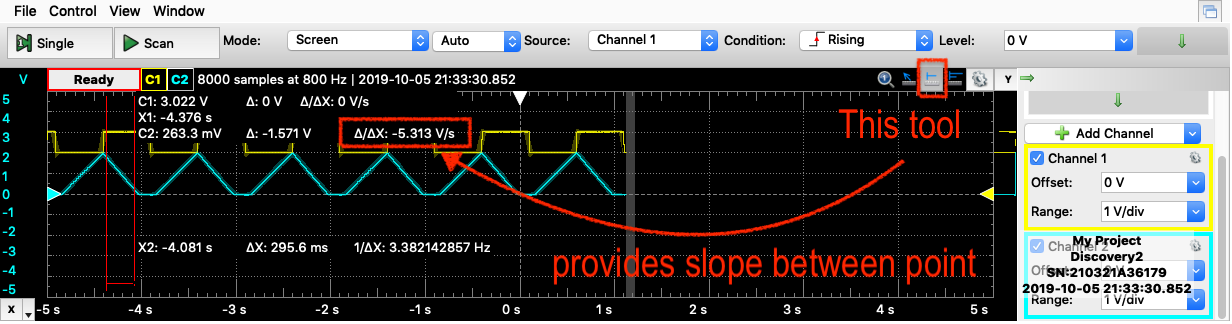
Is your capacitor functioning as expected?

1. Let’s verify the theoretical behavior of a capacitor,

Using Wavegen, change (therefore changing ). Use 5 different and measure across the capacitor. Fill in the table below. 



To measure , use the **vertical** cursor tool on your dataset:



|  |  |
| --- | --- |
|  | (measured) Volts/second |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |

Did you verify our basic capacitor law, ?

For your lab report, consult the lab report guidelines.

Include your data above and comment on whether your circuit is functioning as theorized.

**Challenge: Verifying the *I-V* behavior of a light-emitting diode (optional)**

1. The second Black Box to test is a light emitting diode, LED. Build the circuit shown Figure 3.

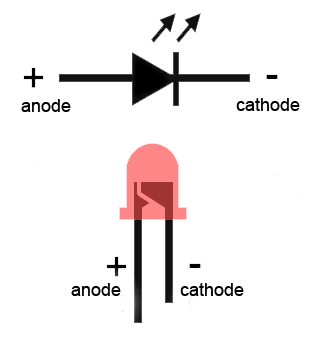
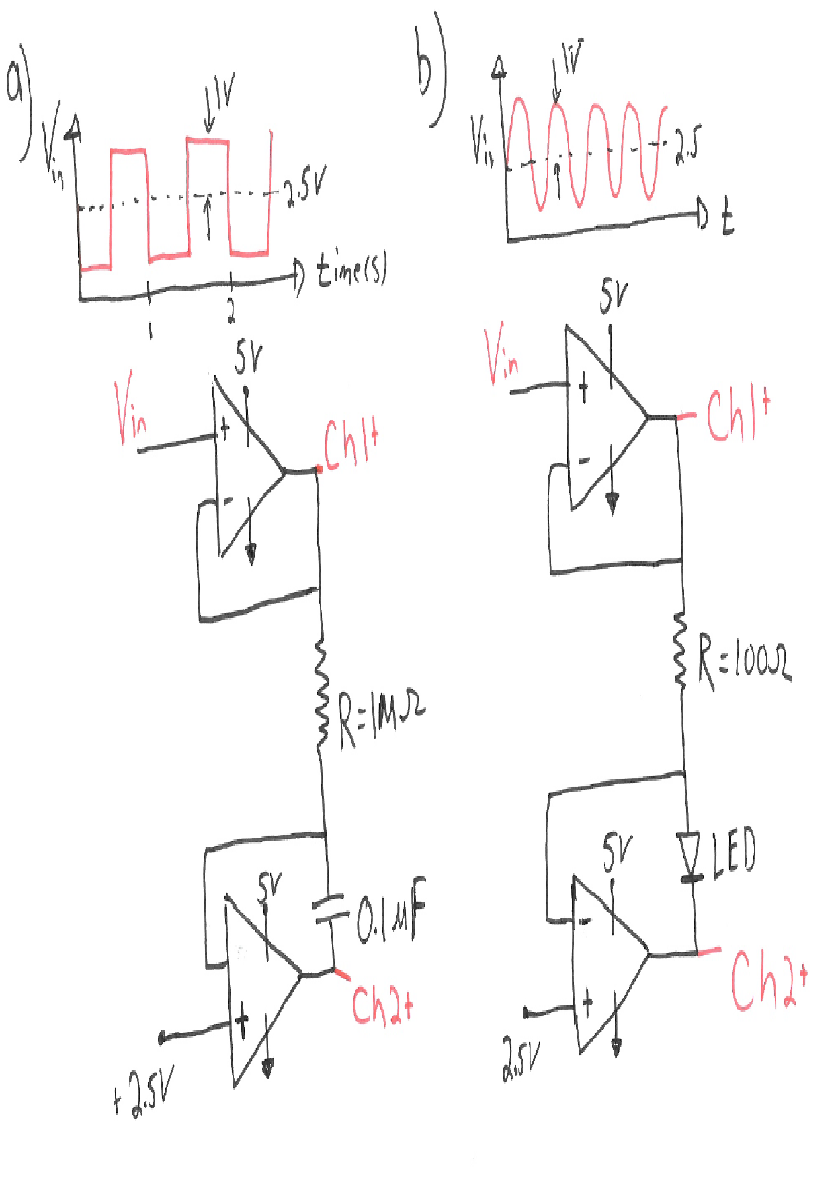
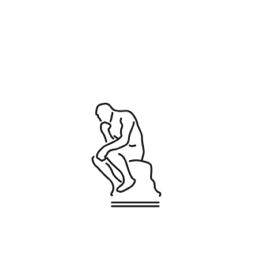
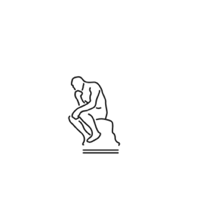


Figure 3. Circuit using LED as Black Box.

1. Connect the Analog Discovery and adjust the settings on Wavegen to Vin in Figure 3.





1. On the scope, add an x-y plot. An idealized V-I curve for an LED looks something like [this](https://i.stack.imgur.com/gcbdC.png) . 

Does your plot make sense for an LED?