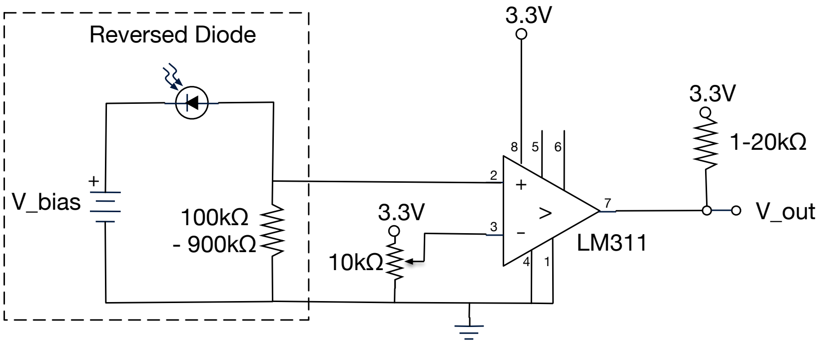
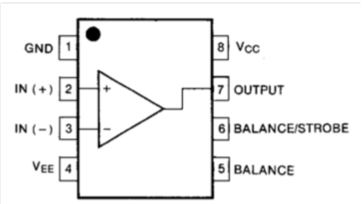
Exercise #3: Signal Conditioning ("digitization")

Higher-quality versions of the Single-Photon Avalanche Diode (SPAD) detectors you're now working with now find commercial application in *quantum key distribution* (currently in use in financial markets as well as applications relating to national security), *laser ranging* (in mass market applications such as focusing the camera in your cell phone), *florescence microscopy* (which is absolutely essential for biomedical work), *etc*. Each of these systems consist of a detector integrated into a "*measurement chain*," which we envision as a modular string of discrete stages, where *information* is passed (typically in the form of a voltage) from one stage to the next.

In Exercise #2, you constructed a "first stage" which converted a current pulse, generated in your SPAD detector, into a voltage pulse (simply by passing the current through a resistor). This week you'll add a "second stage" to that, which you will use to perform *signal conditioning* that is helpful before you add a "third stage" to your measurement chain (in a future exercise). In the schematic below, note that the *dotted* portion is just what you'd *already* put together in Exercise #2, so your first step will be to *reconstruct* that, if need be, and to **make sure that it is working correctly**. As before, make sure that both your oscilloscope probe and oscilloscope channel are set to the ×10 setting. You will be keeping that first scope probe in place even after you add another modular stage to your system.

To perform counting experiments as well as precision **timing** measurements, using pulses coming from an avalanche photodetector, you'll next convert the (still *low-level*) raw pulses coming from your detector into a standard (*high*-level) digital signal that can be unambiguously interpreted by a digital readout system. The circuit to convert the "raw" pulses from your circuit in Exercise #2 (shown inside the dashed square below) into *digital* signals is called a ***discriminator***, a term that originated in the High-Energy Physics community (where a significant portion of all methods for high-speed signal processing were first developed), and describes a circuit that provides an output signal only when an input signal exceeds some threshold value (a "trigger"). You've used such circuitry previously, for example when you were adjusting the trigger level on the oscilloscope in Exercise #2, you should have noticed that more pulses were displayed on screen when the trigger level is low.





Among the additions you'll make today, the key component used to effect a discriminator is called a ***comparator*** (shown in the circuit above as model LM311, with the chip *pinout* shown at right). Essentially, a comparator is just an operational amplifier (*op-amp*), but without the negative (stabilizing) feedback that would normally redirect some of the output back into one of the inputs. In order to have some sense of what, physically, happens inside an op-amp you'll need to get far enough in your review of the physics of the p-n junction, and of transistors. Operationally, whenever the voltage presented at the non-inverting input (labeled with a "+") of the comparator rises to a level *greater than* the voltage at the reference input (labeled with "-"), then the output voltage will rapidly swing all the way up to +3.3Vdc, where anything above +3Vdc corresponds to a "1" in newer digital logic (*previously* common digital logic treated +5Vdc as a "1" but as we pack more sophistication into our chips, the spacing between electrodes is reduced, and newer devices often cannot tolerate the older logic levels). Conversely, whenever the voltage at the non-inverting input (+) of the comparator drops below the voltage at the reference input (-), the output voltage will rapidly pop back down to 0Vdc. (Digital logic now typically treats anything below +1.5Vdc as "0," but none of your input pulses are that large, so you require an *adjustable* trigger level.)

For the moment, you'll have to take my word on the two **Golden Rules** of an *ideal* op-amp:

1. The output changes in a way that would, if feedback were in place, try to eliminate any *difference* between the voltage of the two inputs.
2. Essentially no current flows in or out of the inputs.

In your notebook, explain how the new part of the circuit above will allow you to turn your (initially small) voltage pulse into a pulse with an amplitude of ~ 3 V. [*Hint: invoke the Golden Rules!*]

Procedure:

a. Leave your circuit *and scope probe* from Experiment #2 in place and, after examining the photo above, add in the extra elements required for your discriminator. Because it will be used for later stages in your measurement chain, we elect to provide +3.3Vdc power to your circuit using the onboard power supply of the Teensy microcontroller: you need to connect the microUSB connector to a computer! On the other hand, V_bias for your photodetector should be set using the same external power supply as before, to the same **OPERATING VOLTAGE** you recorded in your results from Experiment #2. Do **not** connect that large voltage to the horizontal rows!
b. By adding a second scope probe, you can *simultaneously* display the photodetector's pulses and the output of the discriminator on an oscilloscope. Adjust the "discriminator trigger level" (set by the variable resistor) so that the output provides one conditioned pulse for every photon pulse.
c. Measure and record the discriminator trigger level. [You may need to adjust this later on, to mitigate the number "false positives" or "dark counts" in your measurements (see Appendix C).]
d. Use *LabVIEW* to record at least one oscilloscope trace illustrative of your working discriminator.