Op-amp workshop, Circuits fall 2020 (Oct 06 and 07, 2020)

Purpose: Operational Amplifiers ("Op-Amps", for short) are a fundamental building block in analog circuits. They have a great many uses, as we will see first-hand in the coming weeks. In this workshop, you'll get to try you hand at building 3 common configurations (See Figure 1).

1) Comparator
2) Active peak detector
3) Buffer (with Rail Splitter)

Both of these figure prominently in the final PPG circuit design. Both also serve as a wonderful introduction to the wide-range of op-amp circuits and principles of operation.

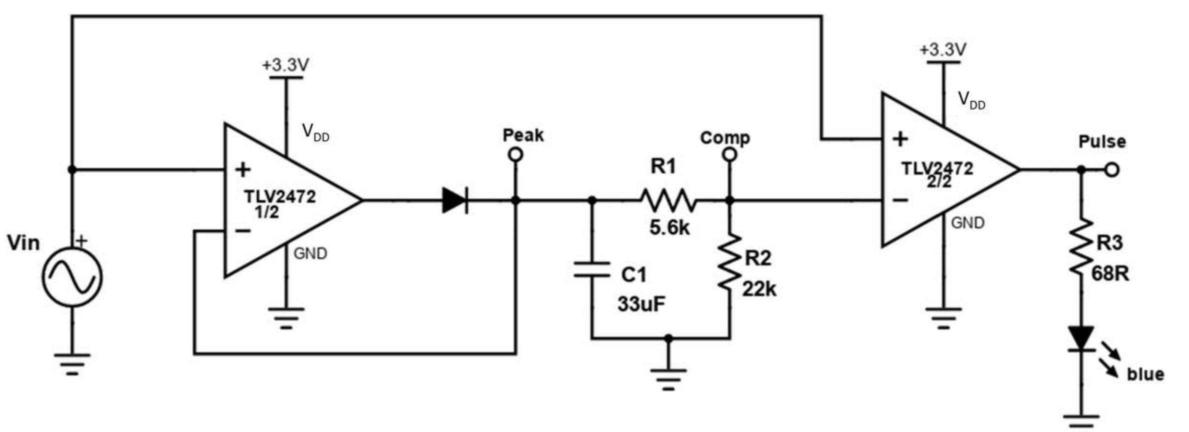

*Figure 1. Active peak detector cascaded to comparator. The comparator serves to illuminate a blue LED when a pulse is detected. Use a TLV2472 op-amp. This is a "**rail-to-rail single supply**" variety of op-amp. More details what the heck that means will follow. For the diode, use a 1N914, the general purpose silicon variety.*

The end goal is to build this circuitry and to do a proof-of-concept demonstration. Turns out you've built major pieces of this previously! Note the "leaky" peak detector. The diode driven in this case by the output of an op-amp. This is not dissimilar for a digital output driving LEDs, as you've done before (though note an op-amp is NOT what sits inside your feather board digital outputs!).

Today, we'll use a TLV2472 op-amp. It has 2 amplifiers inside (see pinout in Figure 4).

Active Peak Detector

Here, we use an opamp (1 amplifier in a 2-amplifier package) in a ***negative feedback*** configuration with the diode. The main point of this op-amp is to recover the 0.7V "lost" across the diode. This is advantageous because 0.7V is a significant chunk of our dynamic range of 0 to 3.3V. We'll discuss how this works in detail very soon. For now, measure the input signal (the 'wiggly' voltage input built from a single potentiometer + Feather 3.3V and ground, as you've done before). Plot the input and the output of the active peak detector, at pins labeled "Peak" and "Comp" (Figure 1). Hopefully, you will see that the "Peak" signal now follows the input without losing the 0.7V due to the diode drop. The op-amp is working to recover that drop.

Comparator

As you might have guessed form the name, the comparator compares the + and – inputs to the op-amp. We typically refers to these inputs v_+ and v_-, formally knows at the "***non-inverting input***" and the "***inverting input***". When v+ > v-, the output of the comparator should swing to the ***positive power rail***, in this case 3.3V. On the other hand, when v- > v+, the output should swing to the ***negative power rail***, in this case, 0V (Gnd). In other words, the comparator simply compares the two inputs and outputs essentially a ***binary signal*** indicating which has the greater voltage.

Build the circuit, and as proof of concept, make 3 simultaneous measurements with the feather, plotting with the Arduino IDE: Vin, Vcomp, Vpulse.

Schmitt-Triggered Comparator

The comparator can sometimes be a bit problematic in the presence of noisy inputs causing the output to undesirably switching between the binary states of 3.3V and GND. One potential fix is called a ***Schmitt Trigger***. This involves adding a positive feedback pathway (via R5), and setting a trigger threshold (via the ratio of R4 and R5). This helps tame the noise-prone output of the comparator via ***hysteresis*** **(see Figure 3).** The question naturally arises: which resistor values do I use. Try out different ones and see what works! R4 = R5 = a few kohms is probably a good starting point.

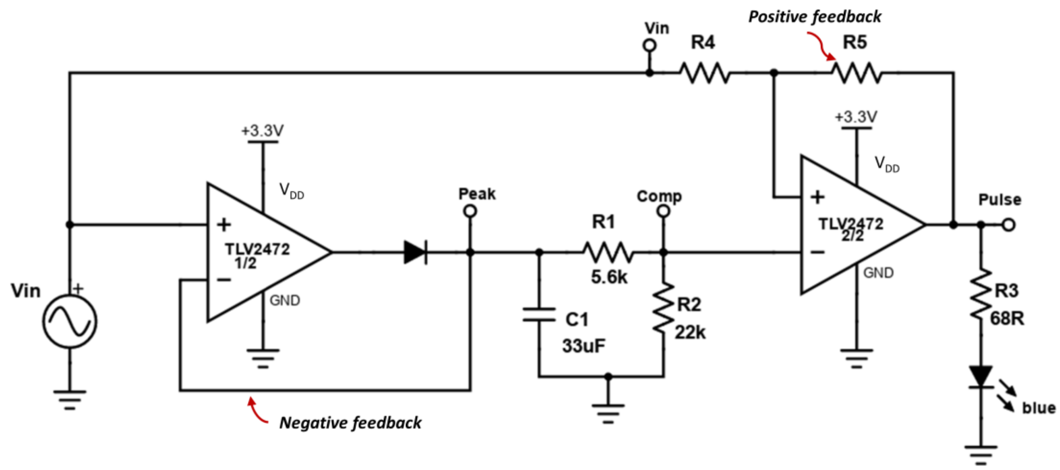

Figure 2. Schmitt triggered comparator. Note the addition of R5 in the positive feedback pathway.

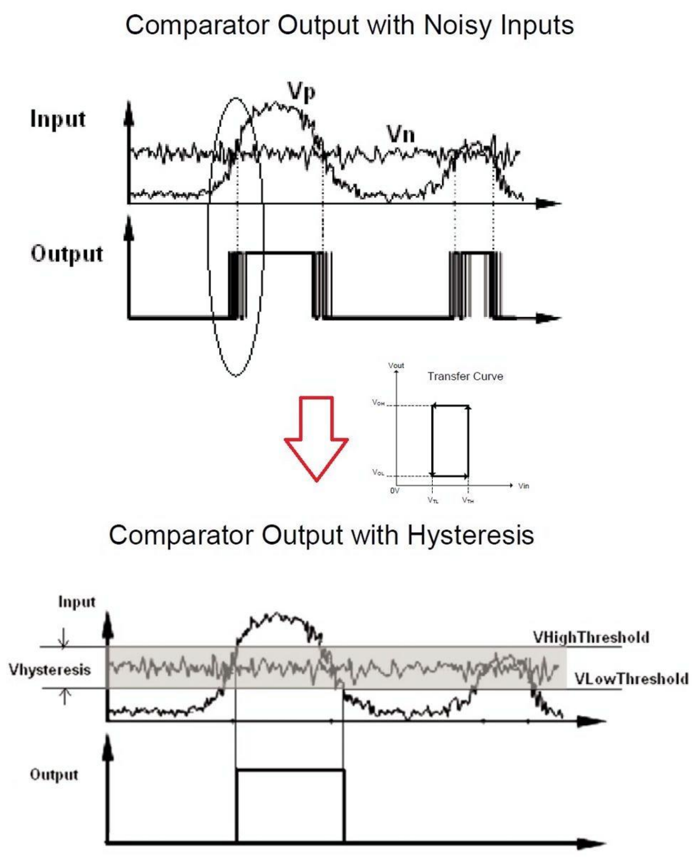

Figure 3. Schmitt trigger hysteresis solves problem of multiple "wrong" transitions due to a noisy signal. Image credit: Cypress semiconductor: https://www.cypress.com/file/119636/download

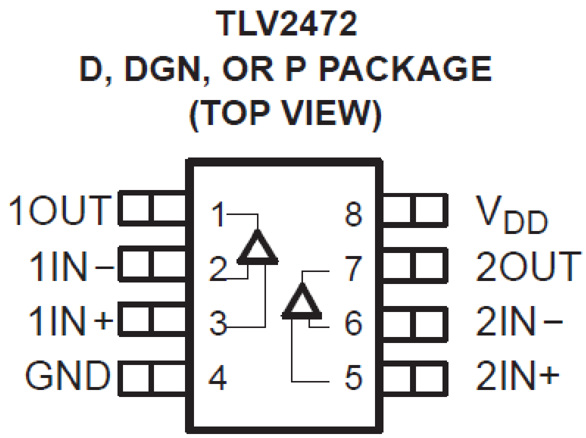

Figure 4. TLV2472 pinout. Note there are two amplifiers inside. The entire package is powered by a single power supply, labeled VDD and GND.

The Buffer and Rail Splitter

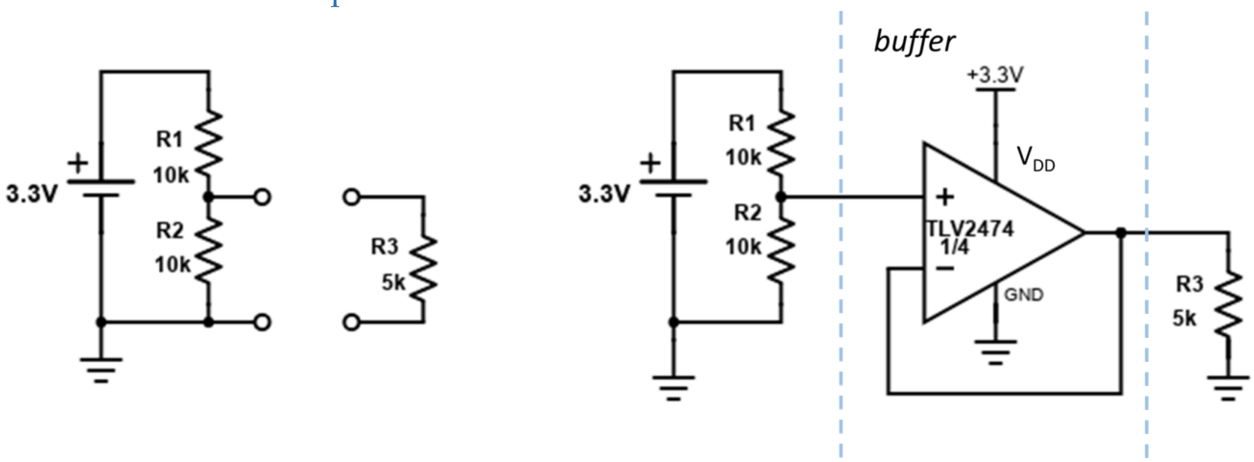

Figure 5. Rail-splitter without (left) and with (right) op-amp buffer.

Here is a classic op-amp application – the ***buffer*** (aka the ***voltage follower***). Here you will explore its application. First, build the voltage divider section of the circuit on Figure 5, left (just with 3.3V and GND, R1 and R2). What is the output voltage supposed to be? Of course, we're splitting it in half! This will be useful later when we need to establish a mid-point in our range of 0 to 3.3V.

a. Build the circuit, make the measurement. Was it nearly 1.65V? Great, next step
b. Now we need to plug other components (circuits building blocks etc) this rail splitter. Can we plug in just anything and still deliver 1.65V? Yes, if—and this is a big if—what

you plug into the rail splitter siphons off no (or very little) current. In other words, the othof R2 and whatever is plugged into it, must be approximately R2. Plug in R3. What voltage do you measure? What did you expect to measure, in view of the fact that you just made a parallel combo with R3 < R2? Hopefully, you should see something less than 1.65V. Which means we are in a bit of trouble here ☹ Fear not…

c. Op-amps to the rescue! Here we will build an op-amp buffer! ☺ Note the negative feedback pathway connecting the output back to the inverting input. The purpose of the op-amp here is to block any current flow, prevent current from siphoning off of R2, whilst still outputting 1.65V, regardless of what you plug in downstream. Build the circuit in Figure 5, right. Measure the output at op-amp output with R3 plugged in. Is it 1.65V (or very close to that value)? What if you plug in other values for R3, do you still get an output of 1.65V. Try a few different values for R3 to find the answer.