In a previous lesson, you learned how op amps are used to compare two voltages and report which of them is more positive. That seems like a pretty simple concept. As with any simple concept, humans will think of all sorts of complicated things to do with it. We've already seen how comparators can be used to regenerate digital information that has been degraded during transmission over a distance. However, there are times when the noise is too great to be rejected by a simple comparator.

Hysteresis

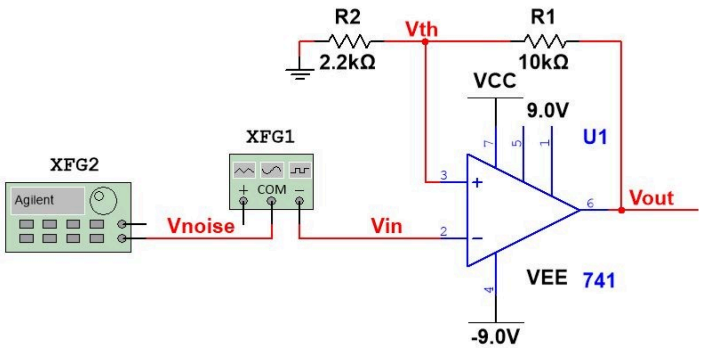
Hysteresis adds improved noise rejection to a comparator circuit. In a simple comparator, the voltage that's being compared to, typically called the "Threshold", is constant. For a zero crossing detector, that threshold is always zero.

Hysteresis introduces a changing threshold. The threshold moves "farther away" from the noise, and shifts depending on whether the output is positive or negative.

From Moodle, open up the Excel spreadsheet called "Data Regeneration". Notice that, in the bottom right chart, there's an extra grey line. That's the Threshold voltage. Notice also that the comparator is in Inverting mode -- that's a requirement for hysteresis.

Increase the noise factor to 1.3, and "refresh (F9)" the screen a few times. Notice that the other three windows are failing consistently, as the noise is crossing the zero line frequently. However, the Hysteresis screen doesn't show any failures. Although the noise is crossing the zero line, it isn't crossing the grey threshold line. When the signal is negative, the threshold line is positive, or "farther away" so the noise doesn't cross it; then the signal is positive, the threshold is negative, so again the noise doesn't cross it. In essence, the improvement in noise rejection is equal to the difference between zero and the threshold, in volts peak, or equal to the difference between the upper and lower thresholds, in volts peak to peak.

But how do we add hysteresis? The clue is in the phrase "move farther away". Unlike with amplification, where negative feedback made the variations smaller by reducing the gain, here we need ***positive feedback*** to increase the variations.



Notice the feedback network. It looks very like what we've used for linear amplifiers, except that it is connected to the non-inverting input. That means it is providing positive feedback instead of negative feedback, and will therefore be a comparator, not an amplifier.

Using Multisim, build the circuit shown above. The odd series arrangement of the two function generators allows us to produce the equivalent of a data pulse with variable noise.

Set up the generic function generator, XFG1 in the schematic, to produce a Square Wave with a frequency of 100 Hz, a duty cycle of 50%, an amplitude of 2.5 V_p (i.e. 5.0 V_{p-p}), and an offset of 0.

Set up the Agilent function generator, XFG2 in the schematic, to produce a Sine Wave with a frequency of 980 Hz, an amplitude of 1 V_{p-p} to begin with, and an offset of 0.

Use a Tektronix 4-channel oscilloscope to display the following:

Channel 1 to display V_{in} on the inverting pin of the op amp

Channel 2 to display V_{th} on the non-inverting pin of the op amp

Channel 3 to display V_{out}

Set all three channels to 5 V/div, and adjust the time base (Horizontal) to display about two cycles of the output signal.

Now, increase the noise signal (Agilent) slowly. At about 5 V_{p-p}, you should see that the noise touches the zero line from both top and bottom. However, the output signal remains unchanged. If this were a simple zero crossing detector, the output would, at this point, start to produce unwanted transitions.

Continue to increase the noise signal slowly. At some point, you should see the output signal start to produce unwanted transitions.

Record the noise voltage, in peak-to-peak volts. [9] V_{p-p}

Subtract the 5 V_{p-p} that you observed when the noise reached the zero line: [4] V_{p-p} This is the improvement in noise rejection resulting from the hysteresis, or positive feedback.

Now, use the measurement features of the Tektronix oscilloscope to measure the difference between the upper threshold and lower threshold voltages (i.e. peak-to-peak voltage of Channel 2). 4 $V_{p\text{-}p}$

The improvement in noise rejection correlates most closely to

- ◯ The noise voltage
- ◉ The difference between the thresholds
- ◯ The digital signal voltage

Look at the traces on your oscilloscope, with the noise set so the output is just beginning to produce unwanted transitions. You should be able to see that the noise is just touching the trace for the threshold voltage as it appears at the non-inverting terminal of the op amp.

Mathematically, the threshold voltage, and hence, the improvement in noise rejection, is easy to determine. Use the oscilloscope to determine the maximum and minimum voltages on the output signal.

$V_{out(max)}$ 8.1 V

$V_{out(min)}$ -8.1 V

Notice that V_{th} is in the middle of a voltage divider between V_{out} and ground. For the two possible output voltages, determine the associated threshold voltages:

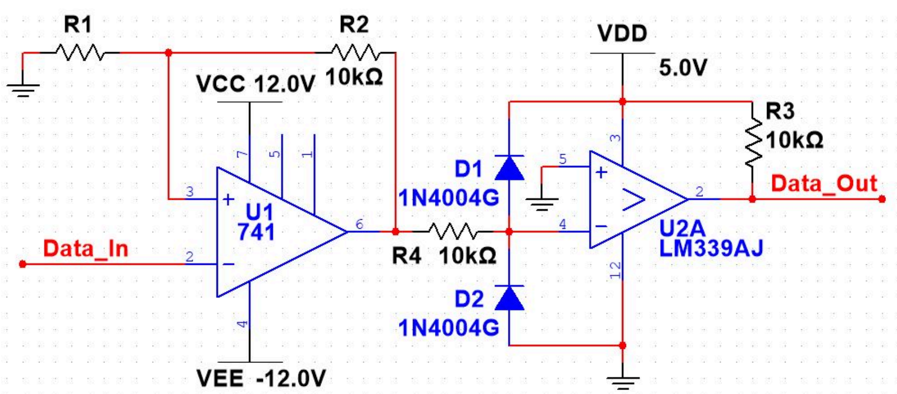
$V_{th(+)}$ = 2 V

$V_{th(-)}$ = -2 V

Find the difference between the upper and lower threshold voltages. This should be very close to the improvement in noise rejection seen earlier, so we'll make the jump and call this the noise improvement in peak to peak volts: 4 $V_{p\text{-}p}$

Worked Example

The following circuit is expected to increase the noise immunity in the output signal by 3.0 $V_{p\text{-}p}$ over a simple zero crossing detector.



First, let's figure out what this circuit does.

- The noisy data at Data_In arrives at the inverting pin of U1, and there's a positive feedback network on the non-inverting pin, referenced to ground. That makes the U1 circuit an inverting zero crossing detector with hysteresis.
- In order for this circuit to work, the noisy Data_In must be "bipolar" (i.e. positive to negative) in order to cross the threshold voltage and trigger the comparator.
- The output voltages from U1 will be approximately +/- 11 V, as the 741 isn't a rail-to-rail op amp.

- U2A is one of four comparators in an LM339 IC. The signal from U1 eventually arrives at the inverting pin of U2A, so, with the non-inverting pin grounded, U2A is an inverting zero crossing detector. With two inversions in the path, the polarity of the cleaned-up Data_Out is the same as the polarity of the noisy Data_In.
- U2A is an open-collector device, so R3 is installed to pull the signal up to +5 V when the internal transistor in U2A isn't pulling Data_Out to ground. So, the output logic is 0 V to +5 V, or standard TTL signalling.
- Notice that U2A is powered from +5 V to ground. This IC is picky about the input signal not exceeding the power rails by very much. That's what R4, D1, and D2 are about:
  - When the output from U1 is +11 V, D1 will be forward biased because current will flow from +11 V to +5 V through D1. That means D1 provides a 0.7 V drop to the +5 V supply, and the input signal to U2A will not exceed +5.7 V.
  - When the output from U1 is -11 V, D2 will be forward biased because current will flow from ground (0 V) to -11 V through D2. That means D2 provides a 0.7 V drop from ground, and the input signal to U2A will not go below -0.7 V.
  - In both directions, R4 provides a resistance across which the remaining voltage from the U1 output can be dropped.
  - This is referred to as either as a clipping circuit because it clips the input signals off at +5.7 V and -0.7 V or as a clamping circuit, because it clamps the input circuit to within 0.7 V of U2A's power rails.

Now, back to the problem at hand: How do we make this circuit improve the noise immunity by 3.0 $V_{p\text{-}p}$?

To do this, the Threshold voltage at the non-inverting pin would have to switch between +1.5 V and -1.5 V. Since the output of U1 switches between +11 V and -11 V, we can rework the voltage divider formula to provide a suitable value for R1:

$$V_{TH} = V_{out}\left(\frac{R_1}{R_1+R_2}\right)$$

so

$$R_1 = R_2\left(\frac{V_{TH}}{V_{out}-V_{TH}}\right) = 10\ k\Omega\left(\frac{1.5\ V}{11\ V\ -\ 1.5\ V}\right) = 1.58\ k\Omega$$

Since we don't have a 1.58 kΩ resistor in our kits, we'll pick the next biggest, because that will increase the noise rejection slightly. So, let's see what the theoretical results will be using a 1.8 kΩ resistor:

$$V_{TH} = V_{out}\left(\frac{R_1}{R_1+R_2}\right) = 11\left(\frac{1.8\ k\Omega}{1.8\ k\Omega+10\ k\Omega}\right) = 1.68\ V$$

Therefore, the improvement in noise rejection is 1.68 V_p or 3.36 $V_{p\text{-}p}$.

Summary

In this lesson, you have learned that

- Noise rejection can be improved using hysteresis
- Hysteresis employs positive feedback to move the threshold voltage "away" from the noise; in other words, the threshold voltage is no longer simply zero, as it would be in a zero crossing detector. It becomes positive when the noisy input is negative, and it becomes negative when the noisy input is positive.
- The threshold voltages are determined from the voltage divider between the output signal and ground.
- The improvement in noise rejection is equal to the difference between the thresholds, in volts peak to peak.