Comparitors and Schmitt Triggers

In ECE 320, we deal with digital circuits. An easy way to create a digital output is to use an op-amp with

- No feedback (a comparitor), or
- Positive feedback (a Schmitt Trigger).

The third case,

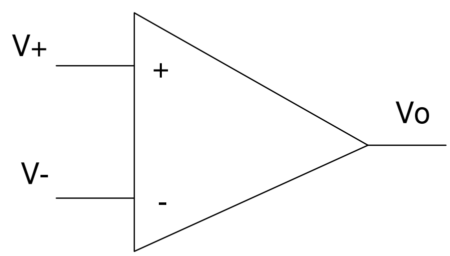
- Negative feedback (an amplifier)

is used in creating linear amplifiers and is covered in ECE 321 Analog Electronics.

An operational amplifier is a 2-input device with

$$V_o \approx k(V^+ - V^-)$$

where k is a large number. For short, the following symbol is used for an operational amplifier:



Operational Amplifier (Op-Amp): Vo = k(V+ - V-)

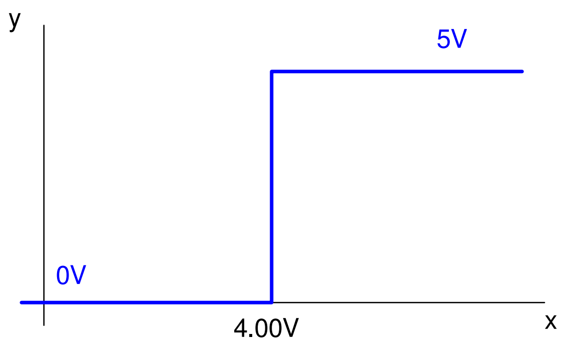
Normally, the power supply for an op-amp isn't important: it doesn't affect the voltage at Vo. When dealing with comparitors and Schmitt Triggers, however, the power supplies *are* important.

- If V+ > V-, the output should go to infinity. In practice, it clips at the + power supply
- If V+ < V-, the output should go to negative infinity. In practice, it clips at the - power supply.

If you want the logic levels to be 10V (true) and 0V (false), then make the power +10V and 0V.

Comparitors:

A comparitor is an op-amp circuit which outputs a binary signal (0V or 5V typically). Instead of having a region where the output is proportional to the input, the output is either 0V (off) or 5V (on).



Input/Output characteristics of a comparitor: the output is either 0V or 5V.

Sometimes, you want to make sure the voltages are binary (0V or 5V) so you can

- Turn off a motor (0V), or
- Turn on a motor (5V)

or

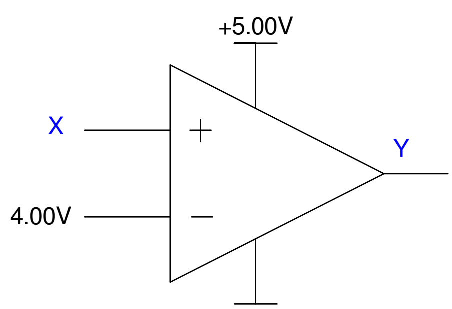
- Turn off a light (0V) or
- Turn on a light (5V)

A comparitor is a circuit which forces the output voltage to be one of two values (0V or 5V in this case).

For example, design a circuit which outputs

- +5V when the input is more than 4.0V
- 0V when the input is less than 4.0V

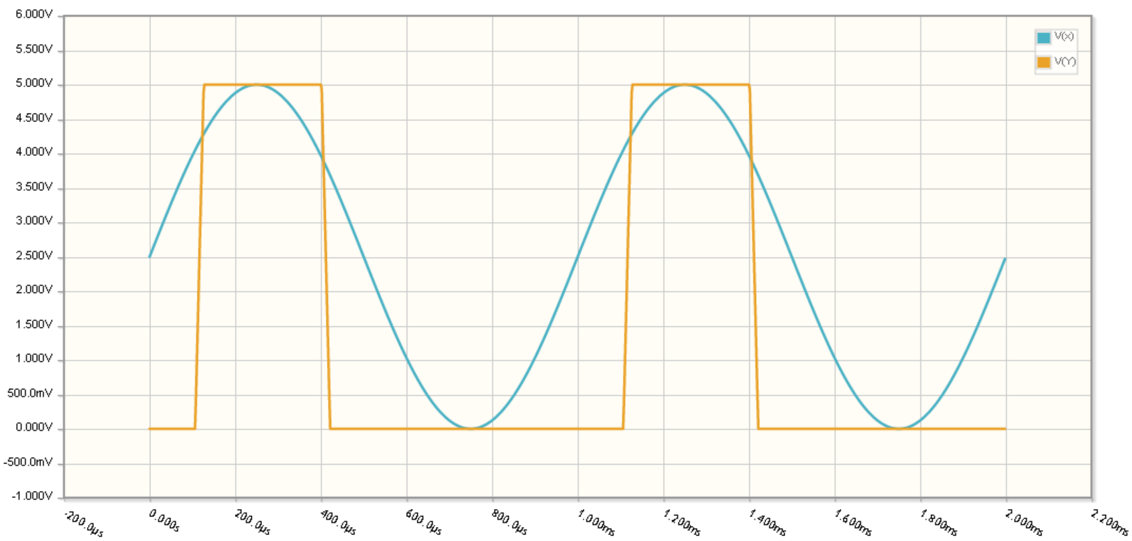
Solution: An op-amp with no feedback works as a comparitor. The limits on Y are set by the power supplies.



Comparitor which implements the function: Y = 5.00 * (X > 4.00V)
Note that V+ is no longer equal to V-

To illustrate how a comparitor works, let X be a sine wave which goes from 0V to 5V. The output (Y) will then be

$$y(t) = \begin{cases} 5V & x > 4.0V \\ 0V & otherwise \end{cases}$$



Output Y (orange) of a comparitor. Notice that the output is either 0V or 5V.

Comparitor Example:

Design a circuit which outputs

- +5V when the temperature is above +20C
- 0V when the temperature is below +20C

Assume a thermistor where

$$R = 1000\ \exp\left(\frac{3905}{T+273} - \frac{3905}{298}\right)\ \Omega$$

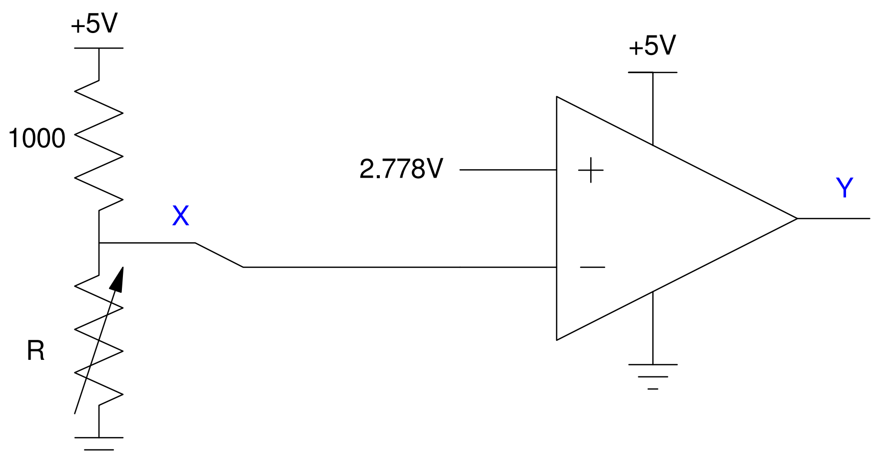
Solution: Use a voltage divider to convert resistance to voltage. At 20C

- R = 1250.59 Ohms
- X = 2.7784V

As temperature goes up

- R goes down
- X goes down, and
- Y goes up (to +5V)

Connect the voltage divider to the negative input.



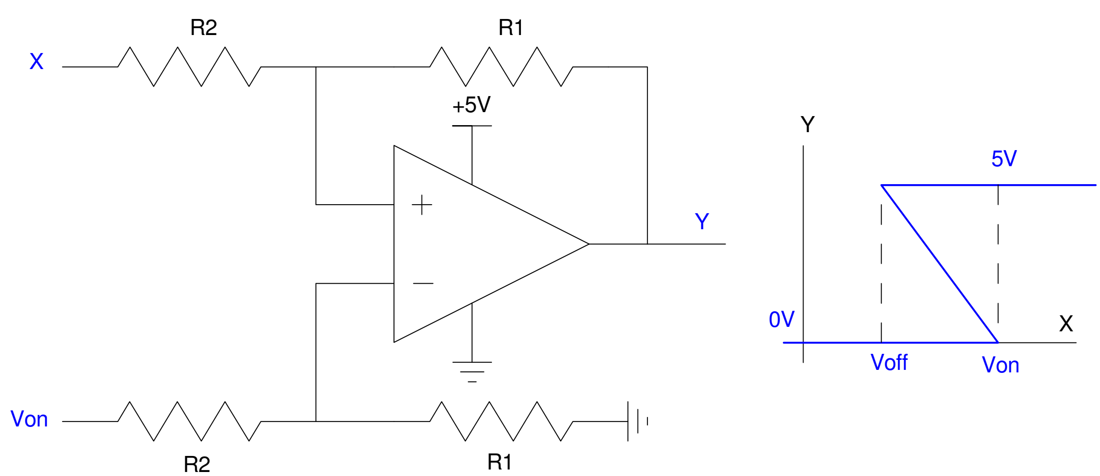
Comparitor: Y = 5V * (T > 20C)

Schmitt Trigger

One problem with comparitors is the output will chatter at +20C: when V+ = V-, the smallest amount of noise can cause the output to slam to +5V (V+ > V-) or 0V (V+ < V-). To fix this problem, hysteresis is added to the circuit:

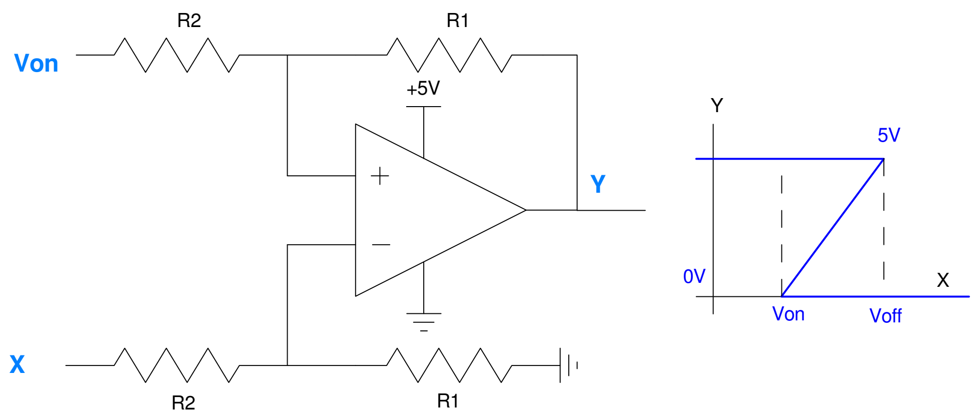
$$Y = \begin{cases} 5V & X > V_{on} \\ 0V & X < V_{off} \\ \text{no change} & V_{off} < X < V_{on} \end{cases}$$

To do this, positive feedback is used.



Schmitt Trigger where Y turns on (5V) for large X

There is also the dual of this circuit: by flipping the inputs, you get the case where Y turns off (0V) for large X



Schmitt Trigger where Y turns off (0V) for large X

Just like the instrumentation amplifier, the slope of the input / output curve determines R1 and R2

$$gain = slope = \left| \frac{5V - 0V}{V_{in} - V_{off}} \right| = \left(\frac{R_1}{R_2} \right)$$

Example: Design a circuit which outputs

- 5V for temperatures more than 20C
- 0V for temperatures below 15C, and
- No change of 15C < T < 20C

Solution: Use a Schmitt Trigger. First, convert temperature to resistance and voltage. Assume a thermistor where

$$R = 1000 \ \exp\left(\frac{3905}{T+273} - \frac{3905}{298} \right) \ \Omega$$

along with a voltage divider with a 1k resistor. At 20C (on)

- R = 1250.59 Ohms
- X = 2.7784V
- Y = 5.00V

At 15C (off)

- R = 1576.17 Ohms
- X = 3.0591 V
- Y = 0.00V

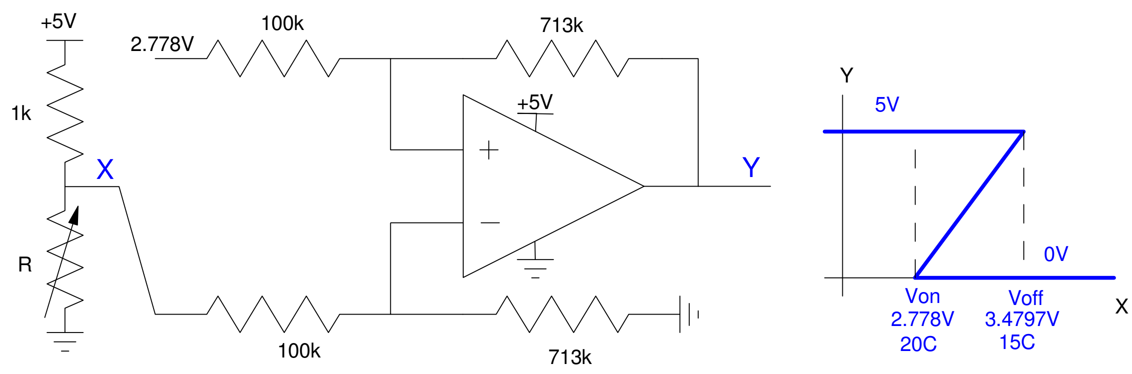
As X goes up, Y goes down. Connect to the minus input.

Y turns on at 2.7784V. Make the offset 2.7784V.

The gain required is

$$gain = \left(\frac{5V - 0V}{3.4797V - 2.7784V}\right) = 7.1296$$

Pick R1 and R2 in a 7.1296 : 1 ratio

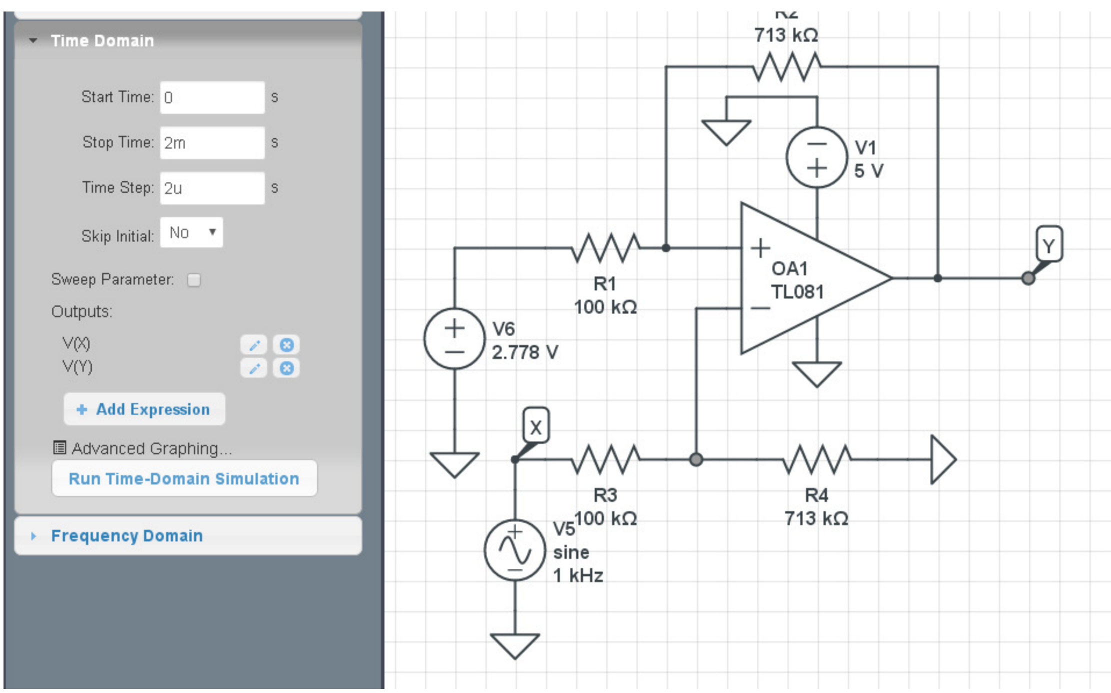


Schmitt Trigger: Y turn on (5V) when T > 20C. Y turns off (0V) when T < 15C.

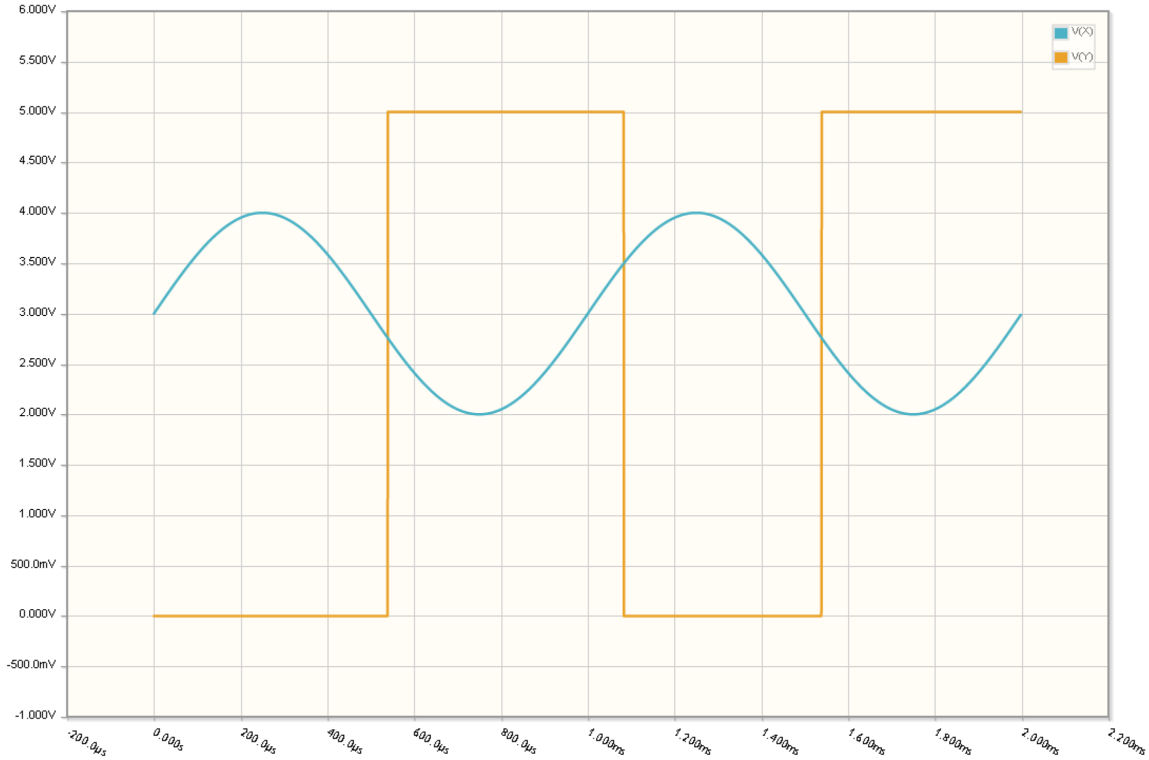
To validate in CircuitLab, you can

- Sweep temperature and verify that Y switches at 20C and 15C, or
- Sweep R and verify that Y switches at 1250 Ohms and 1576 Ohms, or
- Sweep the voltage at X and verify that Y switches at 2.778V and 3.4797V

Doing the latter:



Sweep the voltage at X to see the hysteresis



Output for a Schmitt Trigger
Y (Orange) turns on when X < 2.760V (2.778V calculated)
Y turns off when X > 3.514V (3.4797V calculated)