Comparitors and Schmitt Triggers

Up to now, the op-amps we've been using haven't specified the + and - power supplies. Under most conditions, it doesn't matter what you choose for these - they don't affect the voltage at the output.

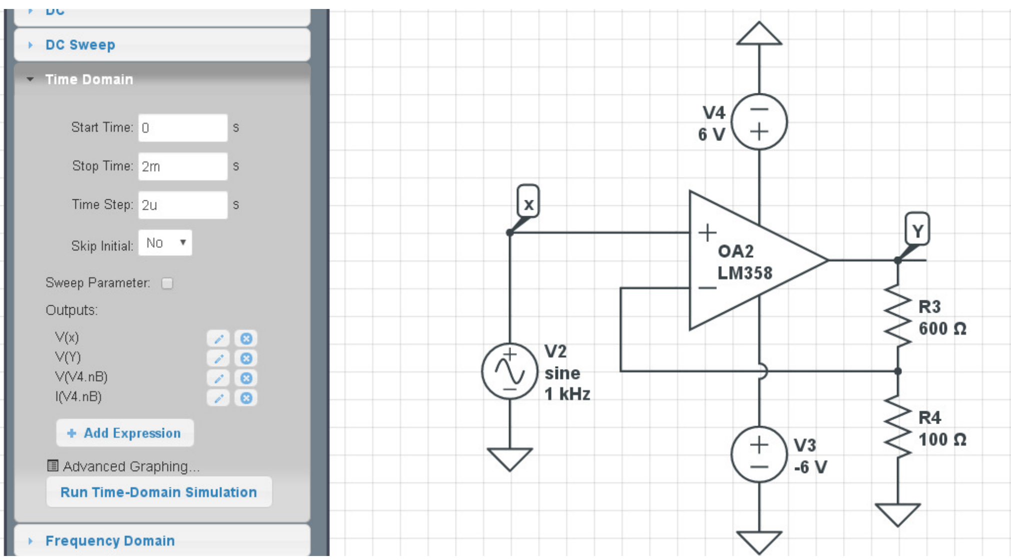
Under some circumstances, however, the power supplies *do* affect the output voltages. This typically happens when you have

- Clipping (are trying to get an output voltage that exceeds your power supplies)
- A comparitor circuit (no feedback), or
- A Schmitt trigger (positive feedback).

Power Supplies and Clipping

The first case where the power supply matters is when you are trying to output a voltage that exceeds the power supply limits, termed clipping. In the circuit below, for example, a noninverting amplifier provides a gain of +7.00 to the signal at x

$$y = 7.00x$$

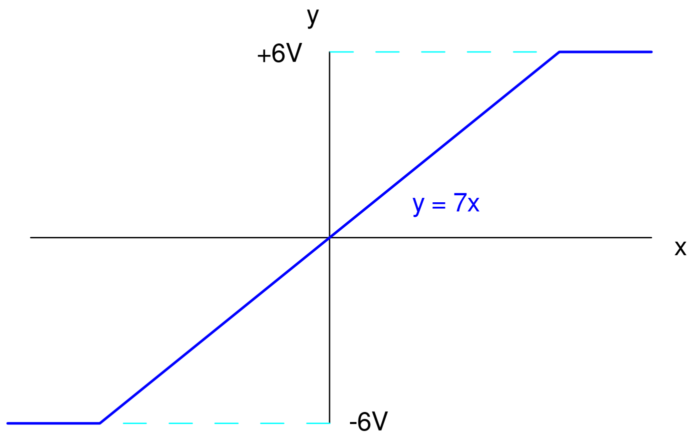


Gain of 7 amplifier. Ideally, y = 7x

With a +6V and -6V power supply, the output will be correct (i.e. y = 7x) as long as the output is in-between these voltages.

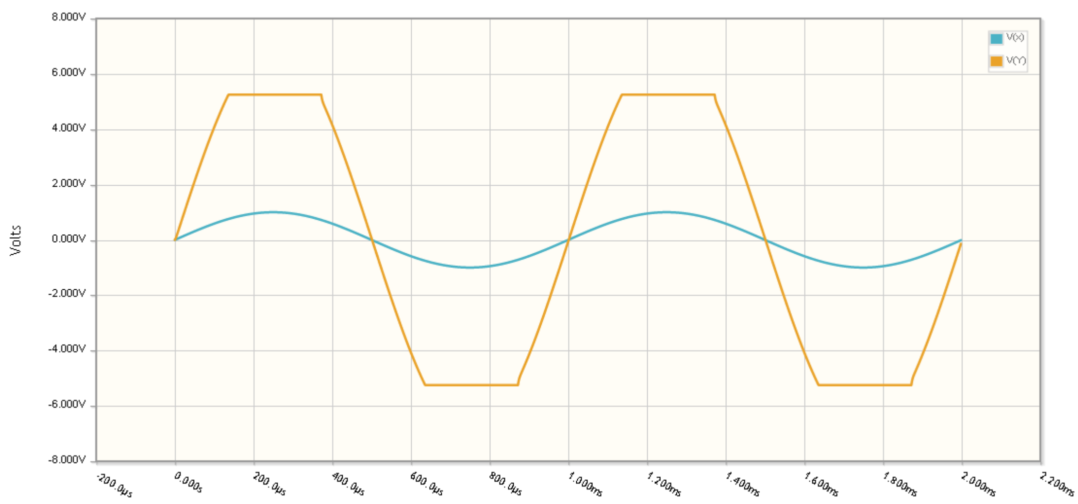
- If you try to output a voltage more than +6.00V, the output will clip at +6.00V (actually slightly less). The op-amp can't create voltage, it can only set the output to something in-between its + and - power supplies.
- Ditto at -6V.

This results in the following input / output relationship



With +/- 6V power supplies, the output (y) is limited to +6V and -6V

If you apply a 1V peak 1kHz sine wave at x, the output will try to be a 7V peak 1kHz sine wave. With a +/- 6V power supply, the output is clipped.



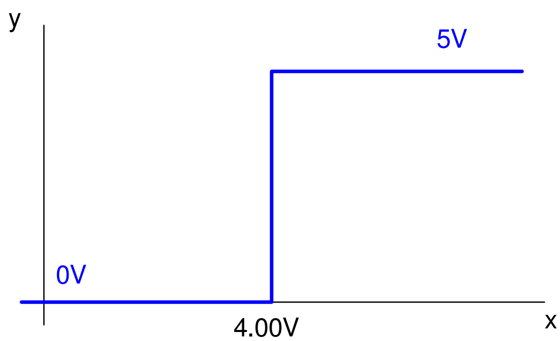
A 1V peak sine wave at the input (x) tries to produce a 7V peak sine wave at the output (y).
The output is clipped at +/- 6V due to the power supply limitations.

To fix this problem, you need to

- Reduce the amplitude of the input, or
- Increase the voltages that power the op-amp.

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

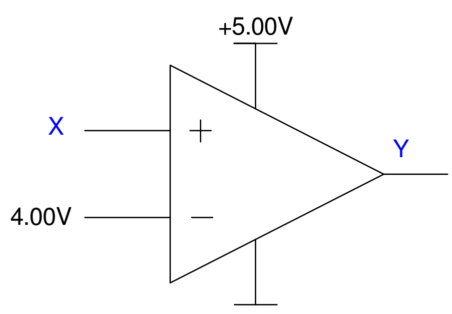
- Turn off a light (0V) or
- Turn on a light (5V)

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

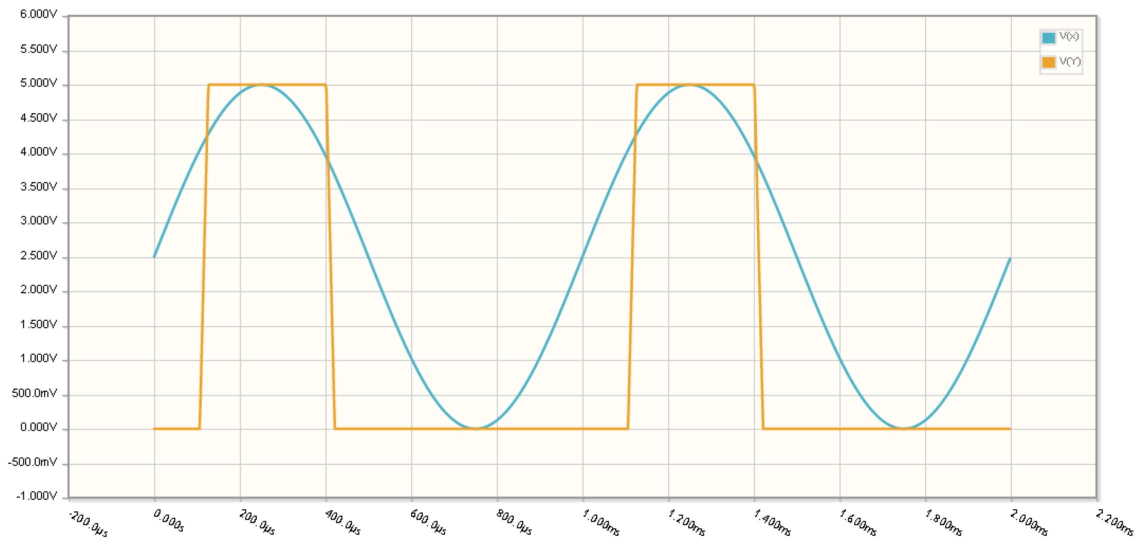
Solution: An op-amp with no feedback works as a comparitor. The limits on Y are set by the power supplies.



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

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

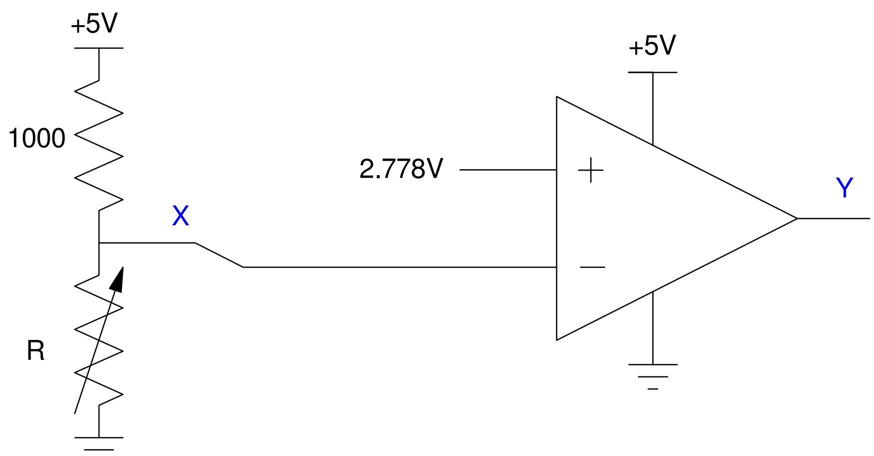
Solution: Use a voltage divider to convert resistance to voltage. At 20C

- 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.



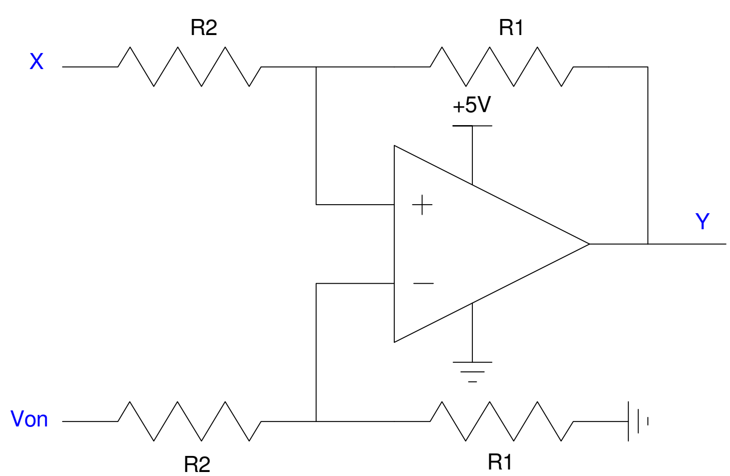
Comparitor: Y = 5V * (T > 20C)

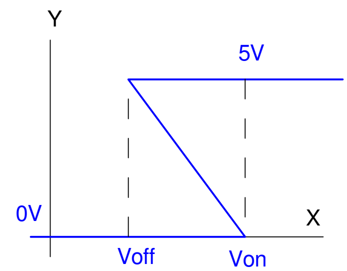
Schmitt Trigger

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:

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

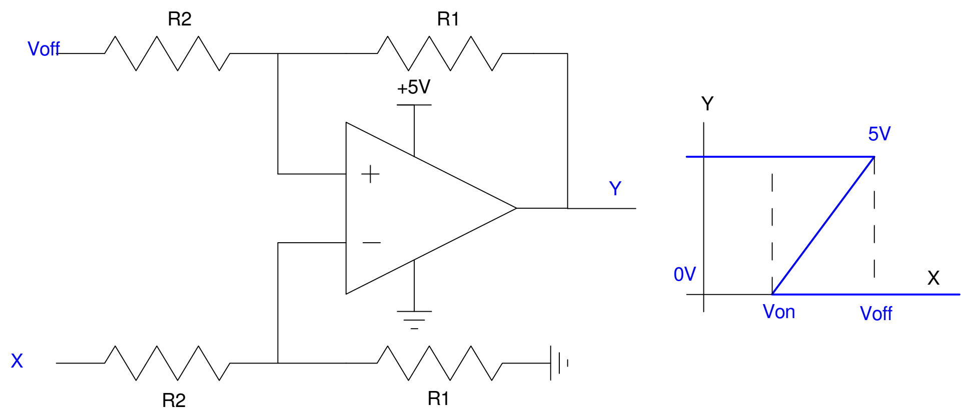
To do this, positive feedback is used.





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

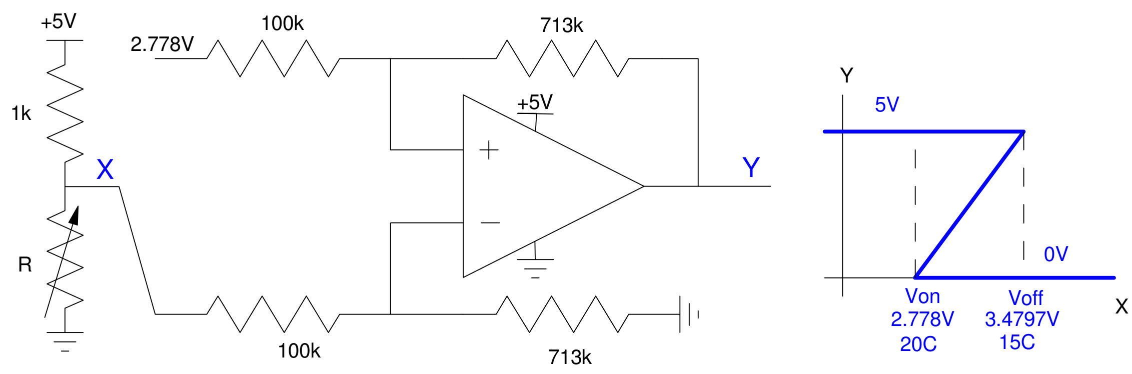
As X goes up, Y goes down. Connect to the minus input.

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 6.1296 : 1 ratio

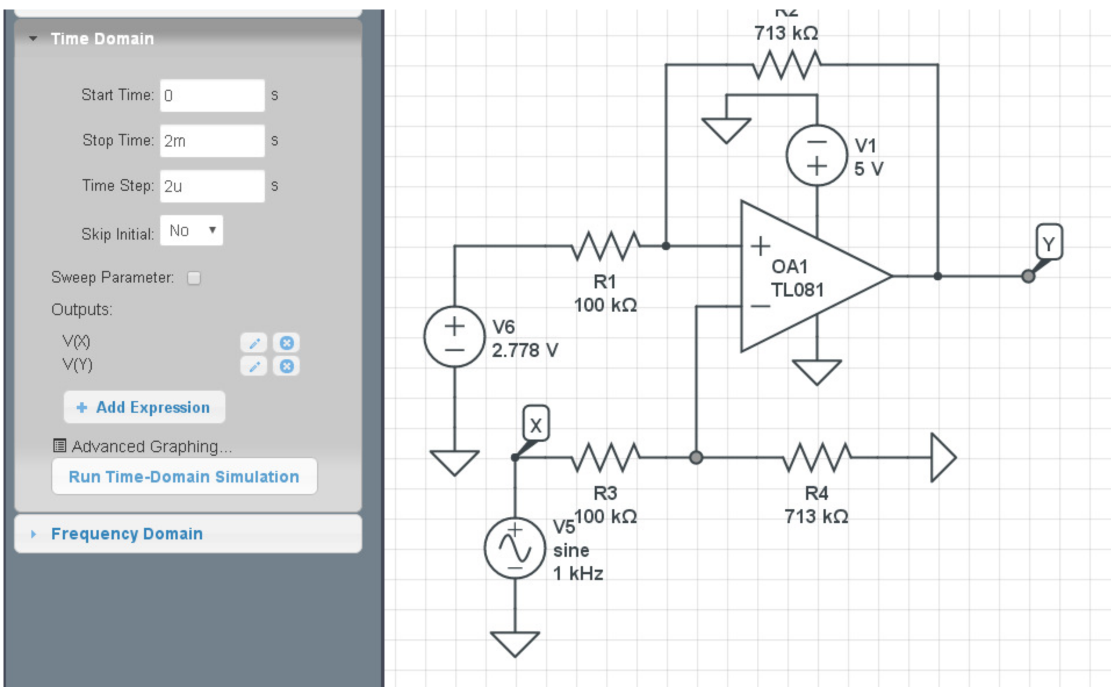


Schmitt Trigger: Y turn on (5V) when T > 20C. Y turns off (0V) when T < 15C.

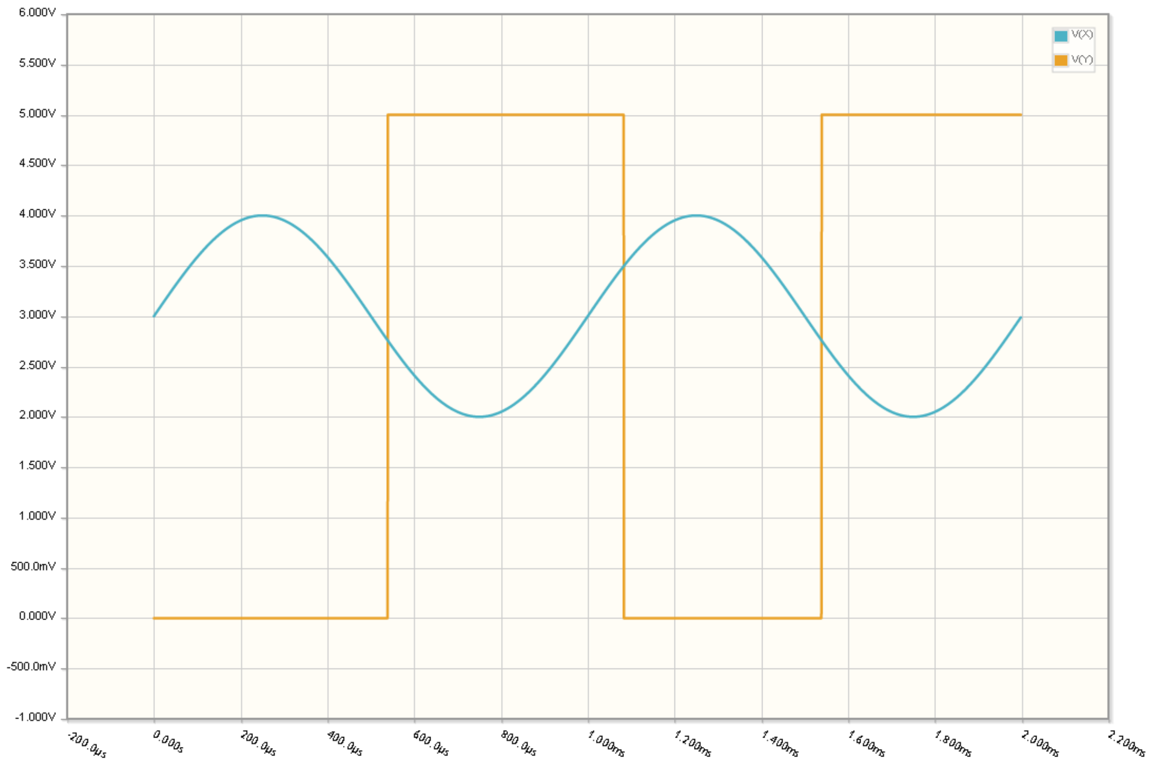
To validate in CircuitLab, you can

- 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)