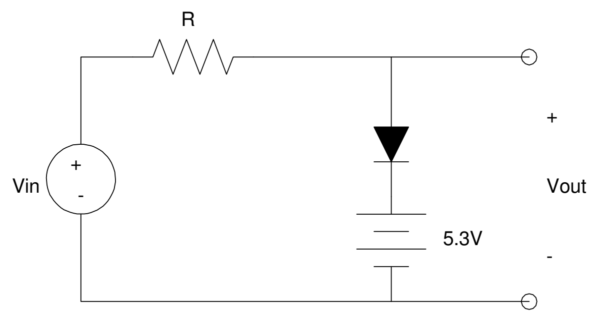
Clippers & Clampers

Clipper Circuits:

Problem: Design a circuit which clips the voltage output at <6V using an ideal silicon diode.

Solution:

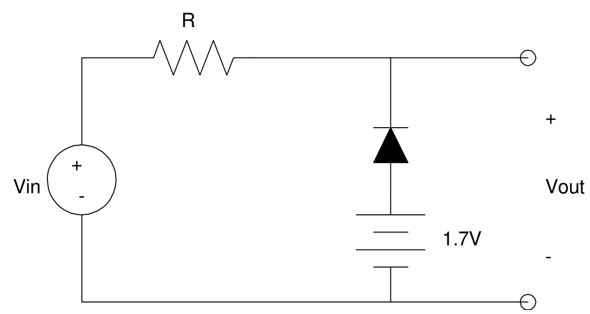


Assume the diode is off. In this case, Vout = Vin.

Now, assume the output is large (say, +10V). The diode has more than 0.7V across it, so it turns on. When it turns on, the output is clipped at +6V (0.7V + 5.3V = 6.0V).

Problem: Design a circuit which clips the voltage at the output at >1V.

Solution:

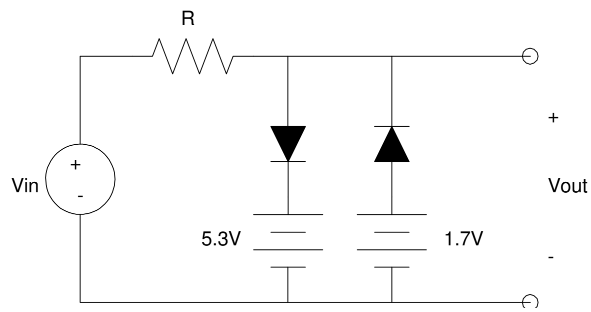


Assume the diode is off. Again, Vout = Vin.

Now, assume Vout is small (say, -10V). Now the diode is forward biased and turns on. The voltage at the output is then 1.0V (-0.7V + 1.7V = 1.0V).

Problem: Design a circuit which clips a signal at +1V < Vout < +6V.

Solution: Put the previous two circuits in parallel:



When Vout is large (+10V), D1 turns on, D2 turns off, and the output clips at +6V.

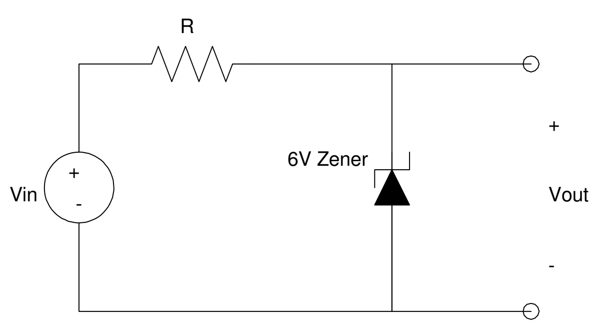
When Vout is small (-10V), D2 turns on, D1 turns off, and the output clips at +1V.

When 1V < Vout < Vin, both diodes are off and Vout = Vin.

Zener Diodes

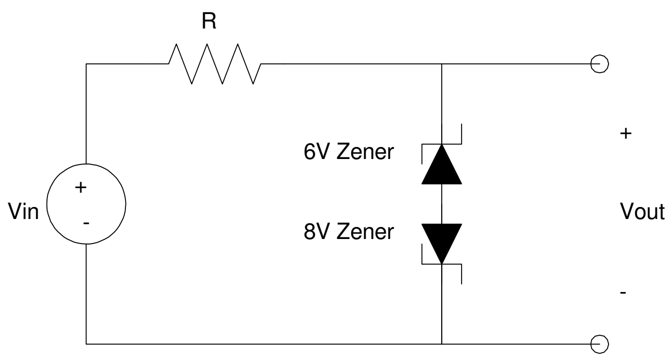
An easier solution is to use a Zener diode. Zener diodes are special diodes which are designed to break down at a certain voltage when reverse biased. For example, a 6V Zener diode will have a fixed, 6V drop across it if you try to reverse bias it by more than 6V. (i.e. a zener diode will dump whatever current is required to hold the voltage at 6V.)

If you want to clip an output at <6V, use a 6V Zener diode as follows. If the output tries to exceed 6V, the Zener diode turns on and keeps the output at +6V. Note that a zener diode is still a diode. If the output tries to go below -0.7V, the diode turns on like any silicon diode would and clips the output at -0.7V as well.



If you want to clip an output at > -8V, flip the diode around and use a 8V zener diode.

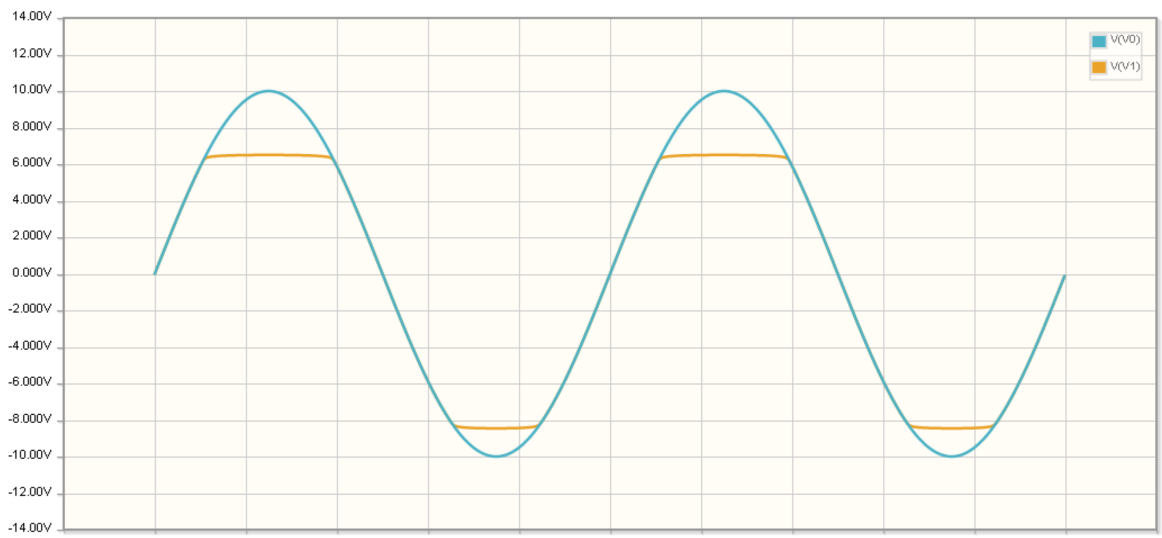
If you want to clip an output between -8V < Vout < +6V, use two zener diodes:



Clipper circuit which limits the output to -8V < Vout < +6V

If you simulate this in CircuitLab, the output isn't *exactly* clipped at -8V and +6V. This is due to

- There is a 0.7V drop across the Zener diode when forward biased (it's still a diode)
- Zener diodes are not ideal: as you push more current through them, the voltage drop increases slightly.

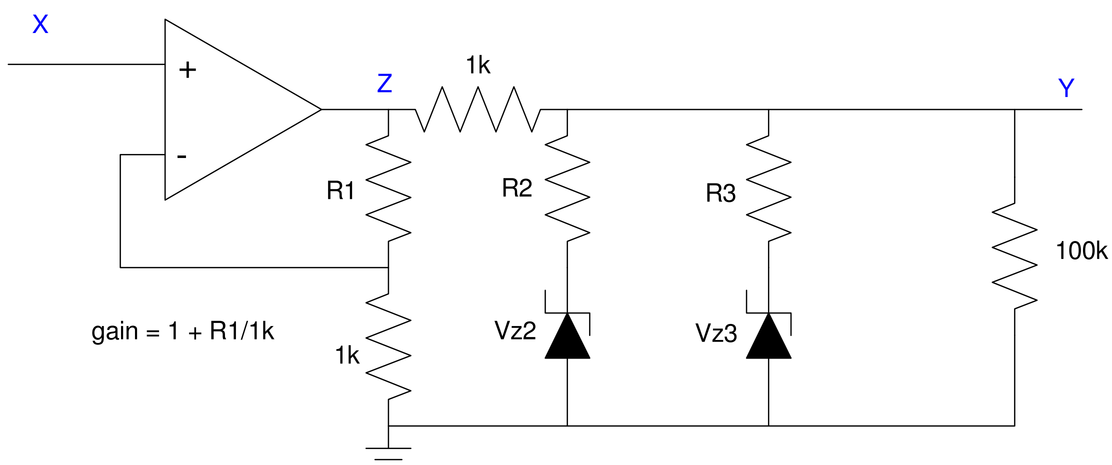


10V sine wave (blue) clipped at -8V and +6V (orange)

This configuration is fairly common. If you want to protect an electronic device from abuse, two zeners are often placed across the input pins as shown above. In normal operation, one of the zener diodes is off and the diodes have no affect. If the operator tries to hit your device with +24V, the zeners turn on. clip the input at +6.7V, and protect your device.

Function Approximation

With a clipper circuit, you can approximate different functions. The heart of this circuit is as follows:



Function Approximation: Vz1 < Vz2 < Vz3

Here, the circuit is to drive a load of 100k or more. So that you can ignore the 100k load, assume a 1k resistor is connected to the op-amp.

The circuit operates as follows:

Assume the zener votlages increase as you go right

Vz2 > Vz1.

The circuit operates in three regions:

Y < Vz1: Both zener diodes are off. This is just a non-inverting amplifier

$$Y = kX = \left(1 + \frac{R_1}{1k}\right)X$$

Vz1 < Y < Vz2: Zener #1 turns on and you get voltage division at the output

$$Slope = k\left(\frac{R_2}{R_2+1k}\right)$$

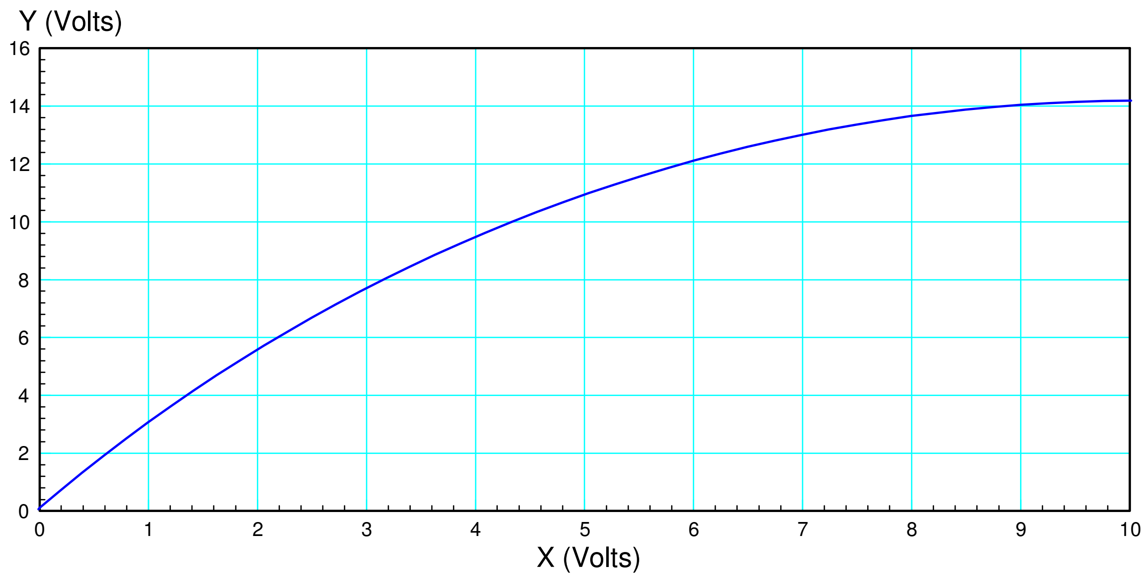
Y < Vz2: Both zener diodes turn on. By voltage division

$$Slope = k\left(\frac{R_1||R_2}{R_1||R_2+1k}\right)$$

It's probably easier to see this with an example.

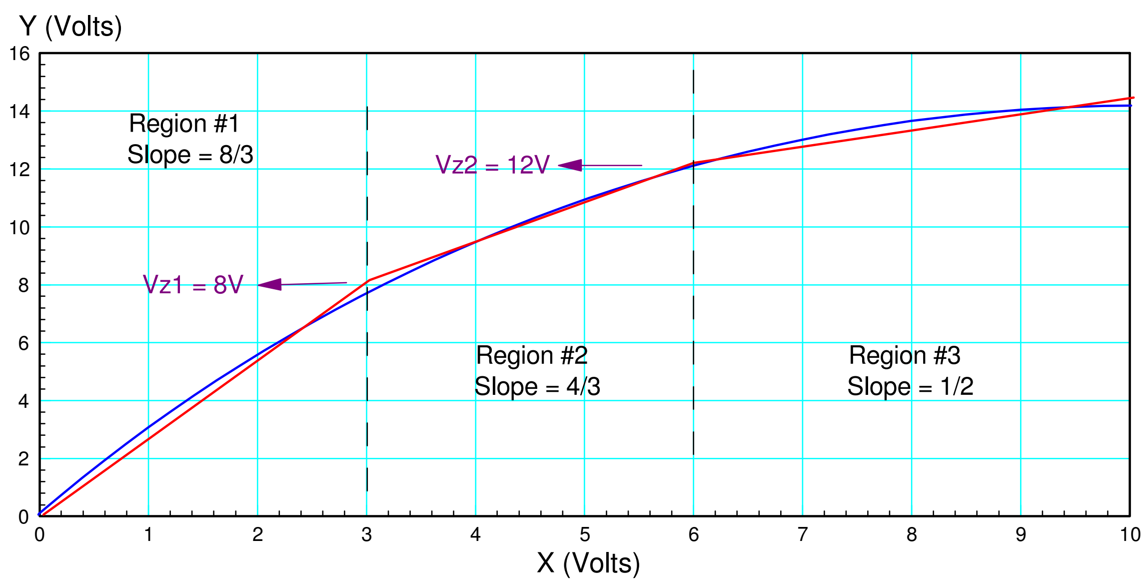
Problem: Design a circuit to implement the following function:

- Tolerance: +/- 0.5V



Solution:

Step 1: Approximate this curve with straight lines. If a line deviations from the function by more than 0.5V (the tolerance), add another straight line.



Approximate the function (blue) with straight lines (red)

Step 2) Find R1 (Set the slope in region #1)

$$Slope = k = 1 + \frac{R_1}{1k} = \frac{8}{3}$$

$$R_1 = 1667\Omega$$

Step 3) Find R2 and Vz2 (Region #2)

The zener voltage is the voltage at the output (y-axis) where the slope changes

$$V_{z1} = 8V$$

The slope is determined by R2 by voltage division

$$slope = k\left(\frac{R_2}{R_2+1k}\right) = \frac{4}{3}$$

$$R_2 = \left(\frac{4/3}{k-4/3}\right)\ 1k = 1k\Omega$$

Step 4: Find R3 and Vz3 (Region #3)

The zener voltage is the voltage at the output (y-axis) where the slope changes

$$V_{z2} = 12V$$

The slope is determined by R2 || R3 by voltage division

$$slope = k\left(\frac{R_2||R_3}{R_2||R_3+1k}\right) = \frac{1}{2}$$

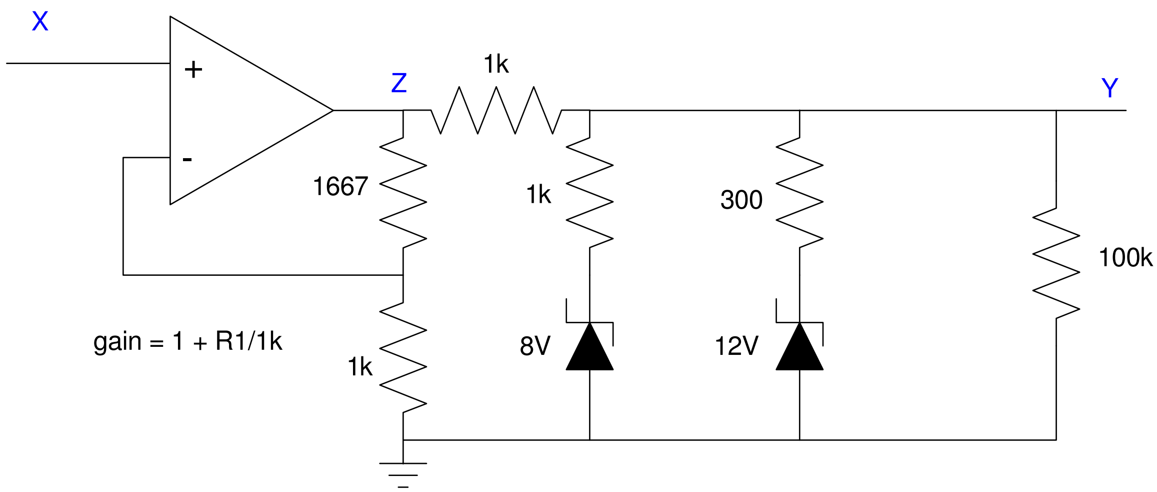
$$R_2||R_3 = \left(\frac{1/2}{k-1/2}\right)\ 1k = 230.77\Omega$$

Since R2 = 1k

$$\frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{230.77}$$

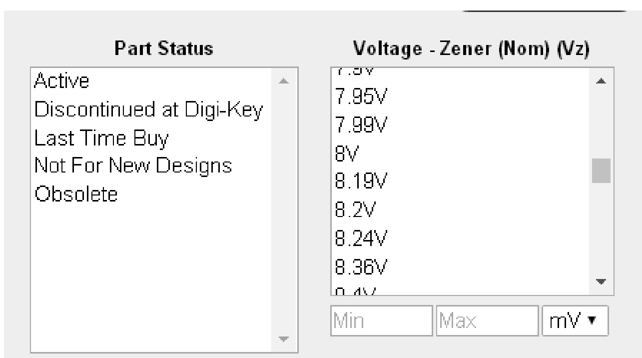
$$R_3 = 300\Omega$$

The resulting circuit is then



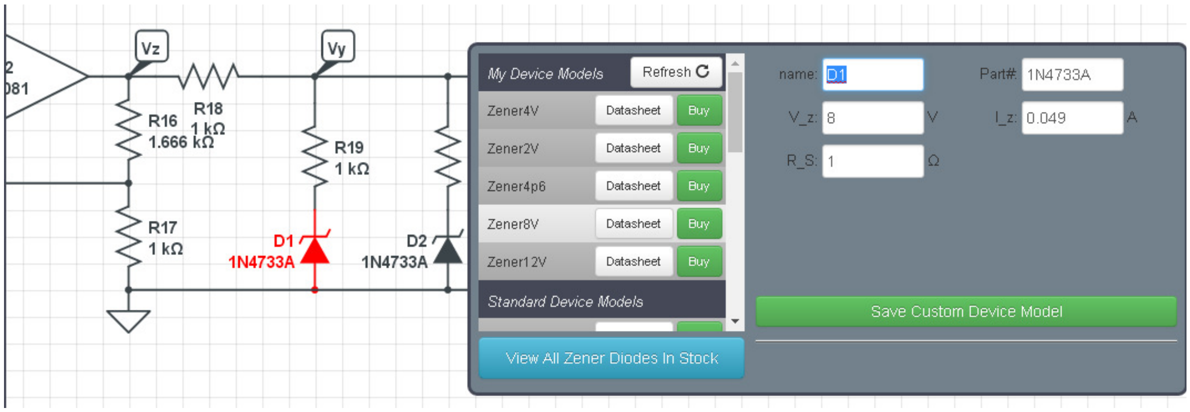
Digikey Parts

Digikey sells over 64,000 zener diodes. Whatever voltage you want, they'll have something close

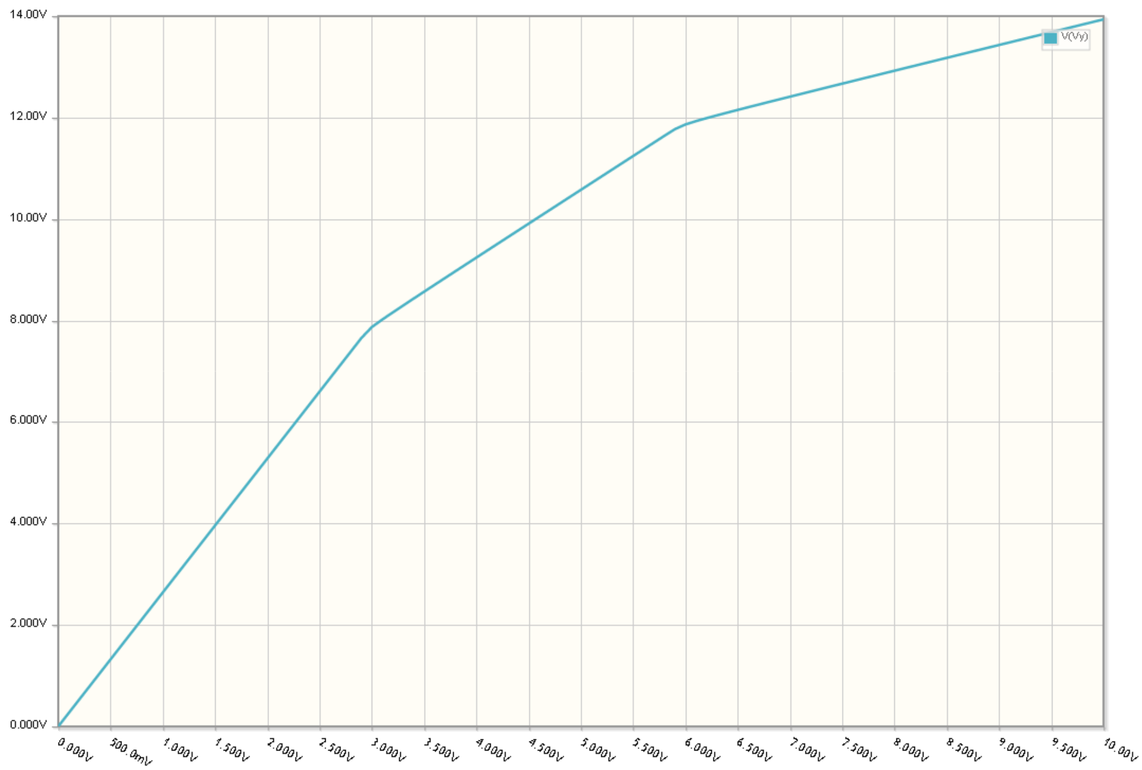


CircuitLab Simulation

CircuitLab doesn't have 8V and 12V zener diodes. You can modify a part to make these, however, by double clicking on the part.



Setting the zener voltages to 8V and 12V, and then sweeping the input voltage from 0V to 10V results in the following voltage plot at Y:



Clipper circuit implementation of Y = f(X)