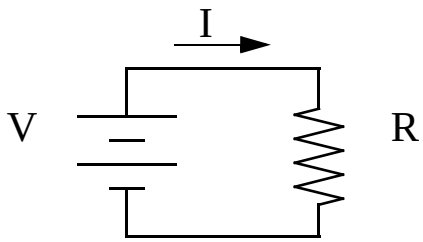
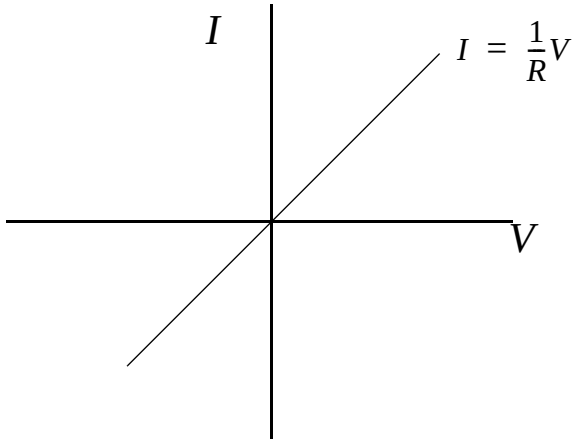
DC Circuits

- Basic DC circuits consist of resistors and batteries.
- Ohm's law governs the behavior of resistors.

$$V = IR$$



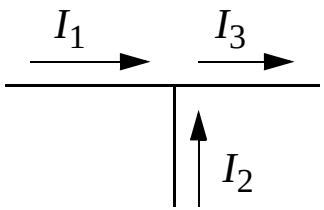
- Ohmic devices have a linear voltage - current relationship.



Kirchhoff's Laws

- There are two rules that can be applied to circuit analysis.

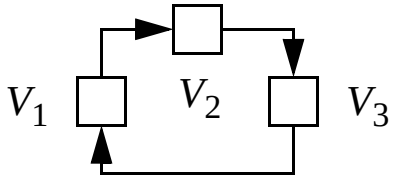
- Kirchhoff's current rule



Current is conserved

$$I_3 = I_1 + I_2$$

- Kirchhoff's voltage rule

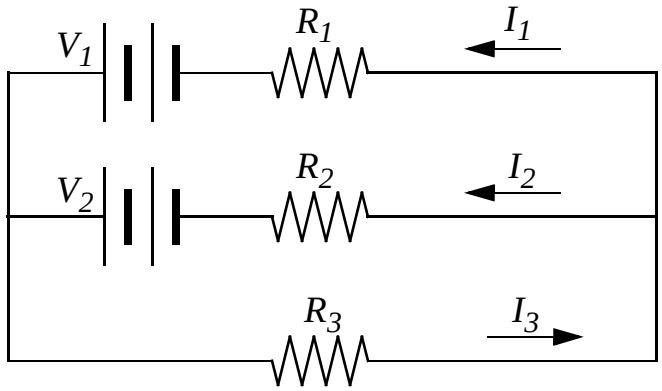


Voltage is conserved

$$V_1 + V_2 + V_3 = 0$$

Branch Method

- Label a current through each branch of the circuit.
- Set up a set of independent equations for the junctions (current law) and loops (voltage law) in the circuit.



V_1 = 16 V

V_2 = 6 V

R_1 = 2 kΩ

R_2 = 4 kΩ

R_3 = 5 kΩ

- Current law: $I_3 = I_1 + I_2$
- Voltage law:

$$V_1 - V_2 = R_1 I_1 - R_2 I_2$$

$$V_2 = R_2 I_2 + R_3 I_3$$

- Solve for I_1, substituting for I_3 and I_2:

$$V_2 = R_2 I_2 + R_3 I_1 + R_3 I_2$$

$$V_2 = R_1 I_1 + V_2 - V_1 + R_3 I_1 + (R_3 / R_2)(R_1 I_1 + V_2 - V_1)$$

$$R_1 R_2 I_1 + R_2 R_3 I_1 + R_1 R_3 I_1 = R_2 V_1 + R_3 V_1 - R_3 V_2$$

$$I_1 = (R_2 V_1 + R_3 V_1 - R_3 V_2) / (R_1 R_2 + R_2 R_3 + R_1 R_3)$$

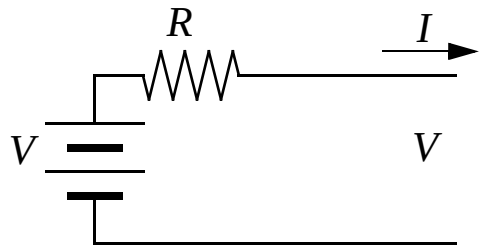
- Finally,

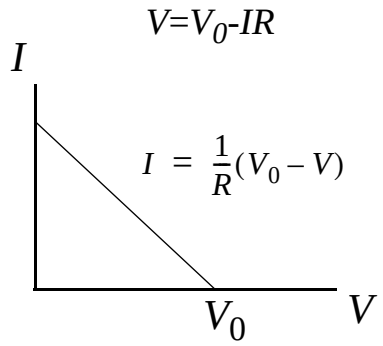
  I_1 = 3 mA, I_2 = -1 mA, I_3 = 2 mA.

Load Line

V-I Curves

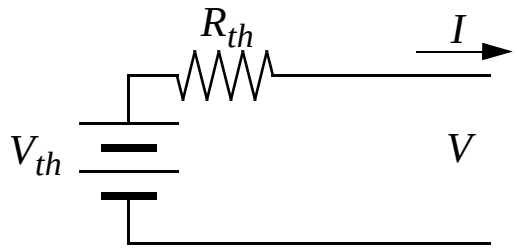
- A battery and resistor in series has a characteristic voltage - current graph.





Thevenin Equivalent

- Any circuit of batteries and resistors can be reduced to one battery and one resistor in series.
- Any set of circuit equations is reduced to $V(I) = V_{th} - IR_{th}$.



Procedure

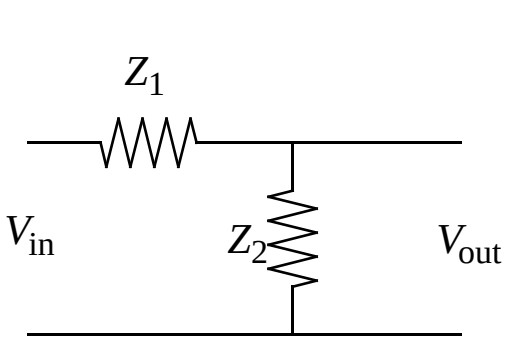
1. Find the voltage with no external circuit as V_{th}.
2. Find the current that would flow through an external short circuit.
3. Find the equivalent resistance as $R_{th} = V_{th}/I_{sc}$.
4. The R_{th} is the same if all batteries are shorted and resistance measured.

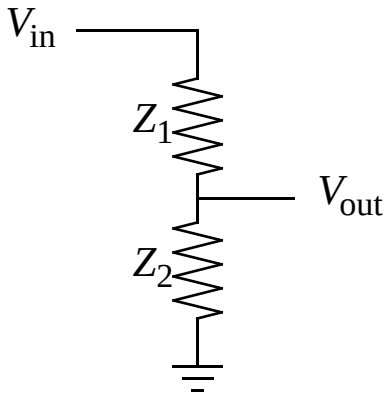
Norton's Theorem

- Any circuit of batteries and resistors can be reduced to one current source and one resistor in parallel.

4-Terminal Circuits

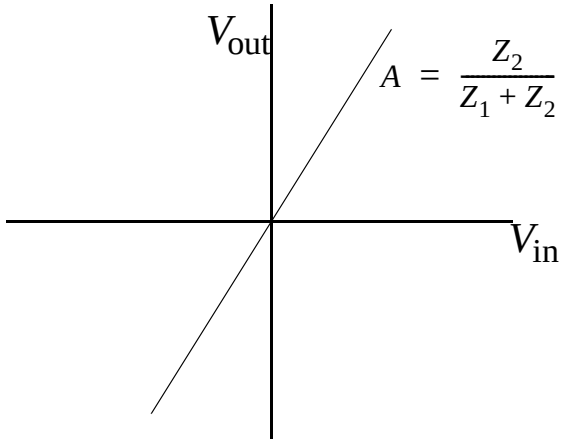
- Voltage dividers





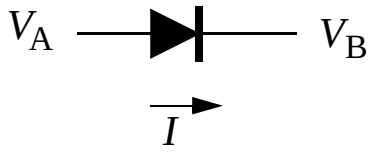
$$\frac{V_{out}}{V_{in}} = \frac{Z_2}{Z_1 + Z_2}$$

- The ratio V_{out}/V_{in} is the *gain A*.
- $V_{out} = f(V_{in})$ is the *transfer characteristic*.



Diodes

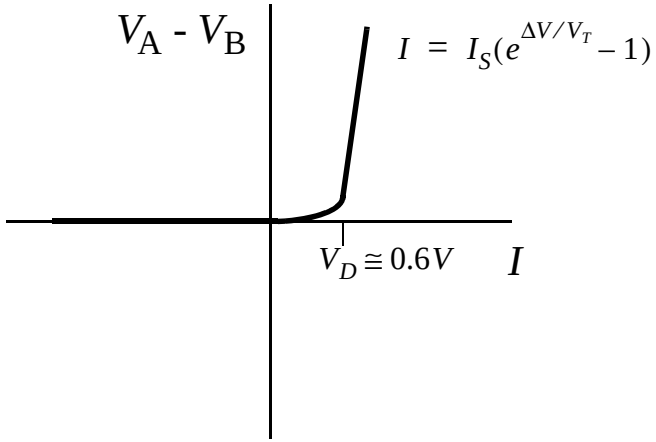
- Diodes permit one-way current flow.



$If\ V_{in} > V_{out} + 0.6\ V,\ i > 0$

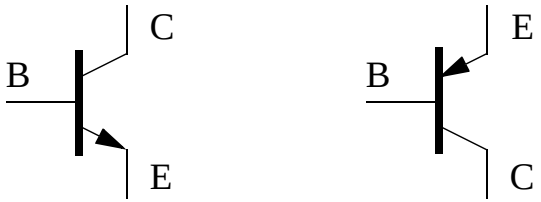
$If\ V_{in} < V_{out} + 0.6\ V,\ i = 0$

- Diode behavior displayed as a *v*-*i* characteristic



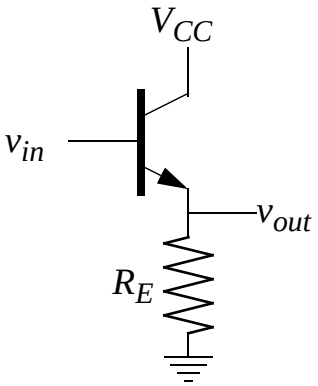
Bipolar Junction Transistor

- The BJT is built like a diode sandwich.
- Quantum properties of the BJT allow for transconductance.



$$I_C = \beta I_B$$

- The emitter follower has the emitter voltage track the base voltage.



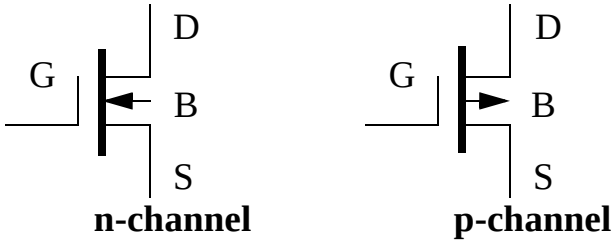
$$V_E = V_B - 0.6V$$

$$v_{out} = v_{in}$$

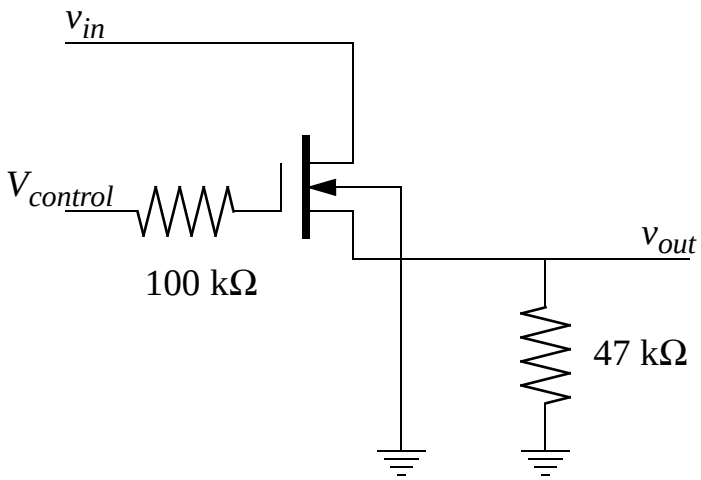
$$I_E = I_C + I_B = (\beta + 1) I_B$$

Field Effect Transistor

- MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) has an input (gate) impedance which is very high (10^{14} Ω).

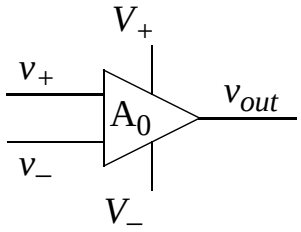


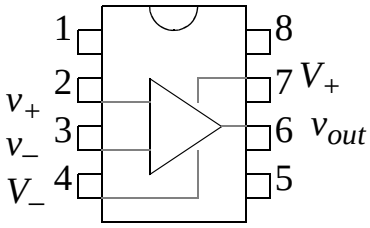
- The MOSFET can be used as a bidirectional switch, like a mechanical switch.
- There is a voltage divider with R_{DS} and the 47 kΩ resistor.
- When the gate is ground or negative, $R_{DS} > 10^{10}$ Ω, $v_{out} < 0.0001 v_{in}$.
- When the gate is + 15 V, $R_{DS} = 100$ Ω, $v_{out} = 0.998\ v_{in}$.



Operational Amplifiers

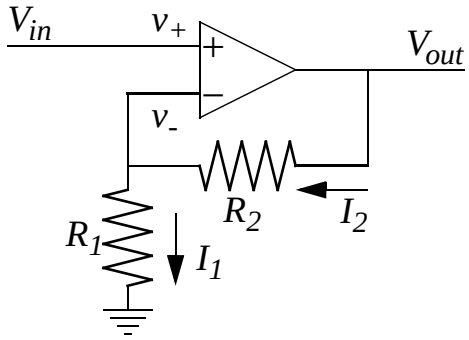
- An op-amp is a difference amplifier with power supplies at V_+ and V_-.





$$v_{out} = A_0(v_1 - v_2)$$

- Op amps have special properties when used with negative feedback.



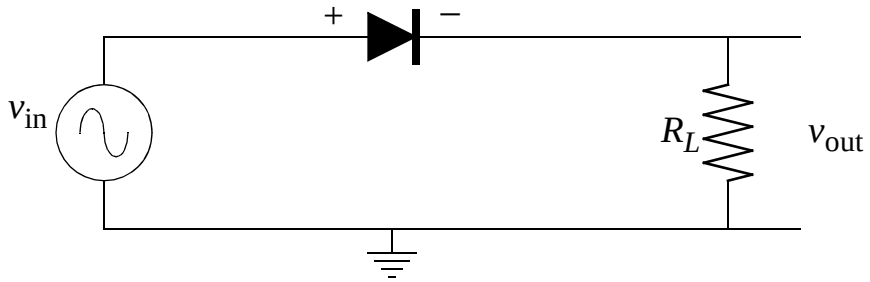
$$A = \frac{V_{out}}{V_{in}} = \frac{I_1R_1 + I_2R_2}{I_1R_1} = 1 + \frac{R_2}{R_1}$$

- There are two rules to analyze a circuit with an op amp.

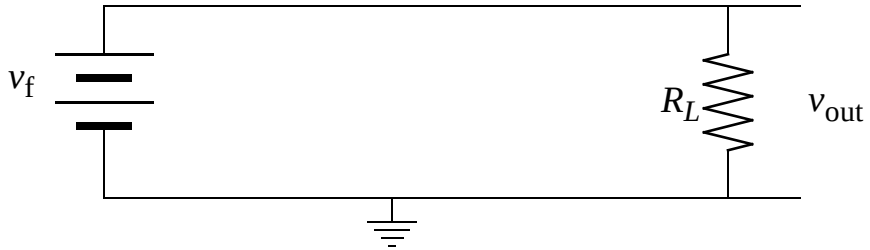
1. $I_+ = I_- = 0$
2. $v_+ - v_- = 0$

Forward Bias Diode

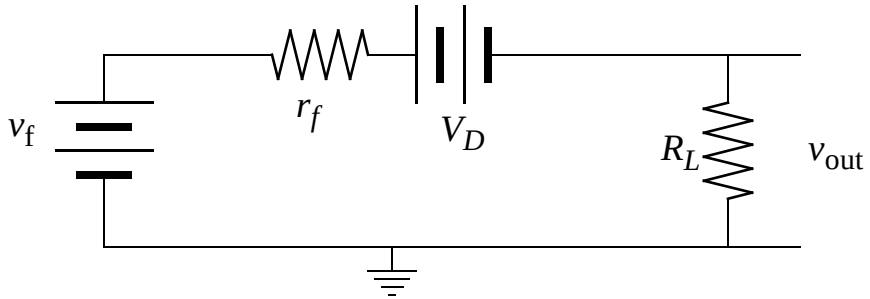
- Consider a single diode with an AC signal.



- A diode will “short-circuit” signals in the forward direction.

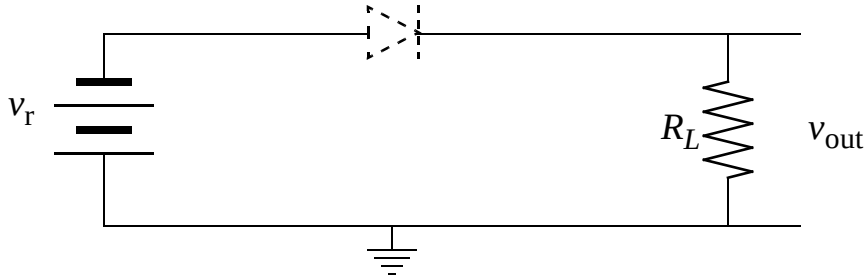


- Real diodes are modeled by an equivalent resistance and diode voltage drop.

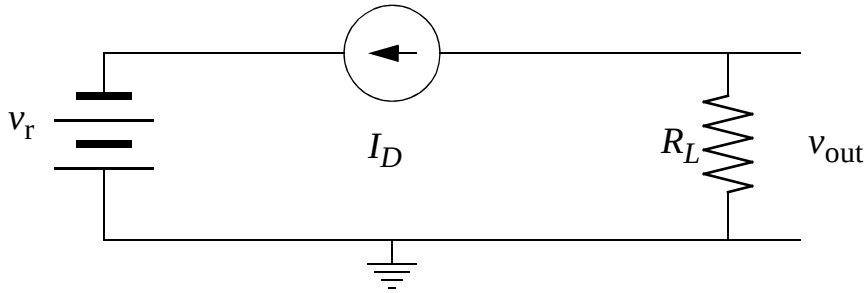


Reverse Bias

- A diode will block signals in the reverse direction.

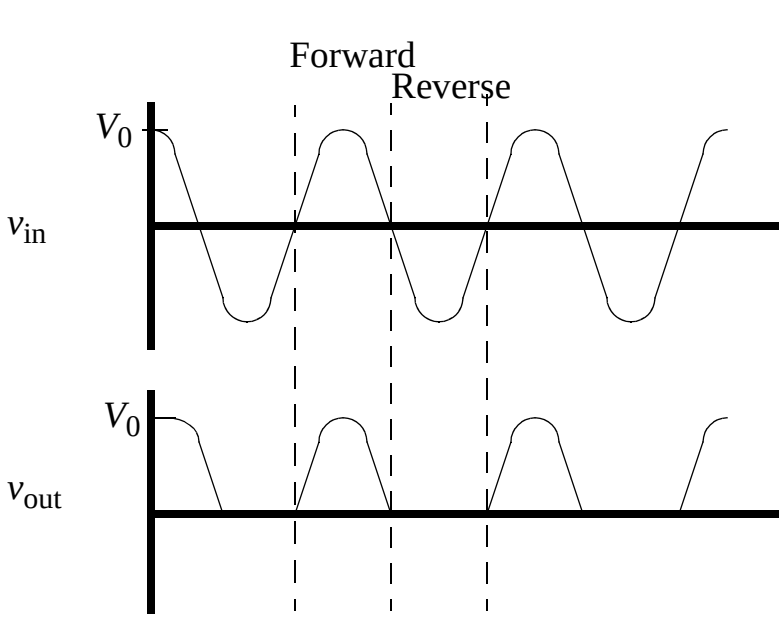


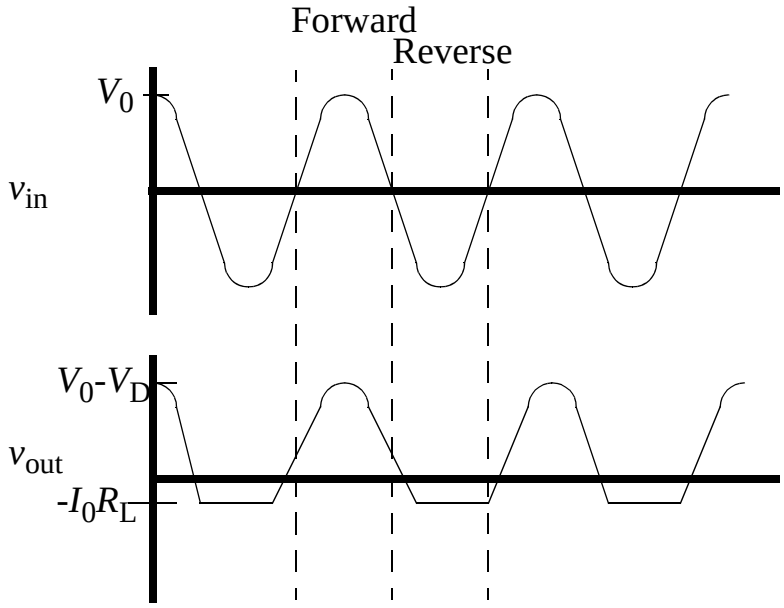
- Real diodes pass a small amount of reverse current.



Half-wave Rectifier

- Ideal behavior doesn't match real behavior.

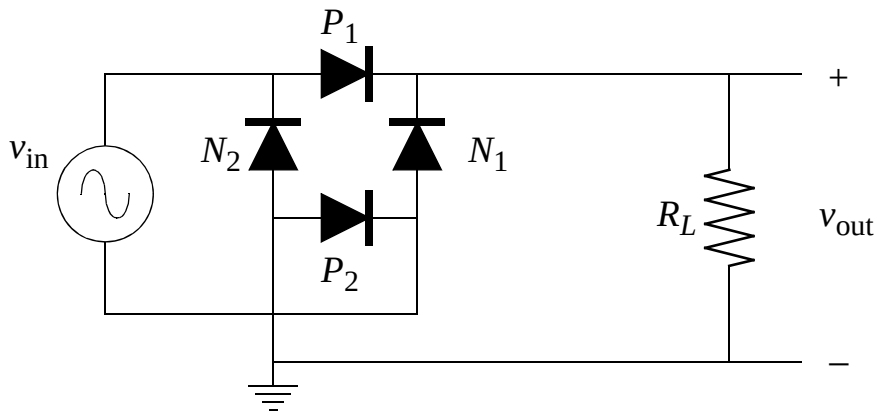


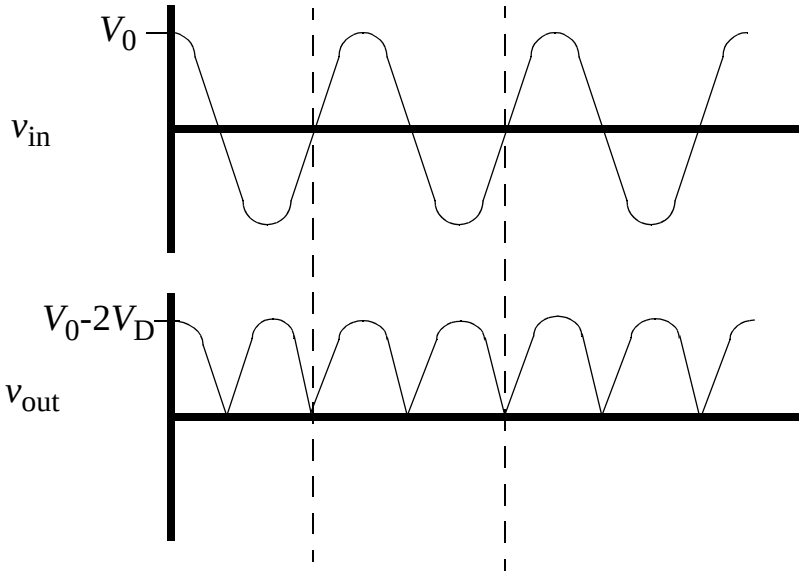


- Forward voltage is slightly less.
- Reverse current isn't zero.

Full-wave Rectifier

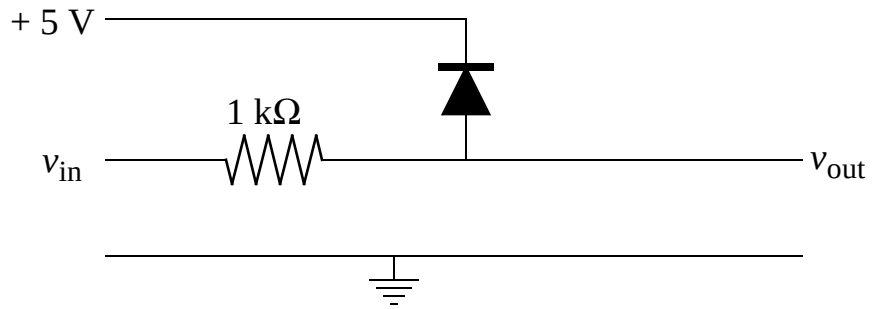
- Two half-have rectifiers in parallel make a full-wave rectifier.
- When v_{in} is positive the current flows through P_1, R_L, and P_2.
- When v_{in} is negative the current flows through N_1, R_L, and N_2.





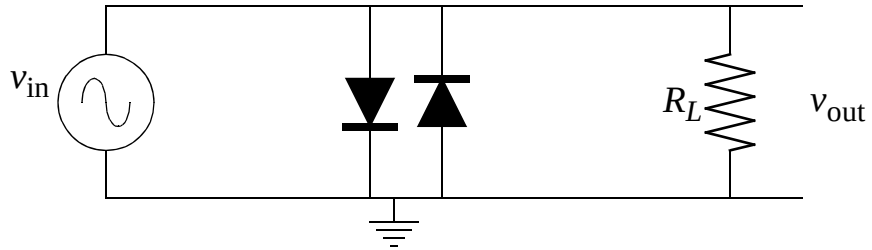
Diode Clamp

- A clamps cuts off current at voltages other than ground.



If $v_{in} > 5.6$ V, $v_{out} = 5.6$ V.

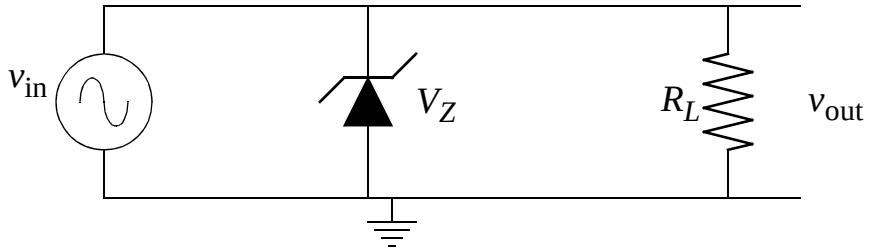
- Two diodes reversed in parallel become a limiter.



If $v_{in} > 0.6$ V, $v_{out} = 0.6$ V, if $v_{in} < -0.6$ V, $v_{out} = -0.6$ V

Zener Diode

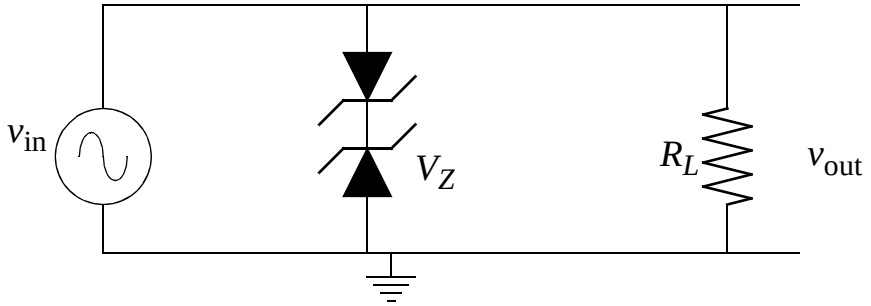
- Zener diodes have well defined reverse breakdown voltages and allow sufficient current to flow to maintain a constant voltage drop.



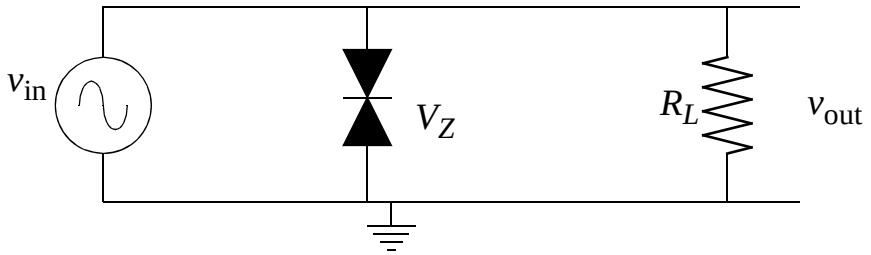
If $v_{in} > V_Z$, $v_{out} = V_Z$.

- Two zeners can be combined to form a limiter.

If $v_{in} > V_Z + V_f$, $v_{out} = V_Z$, if $v_{in} < -(V_Z + V_f)$, $v_{out} = -(V_Z + V_f)$

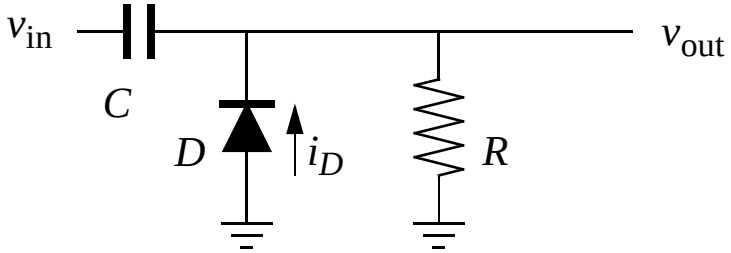


- The pair of diodes are sold in one package as a transient suppressor.



Diode Bias

- Diodes can bias a circuit to a value other than 0 volts.



- Without the diode this is a high-pass filter.
- With the diode: for $v_{in} = V_0 \sin \omega t$, $v_{out} = v_{in} + V_0 - 0.6$ V.