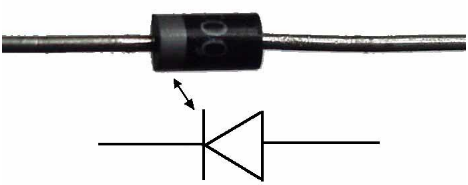
Diode Circuits

Prof. Ali M. Niknejad and Prof. Rikky Muller

U.C. Berkeley

March 2, 2017

Diode Introduction

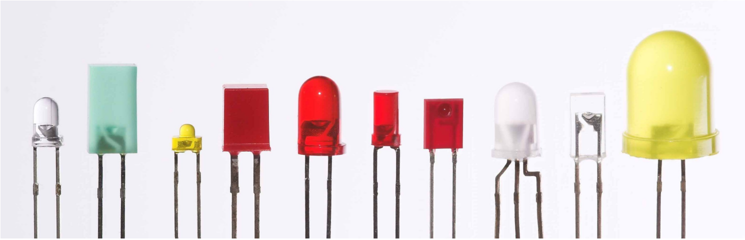


A diode is a non-linear element. To a very good approximation, the current through the diode is exponentially related to the voltage across the diode.

In most of today's lecture, we will excite the diode with "large" signals and therefore we cannot use the small-signal model.

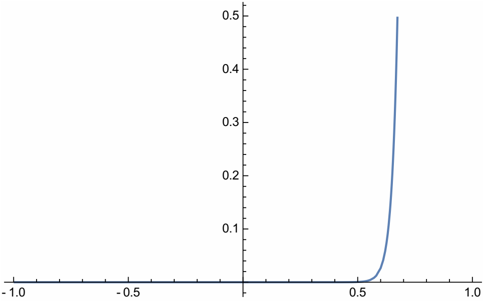
Diodes are manufactured primarily using a semiconducting process. The junction between two semiconducting materials creates a diode.

Light Emitting Diode (LED)



A light emitting diode emits light (of a particular color) when current flows through the diode. The conversion efficiency is much better than light bulbs.

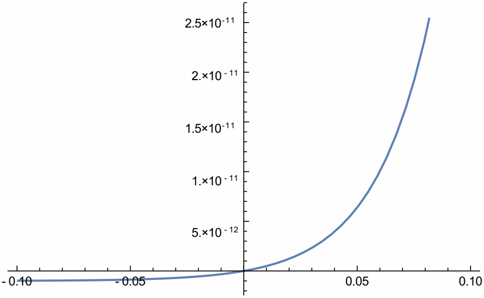
Diode I-V Curve (Forward)



When a "forward-bias" is applied across the diode, lowering the built-in potential, a rush of current flows across the junction. It can be shown that this current is an exponential function of the barrier height.

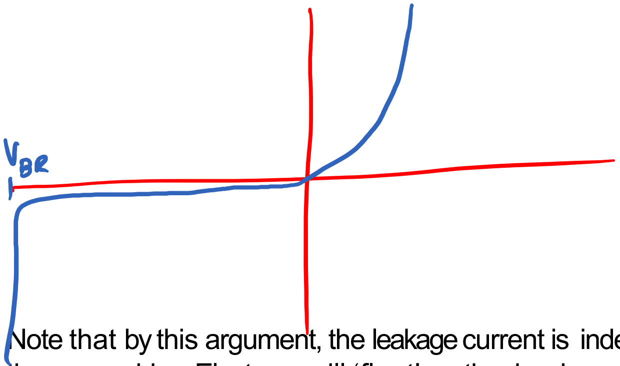
When a "reverse-bias" is applied, the barrier height increases, and so no current flows.

Diode Leakage and Reverse Breakdown



Even without a forward bias voltage, some small leakage current flows through the diode. This is because there are always a very small number of electrons (holes) in the p-type (n-type) material that are moving around. If they reach the potential barrier, they “float up” (remember they are electrons) or “fall” off the barrier. There are so few electrons (holes) in the p-type (n-type) material that this is a rare occurrence.

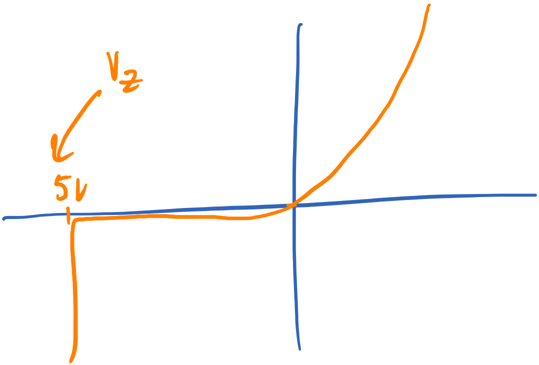
Diode Leakage and Reverse Breakdown



Note that by this argument, the leakage current is independent of the reverse bias. Electrons will 'float' up the barrier no matter the height! Holes will 'fall' down the barrier no matter the height.

If a sufficiently negative voltage is applied, the internal barrier height gets so large that breakdown occurs. Then a seemingly unlimited current can flow.

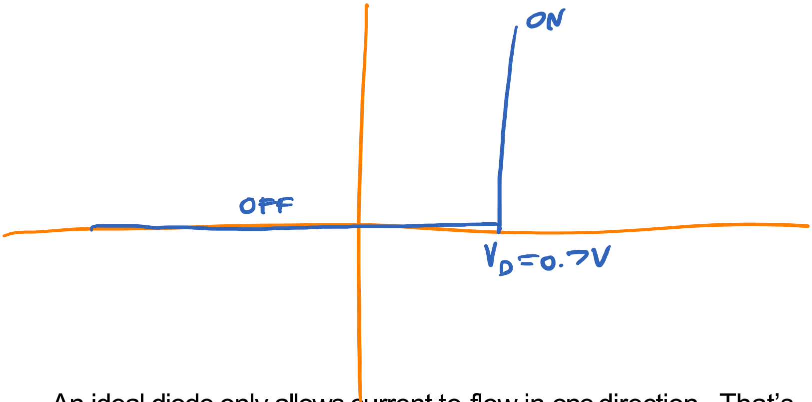
Zener Reference



When breakdown occurs, the diode behaves like a battery. No matter what current is drawn, the voltage is nearly constant. This is often used as a voltage reference.

The breakdown mechanism can be due to quantum mechanical tunneling or due to avolanch breakdown.

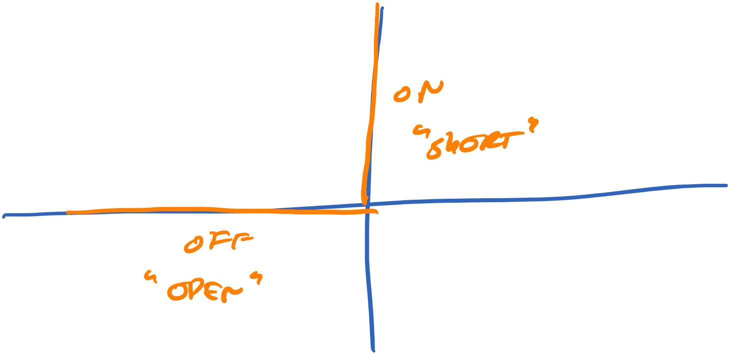
Ideal Diode Model



An ideal diode only allows current to flow in one direction. That's because the current is zero when a negative voltage is applied. When a positive voltage is applied, any current can flow and so the diode looks nearly like a short circuit.

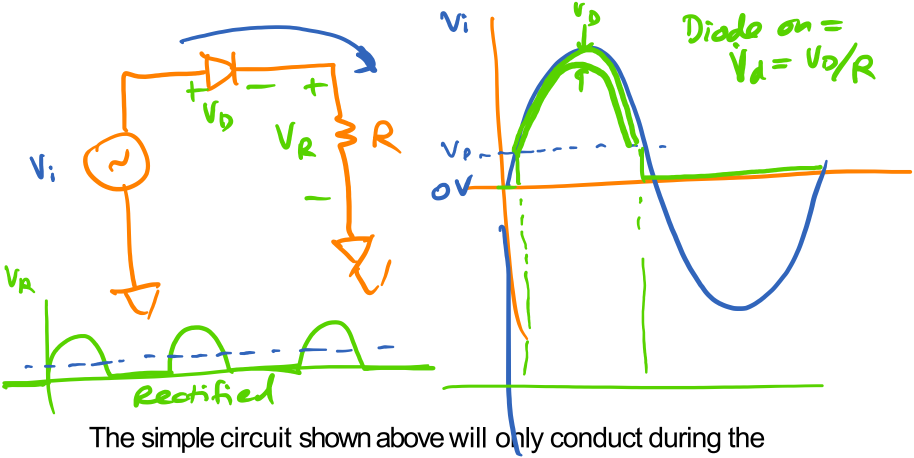
The "on" voltage is related to the required forward bias, which for Si is about 0.7V.

Really Ideal Diode Model



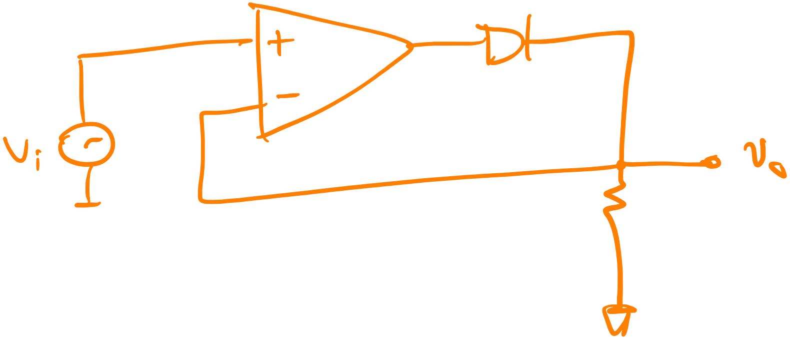
An ideal diode only allows current to flow in one direction. That's because the current is zero when a negative voltage is applied. When a positive voltage is applied, any current can flow and so the diode looks nearly like a short circuit.
Can you give an argumetn for why this ideal diode cannot exist? *Hint:* Try a thermodynamic argument.

Half-Wave Rectifier



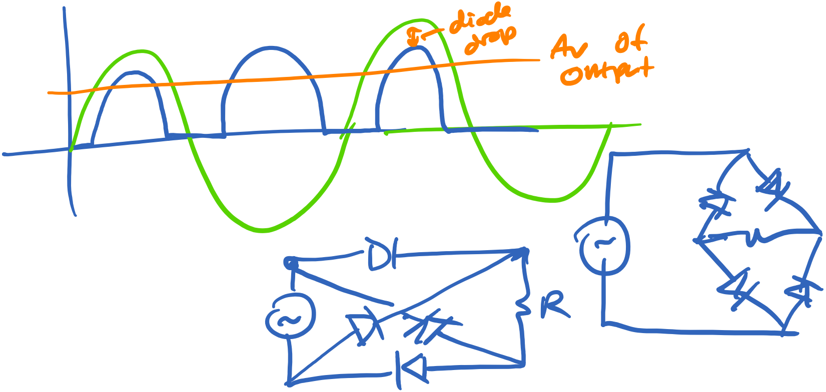
The simple circuit shown above will only conduct during the positive cycle of the sinusoidal voltage.

This is called “rectification” because it fixes the AC voltage if you’re trying to get rid of it’s negative polarity. As we’ll see soon, this way we can easily convert AC to DC.



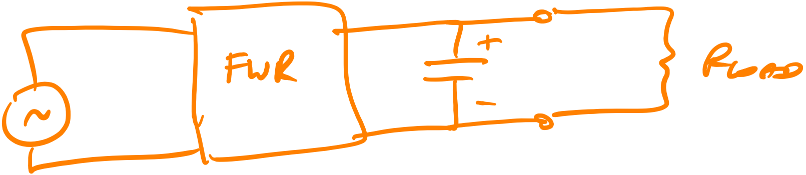
Use an op-amp to make the circuit precise.

Full-Wave Rectifier



This bridge circuit will conduct current during both cycles. Due to the polarity of the diodes, current is always flowing in the same direction through the load, even for a negative voltage.
This means that the circuit performs an absolute value function.

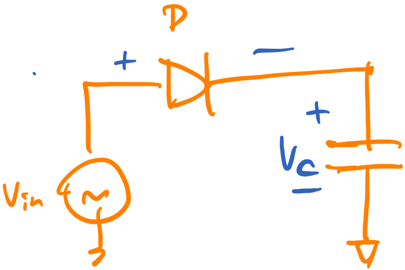
Filtered Rectified Voltage

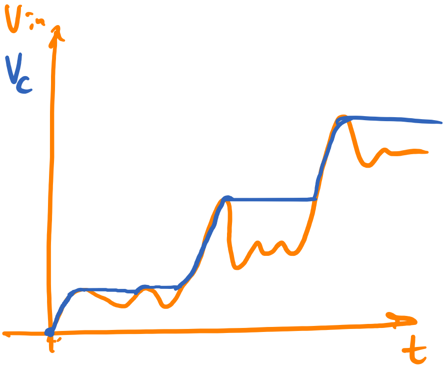


The capacitor is used to filter out the variations in the voltage. During the positive cycle, the capacitor is charged and it holds its output steady. The charging time is very fast because the diode “on” resistance is very small.
During the negative cycle, the diode turns off and the output voltage is provided by the capacitor. If the load current is sufficiently small, then the discharge time constant is

relatively long, and so the voltage droops only a bit.

Peak Detector

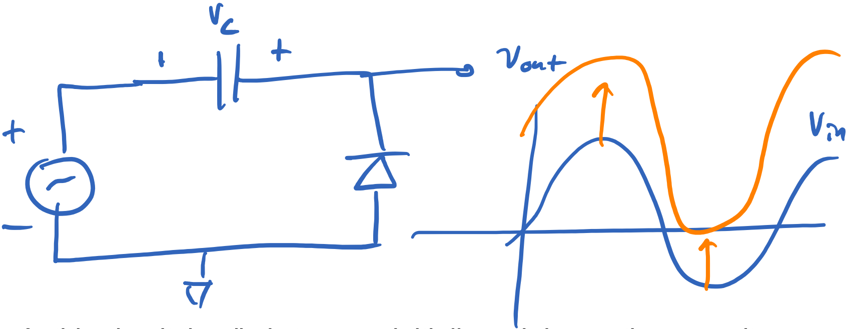




The capacitor is charged to the peak voltage and the output is held at the peak. Any excursions below peak cannot forward bias the capacitor. If a voltage excursion exceeds the peak up to a given point, then the capacitor is quicky charged by the forward biased diode.

If you flip the direction of the diode, you get a negative peak detector.

Level Restorers

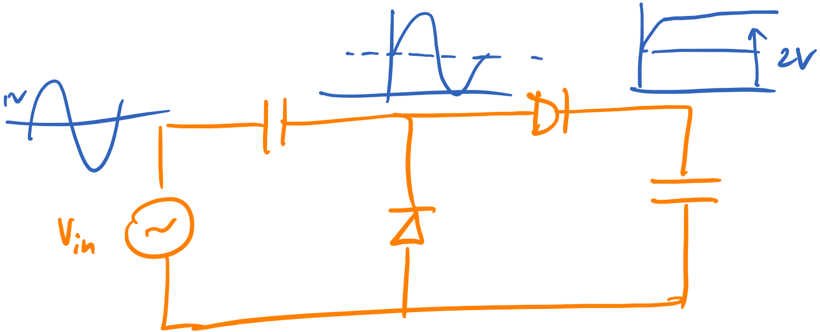


In this circuit the diode turns on initially and charges the capacitor to the AC voltage. Note that once the voltage starts to drop, the diode turns off.

The output voltage is therefore level shifted by the DC voltage held on the capacitor.

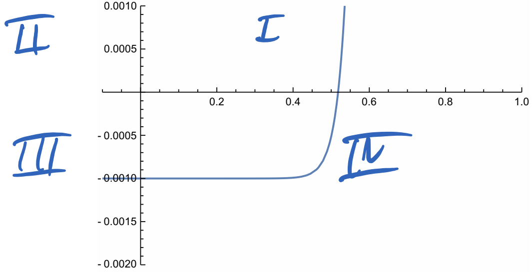
In this case the voltage excursions are now negative and never rise above zero! If a load is connected, then the capacitor should be large enough to minimize the droop.

Voltage Doubler



If we rectify the above voltages, we can generate positive or negative DC voltages of twice the magnitude. This is a voltage doubler!

Solar Cells



Note that a solar cell is equivalent to a forward biased diode in parallel with a current source.
Since the I-V curve falls in the fourth quadrant, it can supply power !
We can easily measure the short-circuit currnet (I_{short}) and the open-circuit voltage (V_{open}). There's an optimal point to operate the solar cell to get the most power output (maximized produce of i and v). In absence of loss, it's the

load resistance that is the ratio of V_{open}/I_{short}