EE105
Microelectronic Devices and Circuits:
Diode Circuits

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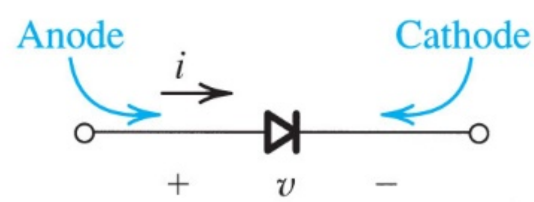
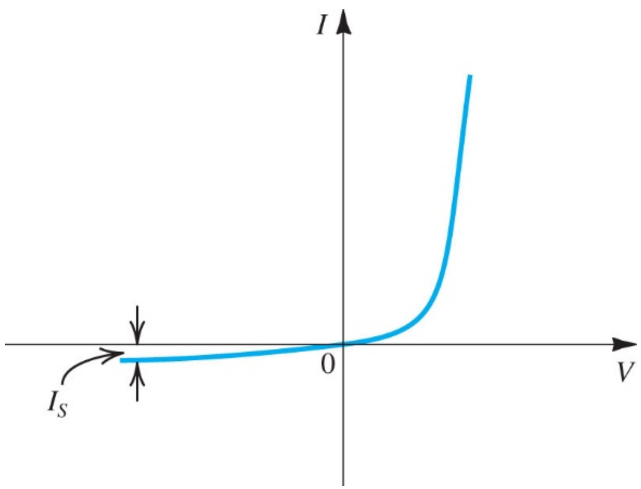
Summary of pn Junction





Built-in potential : $V_0 = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right)$

<u>Under forward bias</u> :

I-V curve : $I = I_S\left(e^{V/V_T} - 1\right)$

Diffusion capacitance : $C_d = \left(\frac{\tau_T}{V_T}\right) I$

<u>Under revserse bias</u> :

Negligible current, $I = -I_S$

Depletion capacitance : $C_j = \frac{C_{j0}}{\sqrt{1 + \frac{V_R}{V_0}}}$

Other important parameter :

Depletion Width: $W = \sqrt{\frac{2e_S}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)(V_0 - V)}$

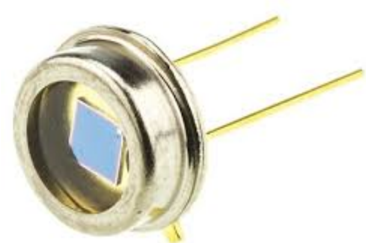
Many Applications of Diodes

LED (Light-Emitting Diode)

LED Lighting

Laser Diode

Solar Cells (PV)



Photodiode

OLED

How Many Diodes are in a Smart Phone?

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http://image-sensors-world.blogspot.com/2017/09/yole-on-iphone-x-3d-innovations.html

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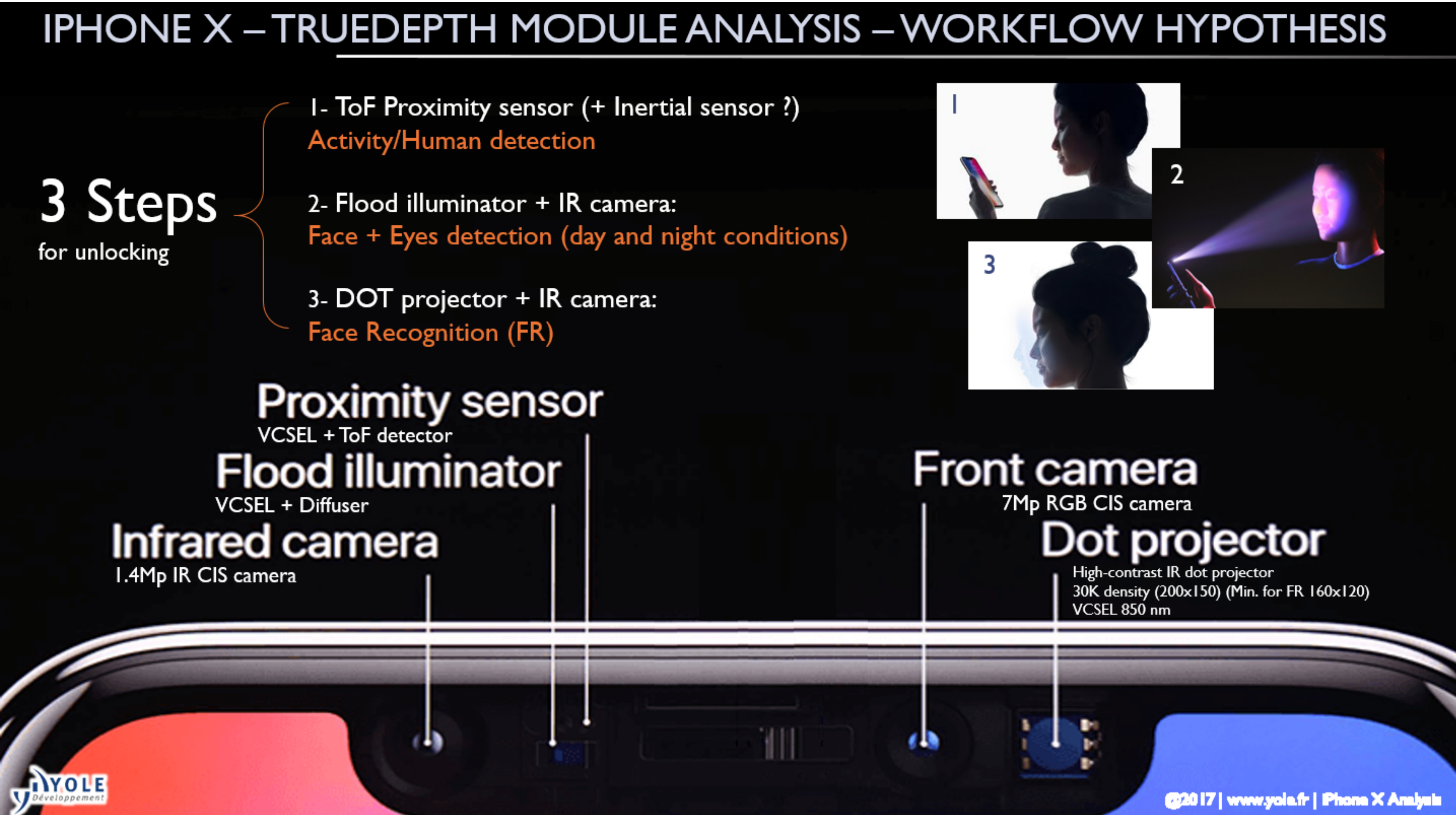

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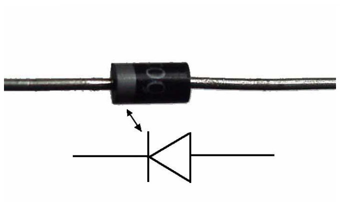
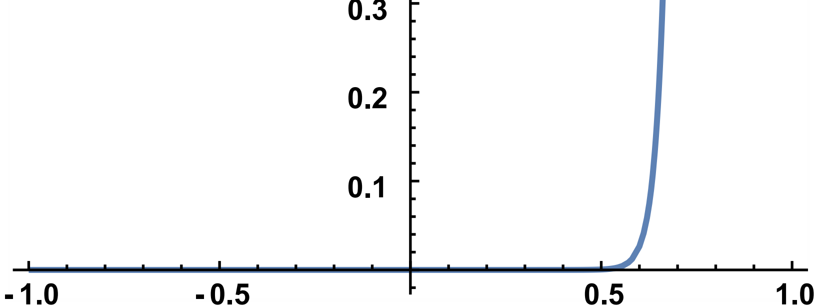
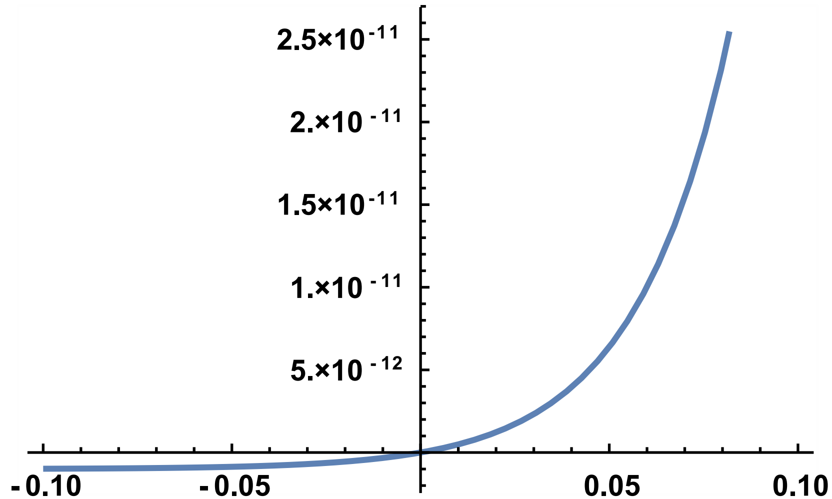
Diode I-V Curve (Forward)



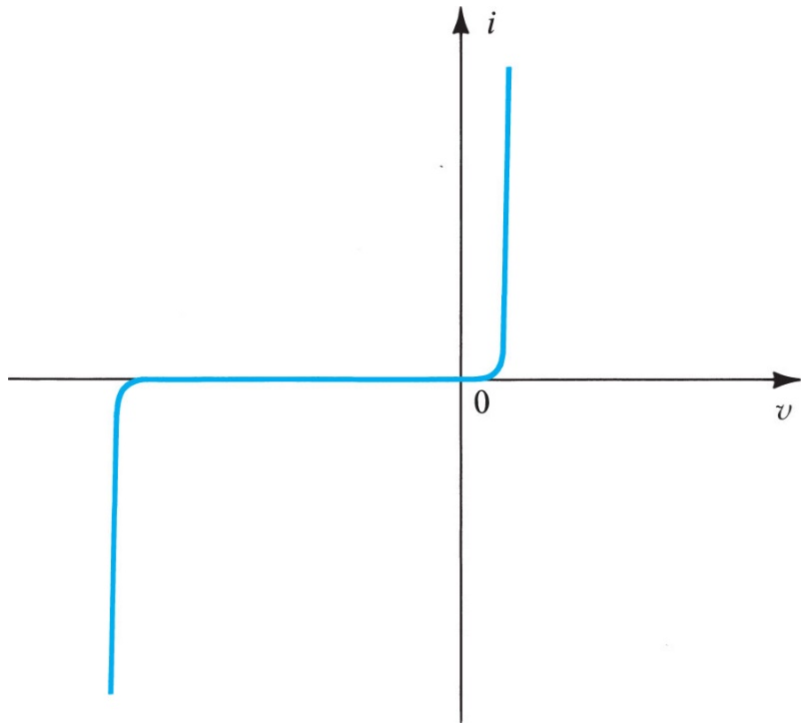


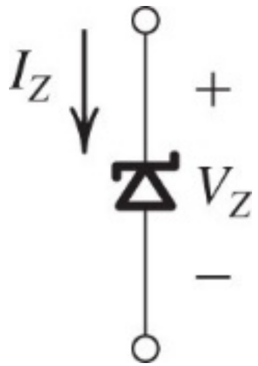


- I-V curve at high current
- *Approximate* "turn-on" voltage at 0.7V for Si
  - There is no exact turn-on voltage
  - Current keeps increasing exponentially

- I-V curve at low current
- Soft increase at forward bias
- Can see reverse saturation current, I_S

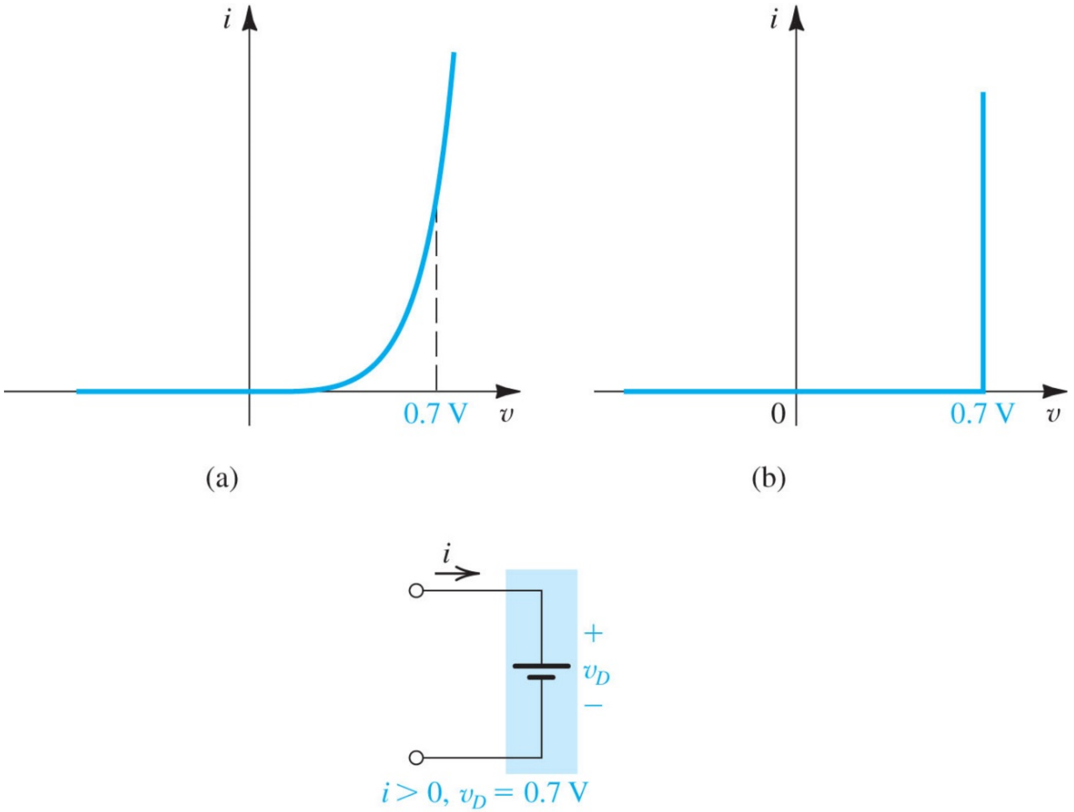
Reverse Breakdown





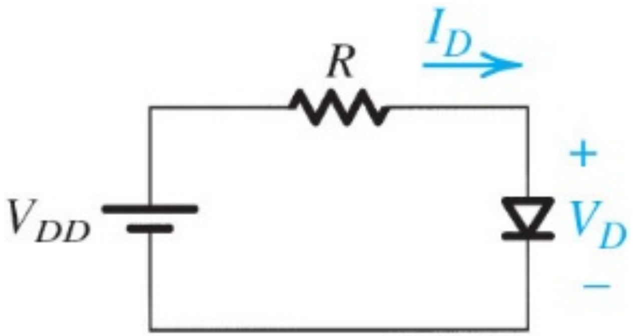
- **At sufficiently large reverse bias voltage, current starts to increase dramatically**
  - **Due to avalanche breakdown or quantum mechanical tunneling**
  - **Breakdown voltage can be designed**
  - **Sometimes used as a voltage limiter**

Ideal Diode Model



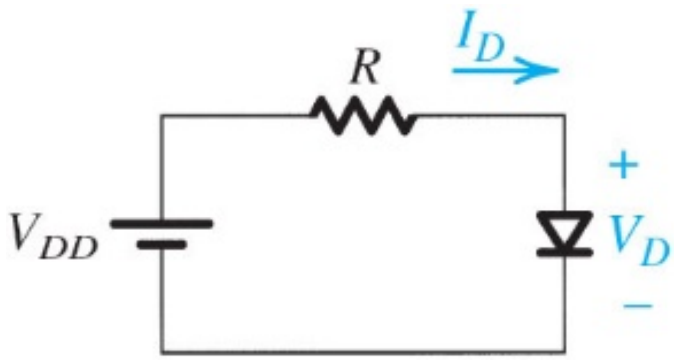
(a) (b) (c)

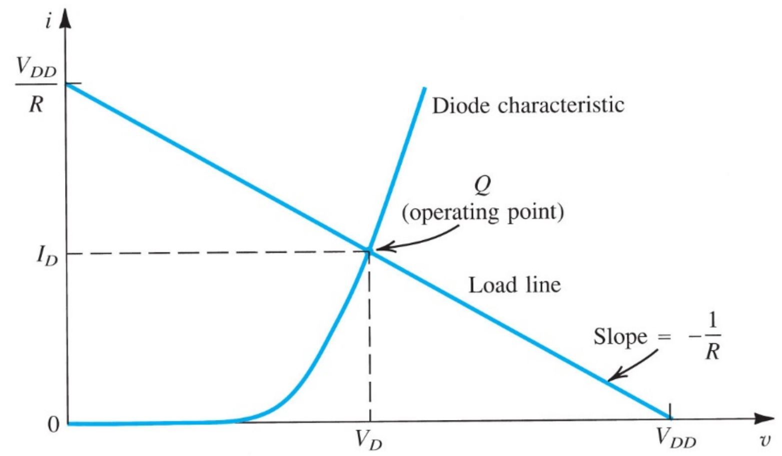
Example:



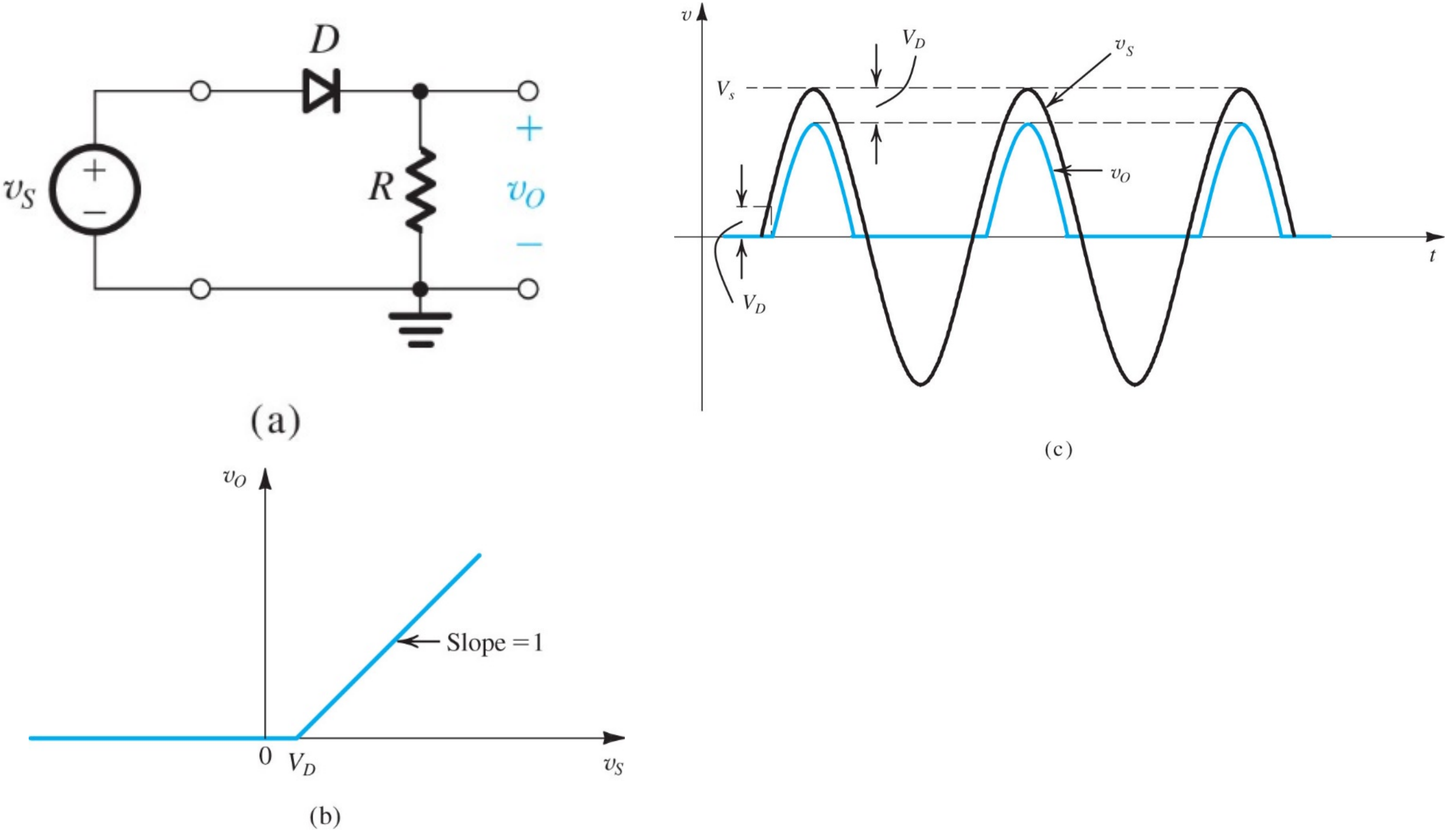
- **An ideal diode only allows current to flow in one direction**
  - **Short circuit for $V > V_{ON}$ (~ 0.7V for Si)**
  - **Open circuit for $V < V_{ON}$ (as well as reverse bias)**

Exact Solution with Real Diode I-V

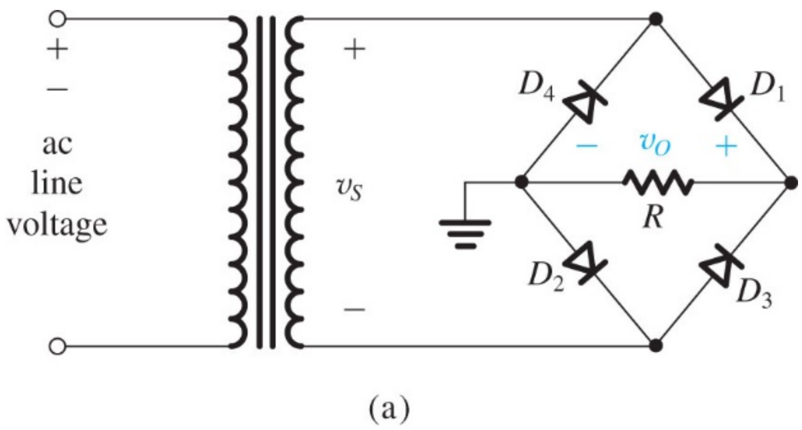




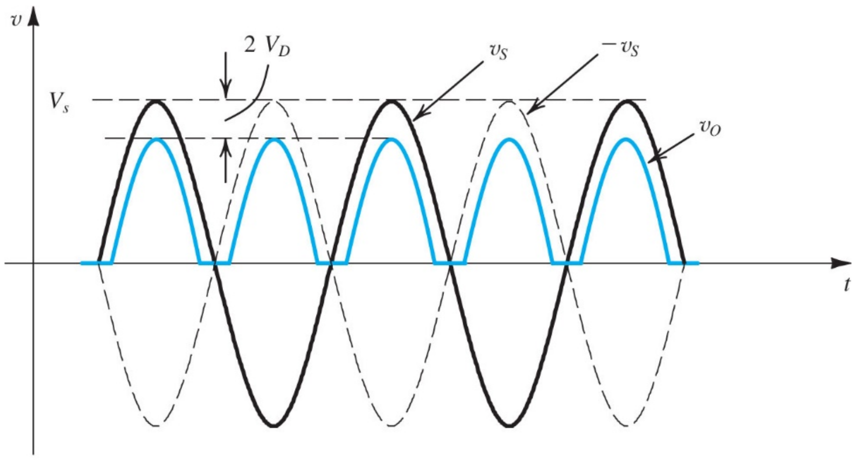
Half-Wave Rectifier



Full-Wave Bridge Rectifier

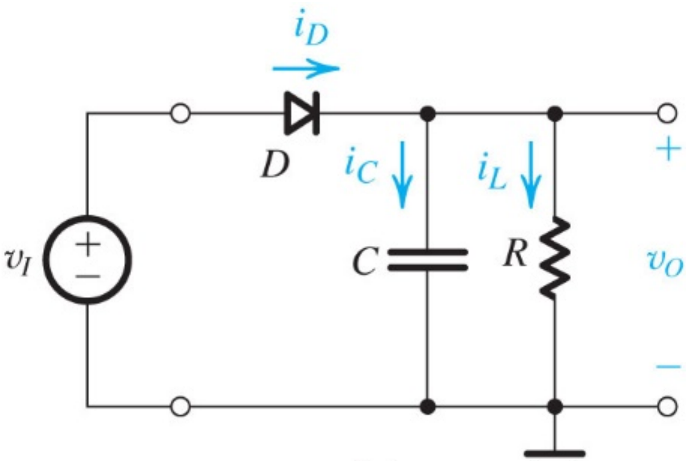


(a)

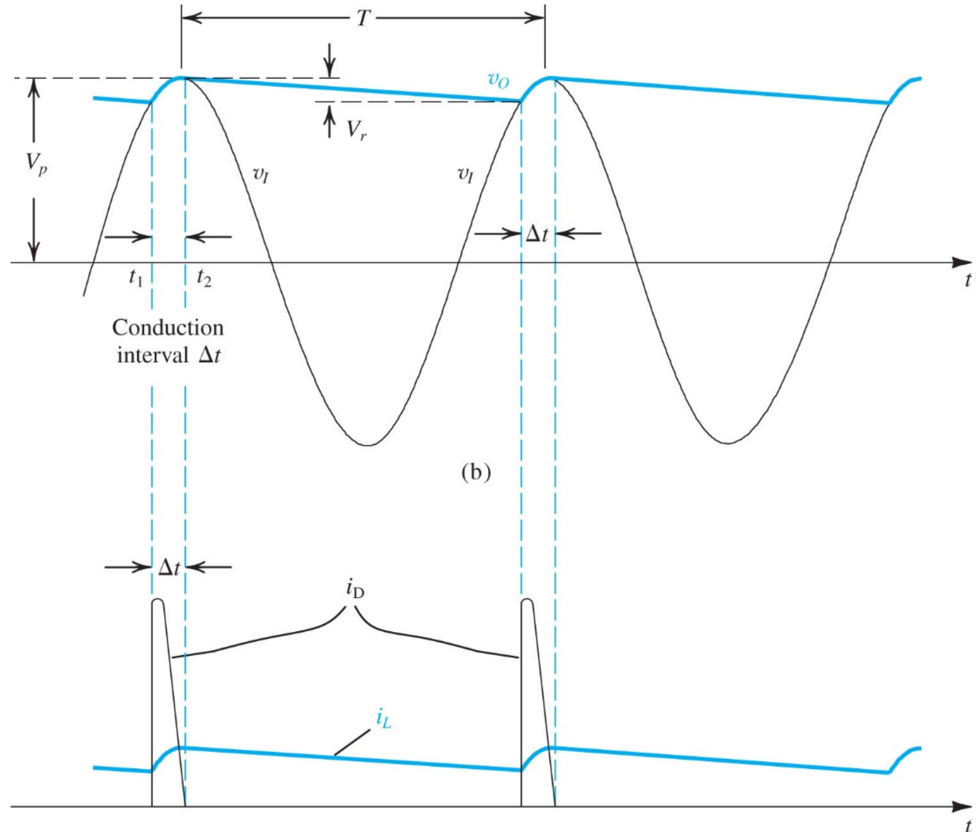


(b)

Filter to Remove Ripples



(a)

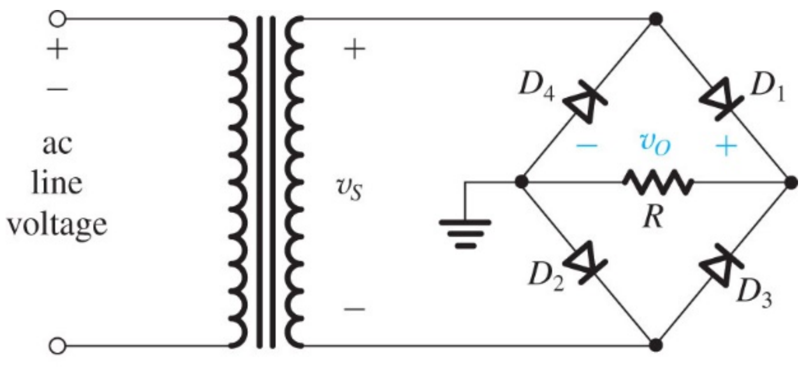


(b)
(c)

What is the RC time constant in forward bias?
What is RC in reverse bias?

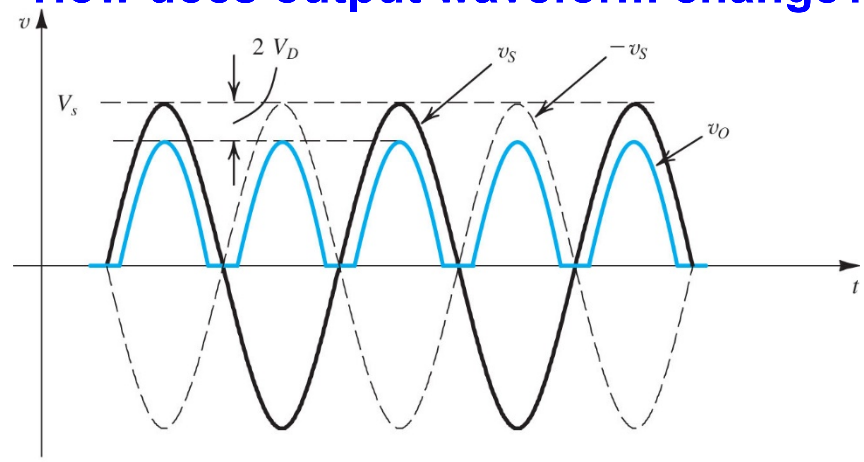
Full-Wave Bridge Rectifier with Smoothing Capacitor

Where do you add capacitor?



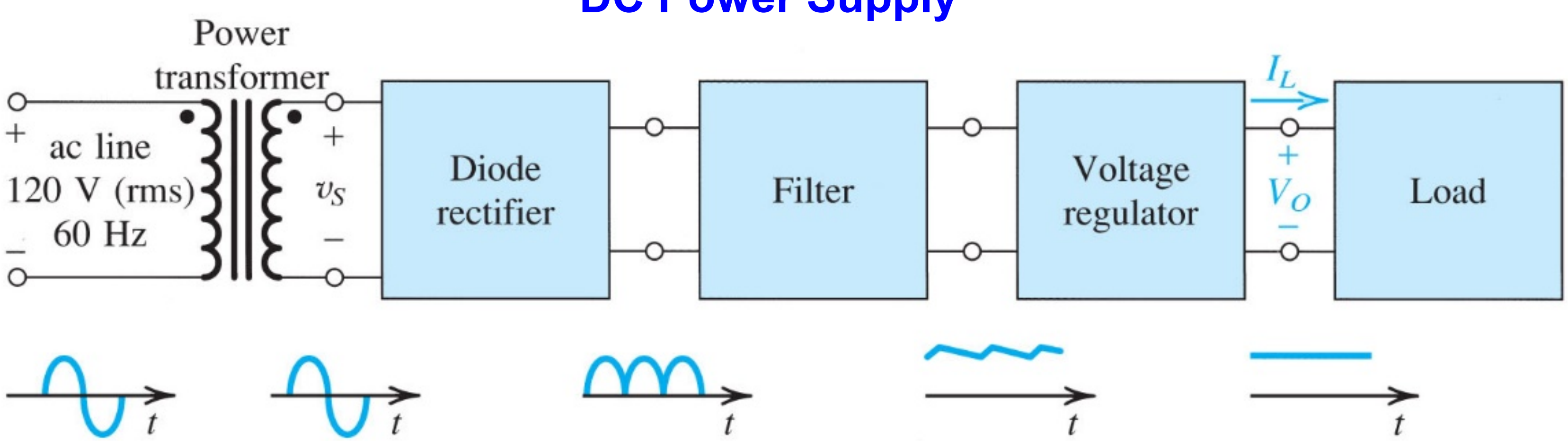
(a)

How does output waveform change?

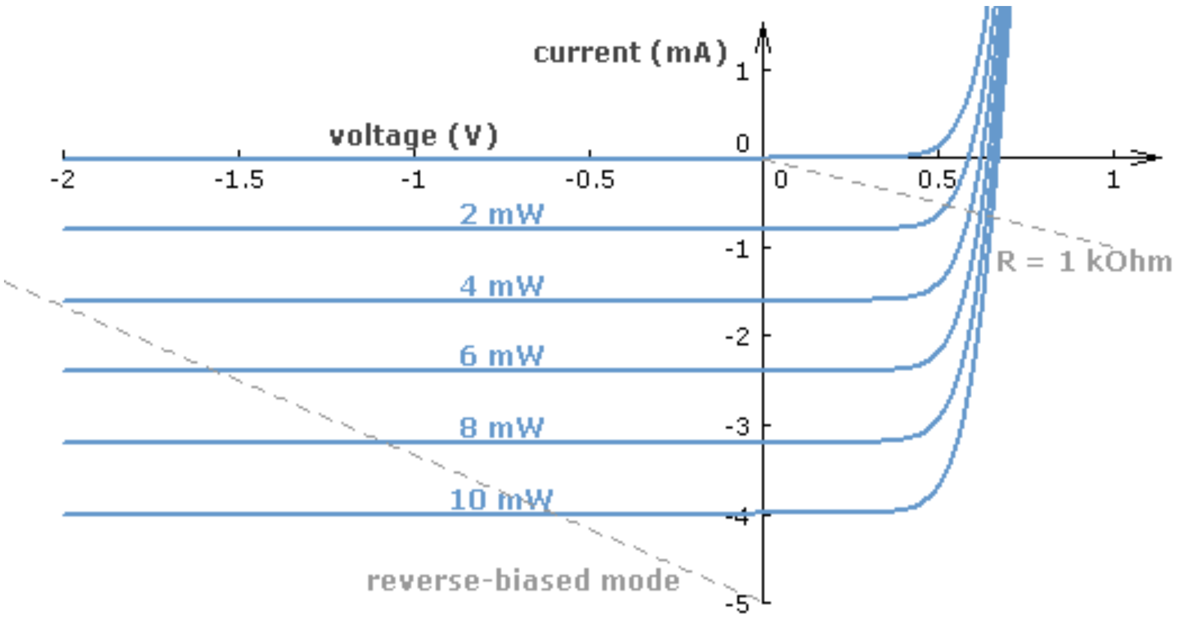


(b)

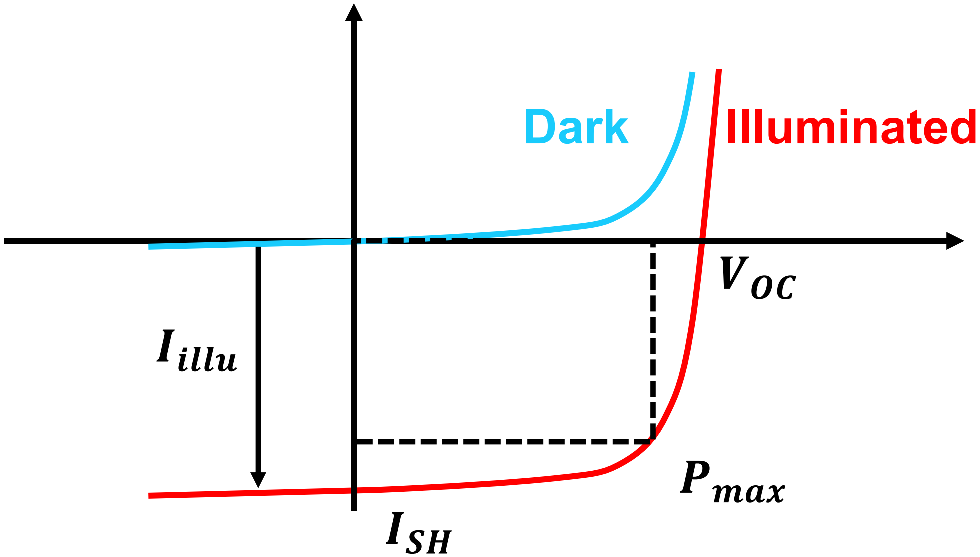
DC Power Supply

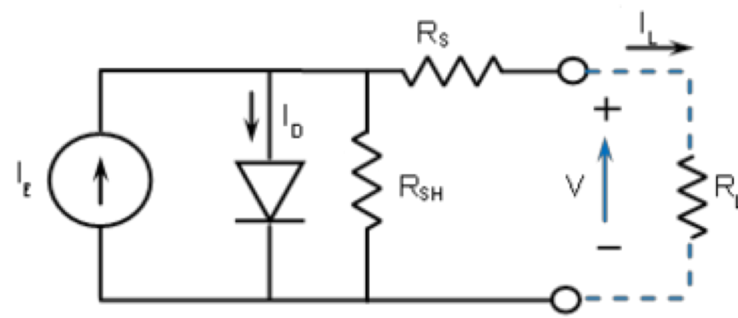


Photodiodes



Solar (Photovoltaic, or PV) Cells



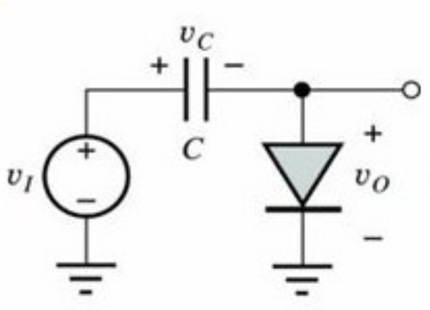


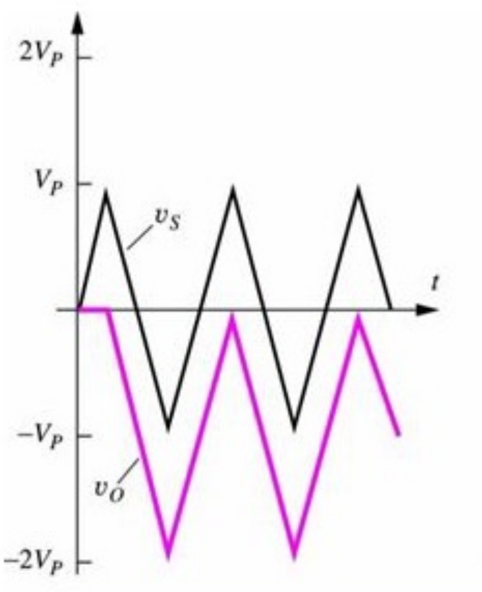
- Operating in the 4th quadrant of the I-V curve
  → It generates power !
- Key parameters:
  - Open circuit voltage, V_{OC}
  - Short-circuit current, I_{sh}
  - Fill factor

Peak Detector

- **The capacitor is charged to the peak voltage and the output is held at the peak**
  - **When input > output, diode is ON, charge capacitor to new peak**
  - **When input < output, diode is OFF. Capacitor holds output at peak**
- **If you flip the direction of the diode, you get a negative peak detector.**

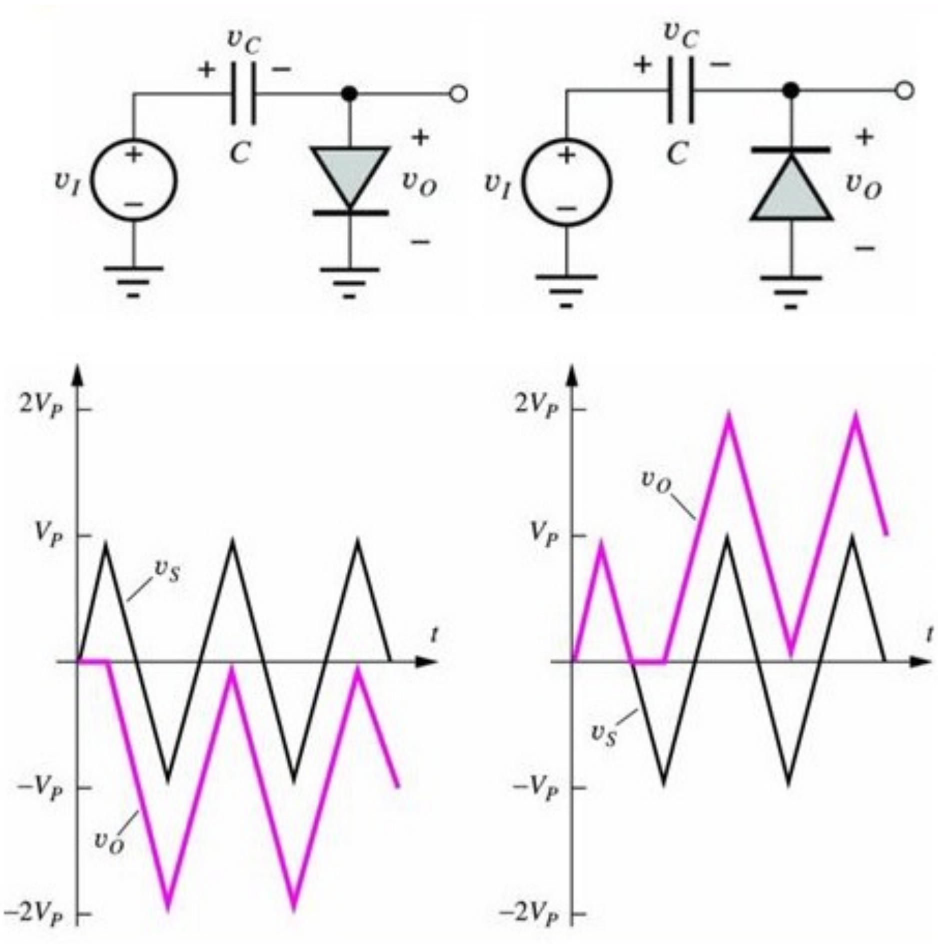
Level Restorers





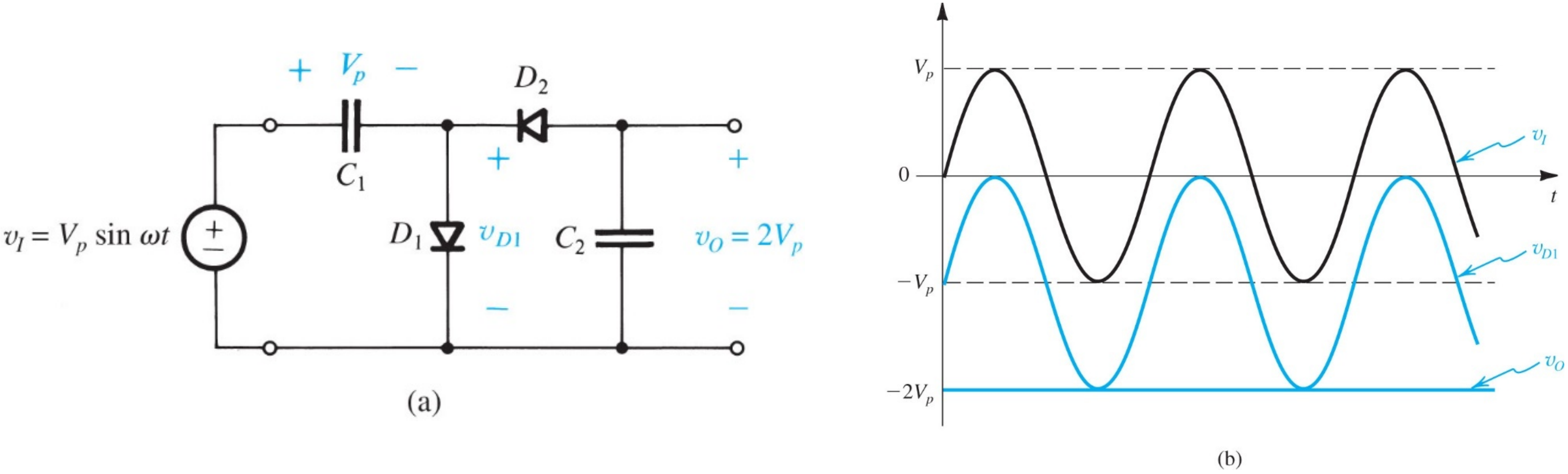
- Diode turns on initially and charges the capacitor to the AC voltage.
  - Note that once the voltage starts to drop, the diode turns off
- The output voltage is therefore level shifted by the DC voltage held on the capacitor
- In this case the voltage excursions are now negative and never rise above zero!
  - If a load is connected, then the capacitor should be large enough to minimize droop

Level Restorers



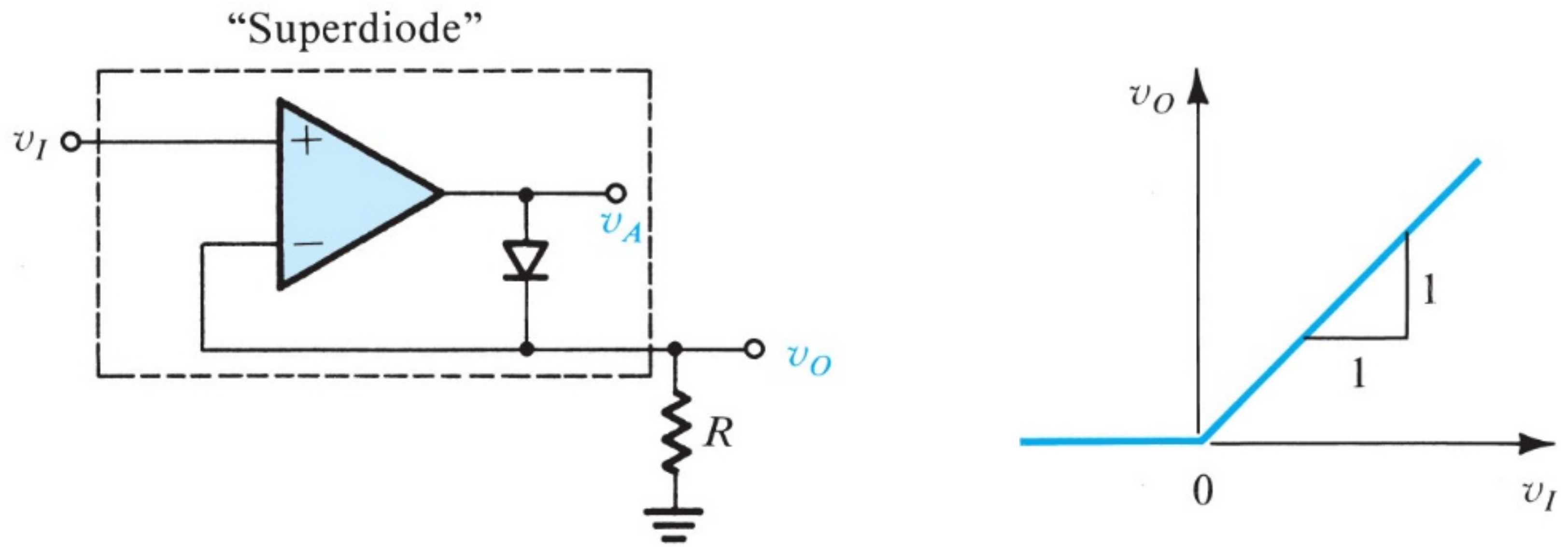
- **If we now flip the direction of the diode, the current will only flow during the negative half cycle, charging the capacitor now in the opposite direction.**
- **Then output is now lifted by the DC voltage stored on the capacitor. The voltage will now always remain positive and never go below zero!**

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!**

"Superdiode"



(a) (b)

Use an op-amp to make circuit precise

Small Signal Resistance