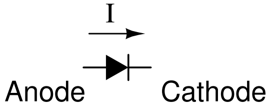
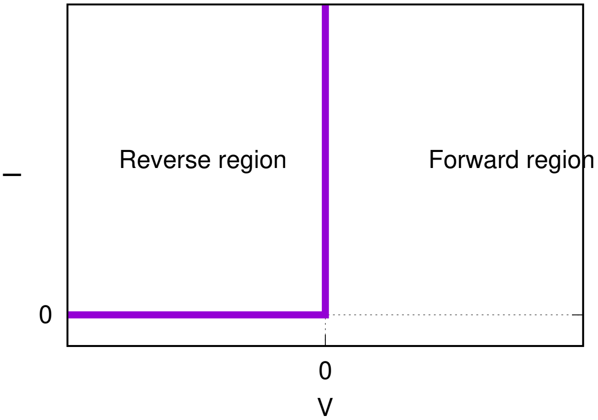
Diodes.

Eugeniy E. Mikhailov

WILLIAM & MARY
CHARTERED 1693

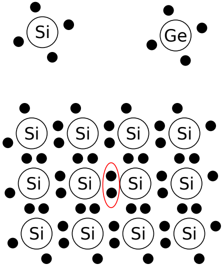
Ideal diode





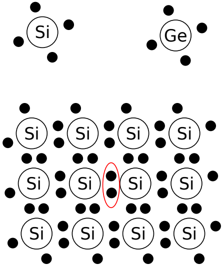
Semiconductors and doping

Pure semiconductor

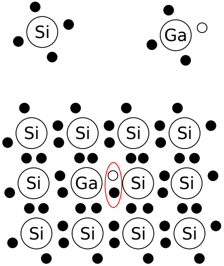


Semiconductors and doping

Pure semiconductor

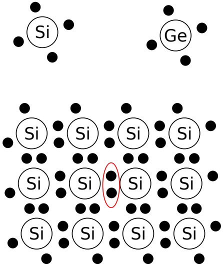


P-doped

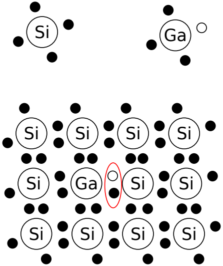


Semiconductors and doping

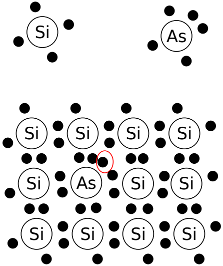
Pure semiconductor



P-doped

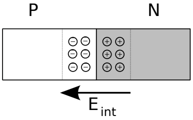


N-doped



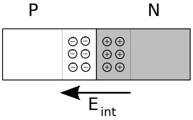
PN-junction

No bias

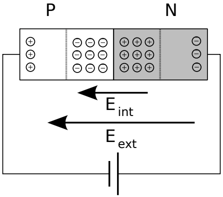


PN-junction

No bias

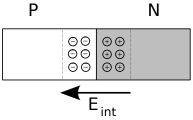


Reverse bias

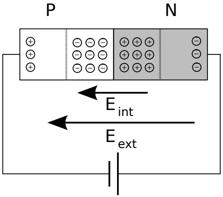


PN-junction

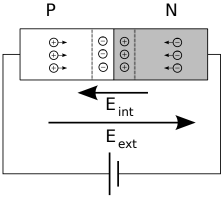
No bias



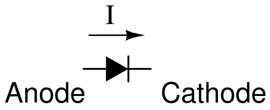
Reverse bias



Forward bias



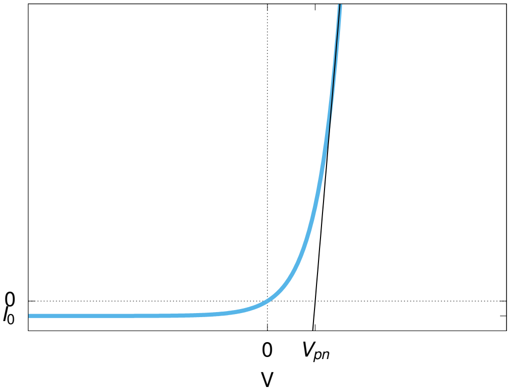
Real diode



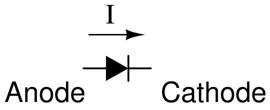
$$I(V) = I_0 \left(e^{V/(nV_T)} - 1 \right)$$

Typical parameters

- saturation current $I_0 = 1$ nA
- thermal voltage $V_T = \frac{kT}{q} =$ 25.85 mV at 300 K
- emission coefficient $n = 1..2$



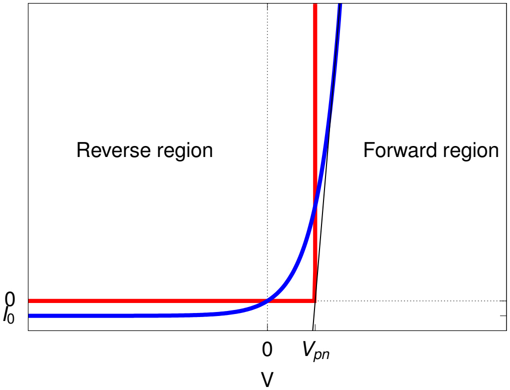
Real diode



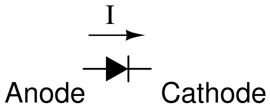
$$I(V) = I_0 \left(e^{V/(nV_T)} - 1 \right)$$

Typical parameters

- saturation current $I_0 = 1$ nA
- thermal voltage $V_T = \frac{kT}{q} =$ 25.85 mV at 300 K
- emission coefficient $n = 1..2$

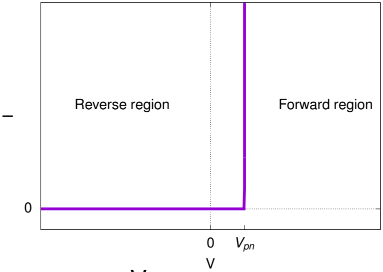


Simplified diode

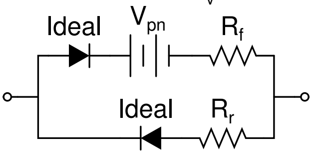


V_{pn} diode P-N junction opening voltage

- $V_{pn} = 0.6$ V for Si
- $V_{pn} = 0.3$ V for Ge



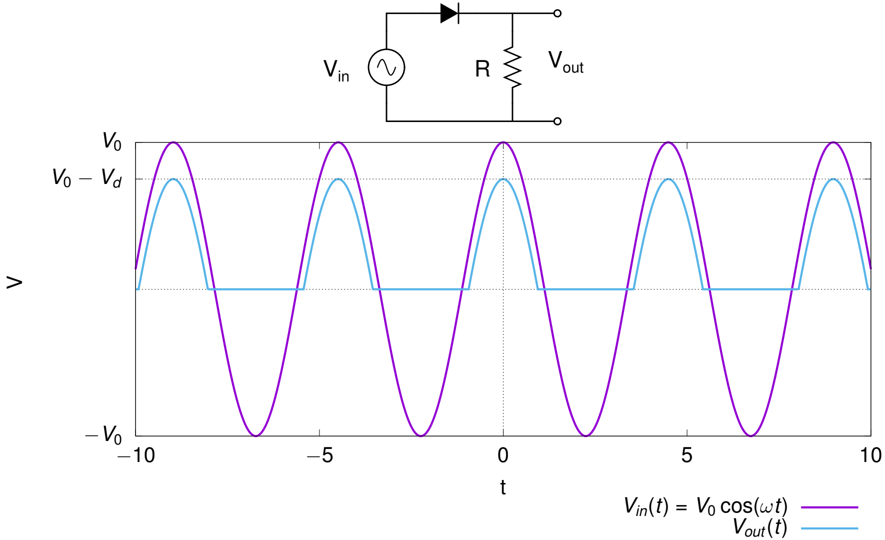
A bit more realistic diode ($R_r \gg R_f$)



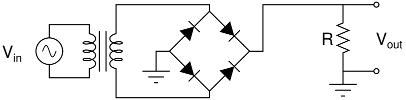
Diodes applications

- Circuit Protection
- Rectification
  - current gate
  - half wave rectifier
  - full wave rectifier
  - Power Supplies
- Frequency manipulation
  - Frequency multiplier
  - Mixers
- and more ...
  - Voltage clamps
  - light emitting diodes (LED)
  - photo-diode

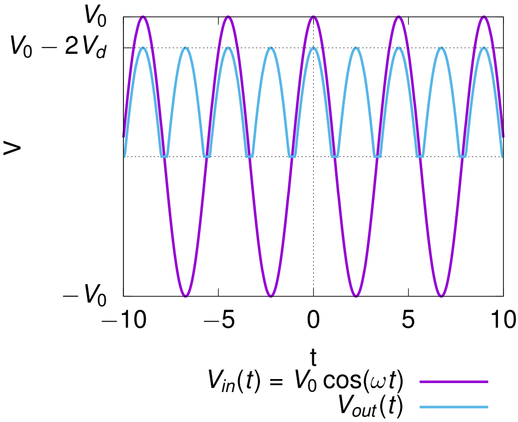
Half-wave rectifier, current gate



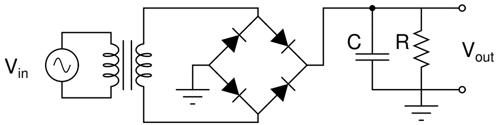
Full-wave rectifier: $V_{in} \gg V_d \rightarrow V_{out} \approx |V_{in}|$

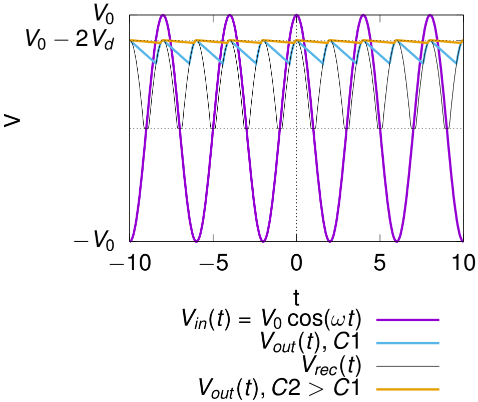


Why
$\max(V_{out}) = V_0 - 2V_d$?



Full-wave rectifier filtered - power supply





Ripples size

$$V(t) = \frac{Q(t)}{C} = \frac{Q_{max} - \int_0^t I dt}{C}$$

$$= V_{max} - \int_0^t \frac{I}{C} dt$$

$$\Delta V = V_{max} - V(t) = \int_0^t \frac{I}{C} dt$$

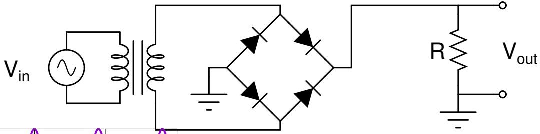
$$I \leq I_{max} = \frac{V_{max}}{R}$$

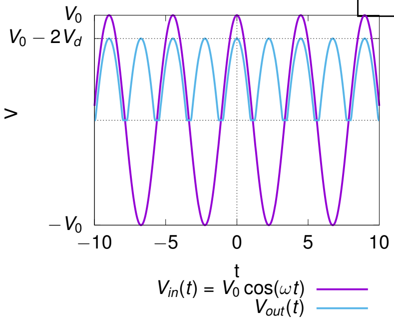
$$t \leq T = \frac{1}{2f_{in}}$$

$T \ll RC$

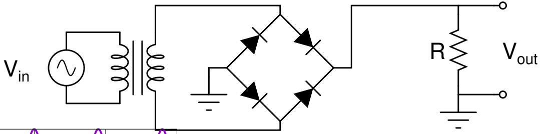
$$\Delta V \leq \frac{V_{max}}{2RCf_{in}}$$

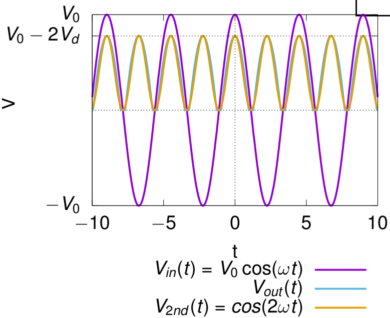
Full-wave rectifier as Frequency doubler



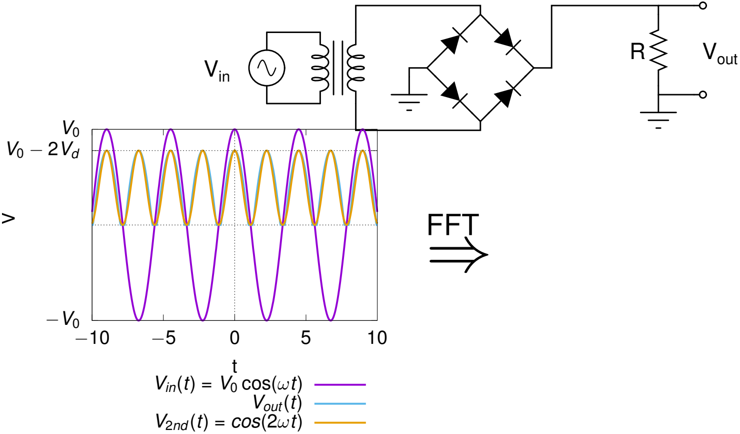


Full-wave rectifier as Frequency doubler

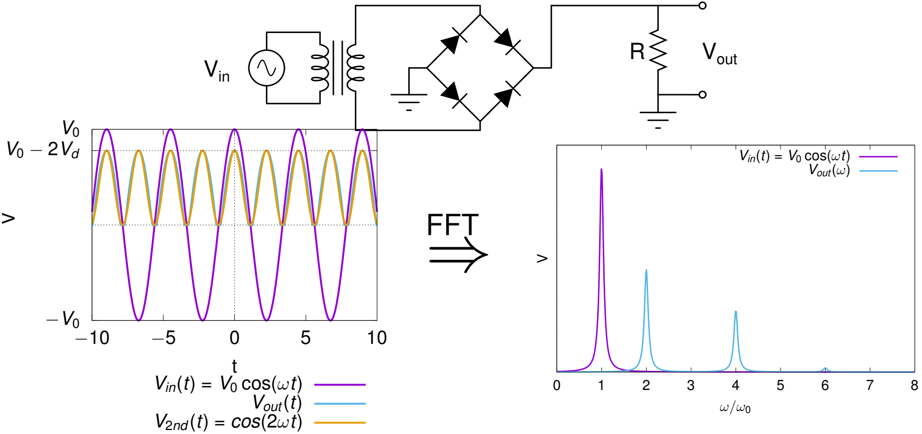




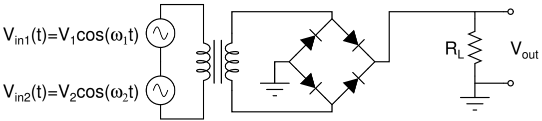
Full-wave rectifier as Frequency doubler



Full-wave rectifier as Frequency doubler



Full-wave rectifier as Frequency adder



$$V_{out}(t) = |V_{in}(t)| = \sqrt{V_{in}^2(t)} = \sqrt{(V_1 \cos(\omega_1 t) + V_2 \cos(\omega_2 t))^2}$$

$$= \sqrt{V_1^2 \cos^2(\omega_1 t) + 2 V_1 V_2 \cos(\omega_1 t) \cos(\omega_2 t) + V_2^2 \cos^2(\omega_2 t)}$$

Assuming $V_1 \gg V_2$

$$V_{out}(t) \approx \sqrt{V_1^2 \cos^2(\omega_1 t) + 2 V_1 V_2 \cos(\omega_1 t) \cos(\omega_2 t) + \cancel{V_2^2 \cos^2(\omega_2 t)}}$$

$$\approx V_1 \left(\cos(\omega_1 t) + \frac{V_2}{V_1} \cos(\omega_1 t) \cos(\omega_2 t) \right)$$

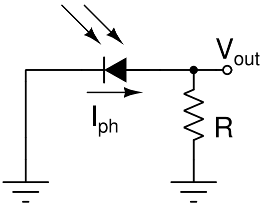
$$\approx V_1 \left(\cos(\omega_1 t) + \frac{V_2}{V_1} \frac{\cos((\omega_1 + \omega_2)t) + \cos((\omega_1 - \omega_2)t)}{2} \right)$$

Light sensing with photodiodes

Photocurrent I_{ph} proportional to light power P_{light}

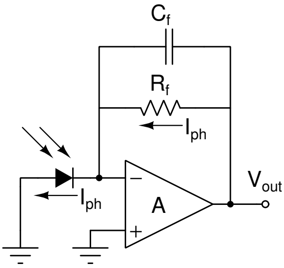
Simple photodiode circuit

$$V_{out} = RI_{ph}$$



Transimpedance amplifier

$$V_{out} = R_f I_{ph}$$



Problems:

- Performance changes with load
- Max output is about V_d