Diodes.

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Week 5

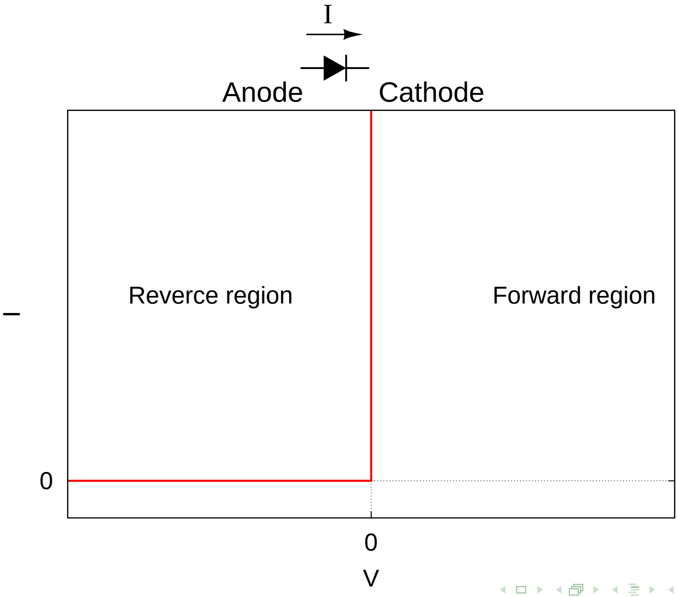
Midterm exam

Where: In the lab
When: During the first hour of the lab
Material:

- everything from first 4 weeks of class
- Resistors, capacitors, inductors, and transformers.
- Kirchhoff’s laws
- Thévenin’s theorem
- Voltage divider
- Filters
- Complex impedances.
- Source impedance

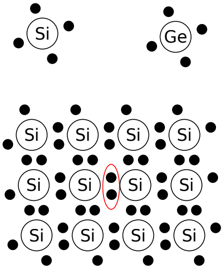
Lab will follow the midterm.
You can skip design exercise preparation prior to the lab however at the time of log book submission it must be fully done. Treat it as a home work.

Ideal diode



Semiconductors and doping

Pure semiconductor



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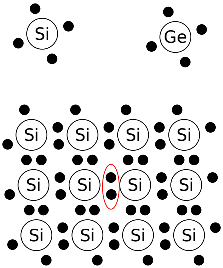
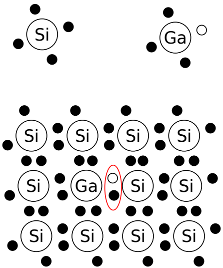


P-doped



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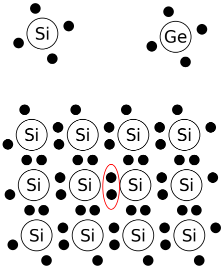

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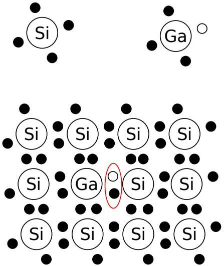
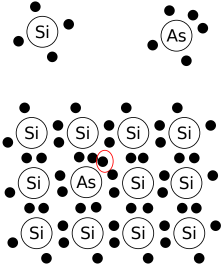
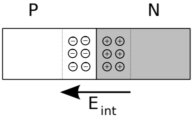


N-doped



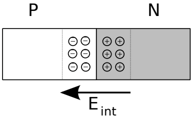
PN-junction

No bias

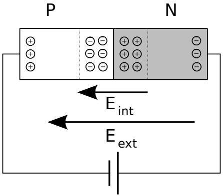


PN-junction

No bias



Reverse bias



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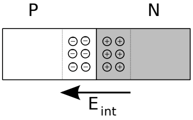

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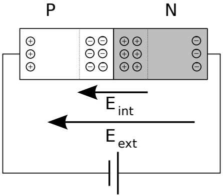
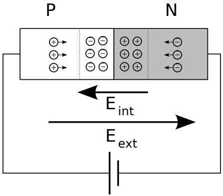
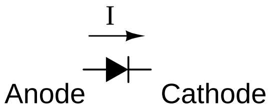


Forward bias



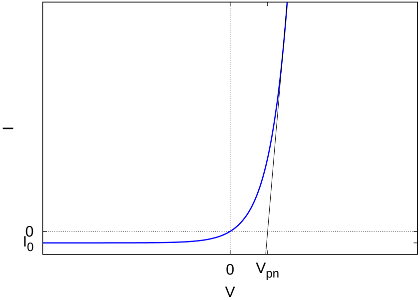
Real diode



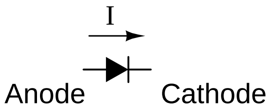
$$I(V) = I_0 \left(e^{V/(nV_T)} - 1 \right)$$

Typical parameters

- saturation current
  $I0 = 1$ nA
- thermal voltage
  $V_T = \frac{kT}{q} = 25.85$ mV at 300 K
- emission coefficient
  $n = 1..2$



Real diode



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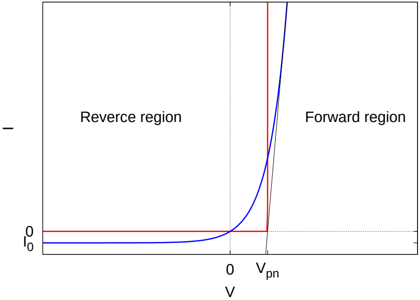
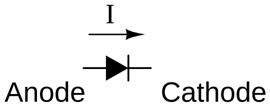
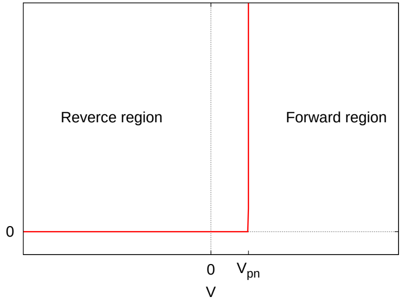


Simplified diode

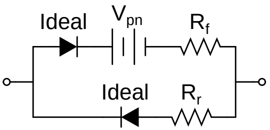


V_{pn} diode P-N junction opening voltage

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



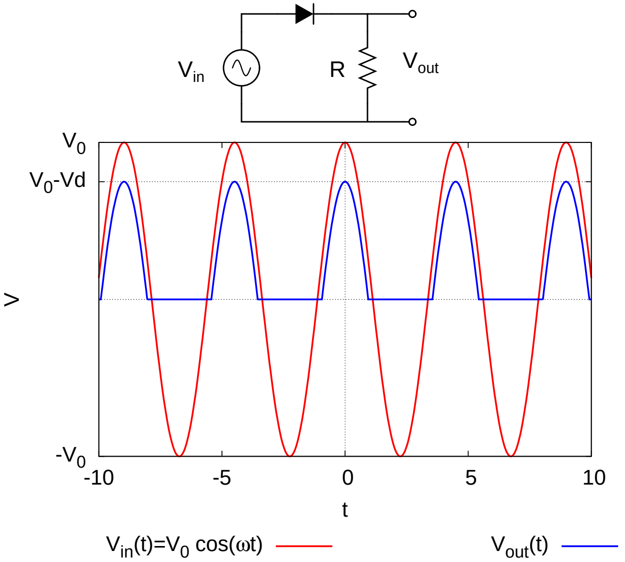
A bit more realistic diode ($R_r \gg R_f$)



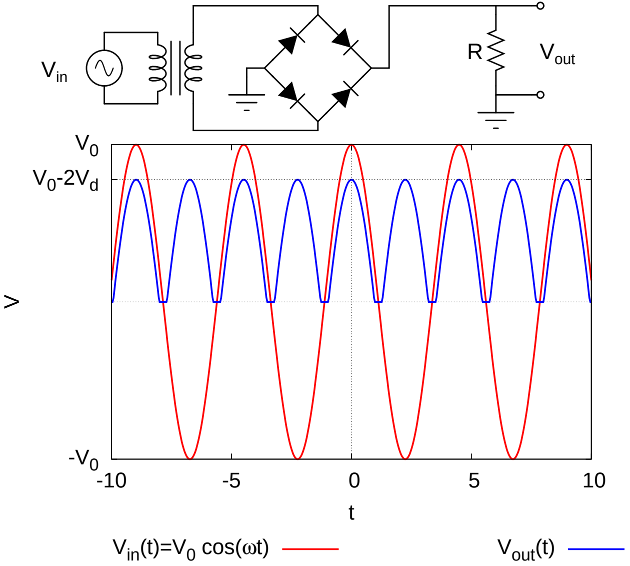
Diodes applications

- 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

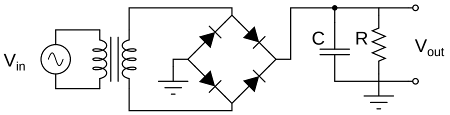
Half-wave rectifier, current gate

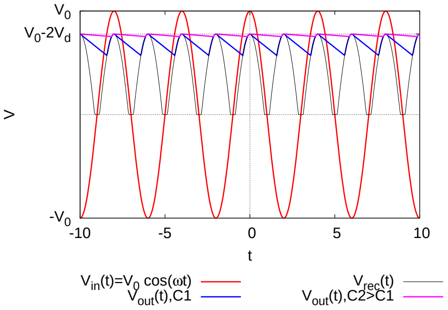


Full-wave rectifier



Full-wave rectifier filtered - power supply





Ripples size

$$V = \frac{Q}{C}$$

$$V(t) = \frac{Q_{max} - It}{C} = V_{max} - \frac{It}{C}$$

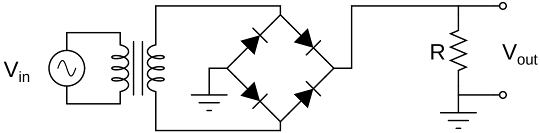
$$I \leq I_{max} = \frac{V_{max}}{R_L}$$

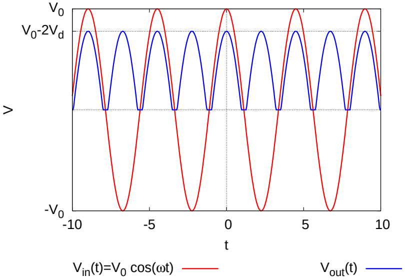
$$t \leq T = \frac{1}{2f_{in}}$$

$$\Delta V = V_{max} - V(t)$$

$$\Delta V \leq \frac{V_{max}}{2R_L C f_{in}}$$

Full-wave rectifier as Frequency doubler





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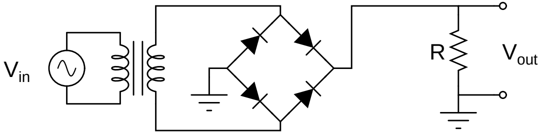

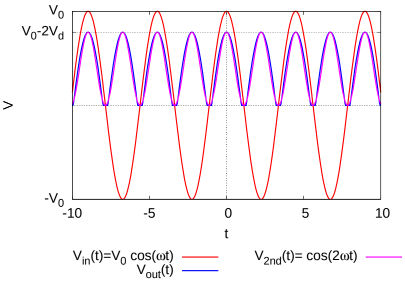

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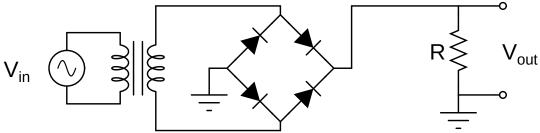
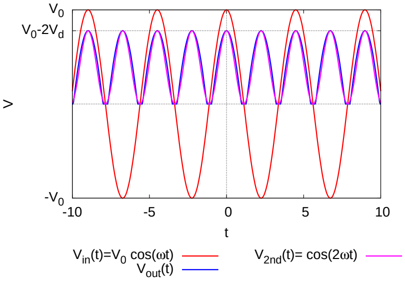
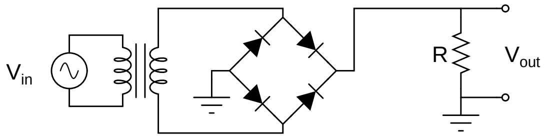
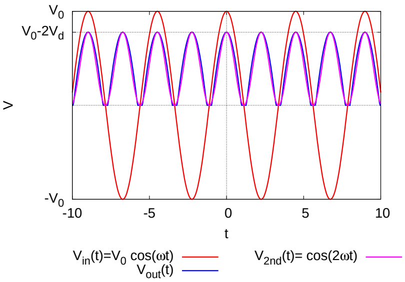




FFT ⇒

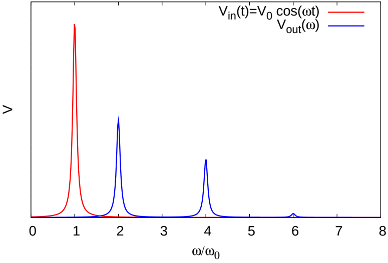


V_{in}
R
V_{out}



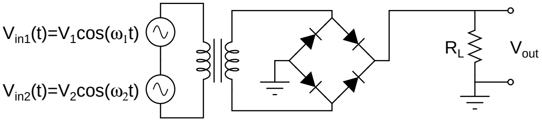
V_0
V_0-2V_d
V
-V_0
-10
-5
0
5
10
t
V_{in}(t)=V_0 cos(ωt)
V_{out}(t)
V_{2nd}(t)= cos(2ωt)

FFT ⇒



V_{in}(t)=V_0 cos(ωt)
V_{out}(ω)
V
0
1
2
3
4
5
6
7
8
ω/$ω_0$

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 $V_1 \gg V_2$

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

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

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