Diodes.

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Lecture 05

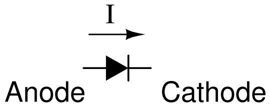
Midterm exam

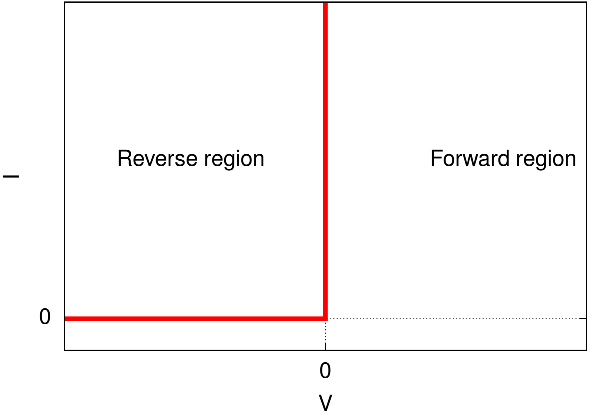
Where: In the lab
When: During the first hour of the lab
Material:

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

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.

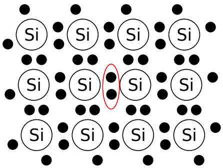
Ideal diode





Semiconductors and doping

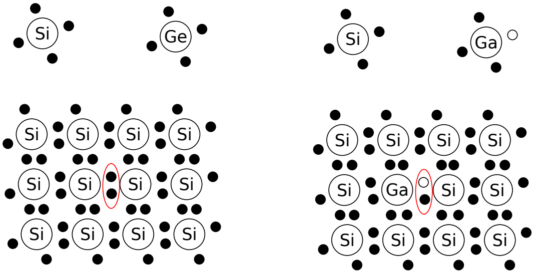
Pure semiconductor



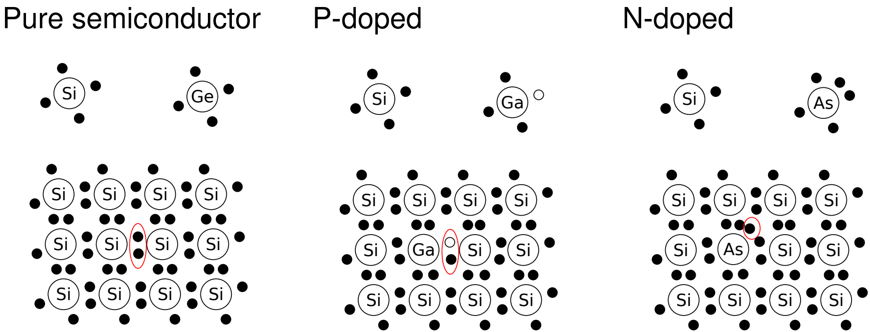
Semiconductors and doping

Pure semiconductor

P-doped

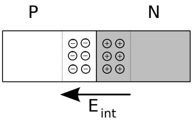


Semiconductors and doping



PN-junction

No bias



PN-junction

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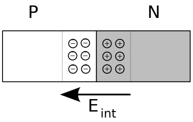
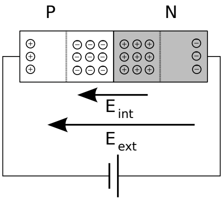


Reverse bias



PN-junction

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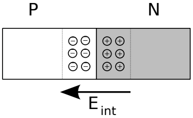
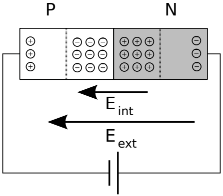
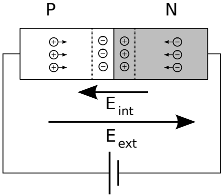


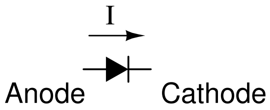
Reverse bias



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
  $n = 1..2$

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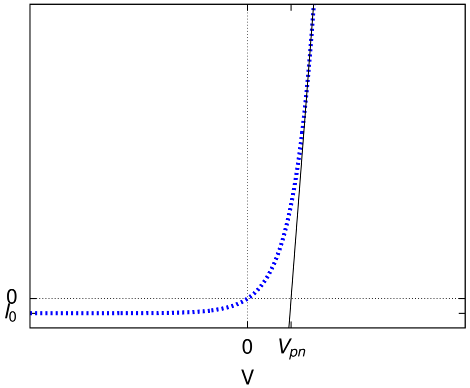
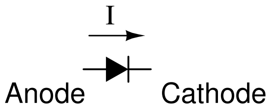


Real diode



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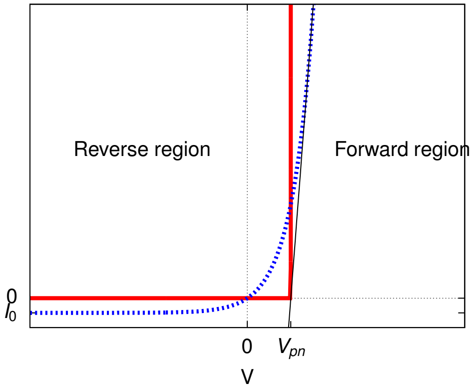
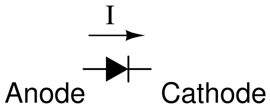
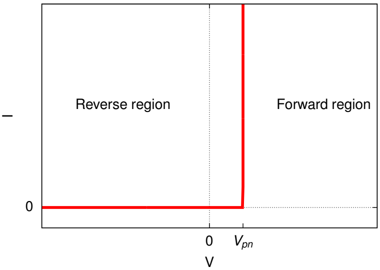


Simplified diode

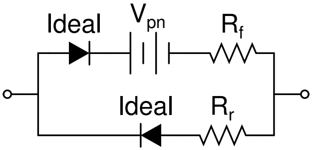


V_{pn} diode P-N junction opening voltage

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



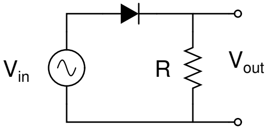
A bit more realistic diode ($R_r \gg R_f$)

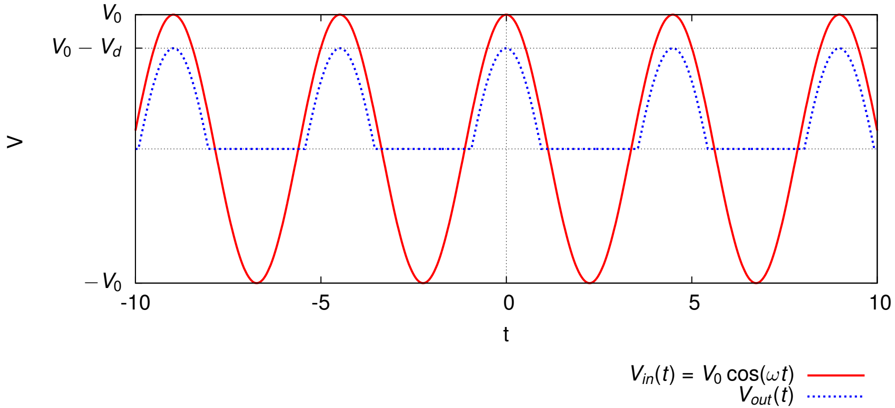


Diodes applications

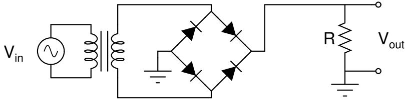
- Circuit Protection
- Rectification
  - current gate
  - half wave rectifier
  - full wave rectifier
  - Power Supplies
- Frequency manipulation
  - Frequency multiplier
  - Mixers
- and more ...
  - Voltage clamps
  - light emitting diodes (LED)
  - photo-diode

Half-wave rectifier, current gate

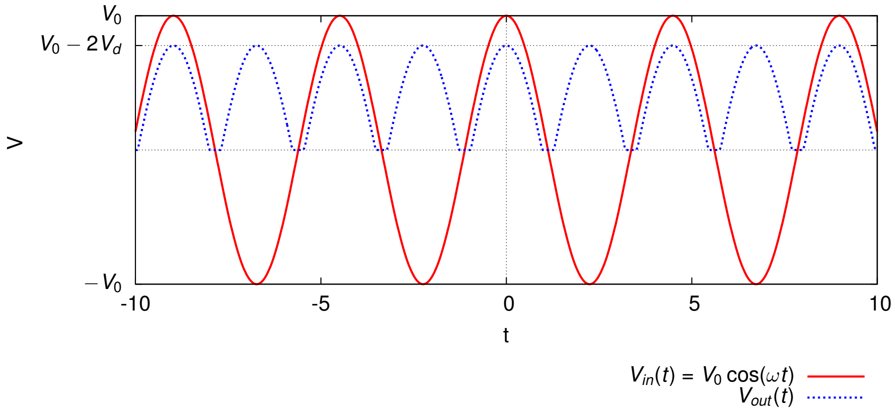




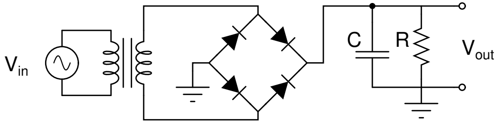
Full-wave rectifier: $V_{in} \gg V_d \rightarrow V_{out} \approx |V_{in}|$

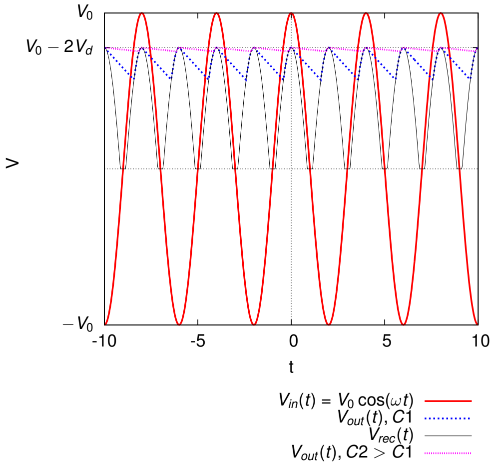


Why
$\max(V_{out}) = V_0 - 2V_d$?



Full-wave rectifier filtered - power supply





Ripples size

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

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

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

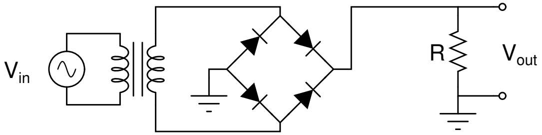
$$I \leq I_{max} = \frac{V_{max}}{R}$$

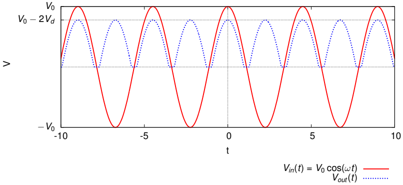
$$t \leq T = \frac{1}{2f_{in}}$$

$T \ll RC$

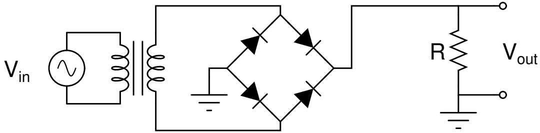
$$\Delta V \leq \frac{V_{max}}{2RCf_{in}}$$

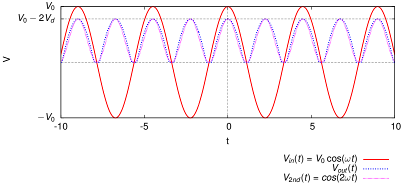
Full-wave rectifier as Frequency doubler





Full-wave rectifier as Frequency doubler





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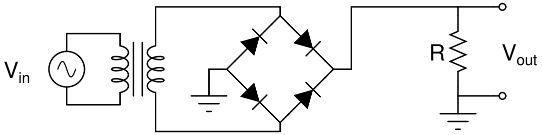
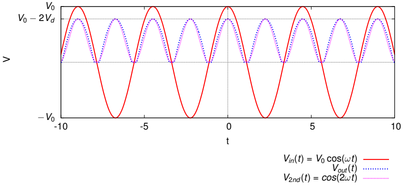
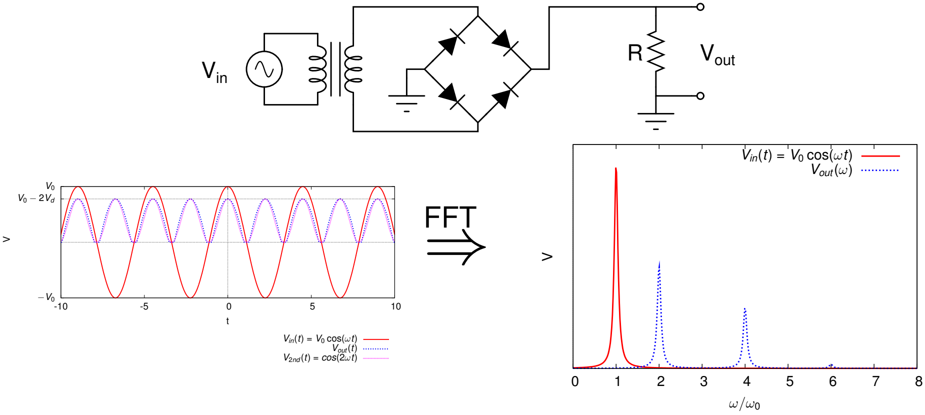


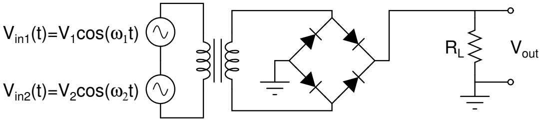


FFT $\Rightarrow$

Full-wave rectifier as Frequency doubler



Full-wave rectifier as Frequency adder



$$V_{out}(t) = |V_{in}(t)| = \sqrt{V_{in}^2(t)} = \sqrt{(V_1\cos(\omega_1 t) + V_2\cos(\omega_2 t))^2}$$
$$= \sqrt{V_1^2\cos^2(\omega_1 t) + 2V_1V_2\cos(\omega_1 t)\cos(\omega_2 t) + V_2^2\cos^2(\omega_2 t)}$$

Assuming $V_1 \gg V_2$

$$V_{out}(t) \approx \sqrt{V_1^2\cos^2(\omega_1 t) + 2V_1V_2\cos(\omega_1 t)\cos(\omega_2 t) + \cancel{V_2^2\cos^2(\omega_2 t)}}$$
$$\approx V_1\left(\cos(\omega_1 t) + \frac{V_2}{V_1}\cos(\omega_1 t)\cos(\omega_2 t)\right)$$
$$\approx V_1\left(\cos(\omega_1 t) + \frac{V_2}{V_1}\frac{\cos((\omega_1+\omega_2)t) + \cos((\omega_1-\omega_2)t)}{2}\right)$$