

Diodes.

Eugeniy E. Mikhailov

The College of William & Mary



Lecture 05

Midterm exam

Where: In the lab

When: During the first hour of the lab

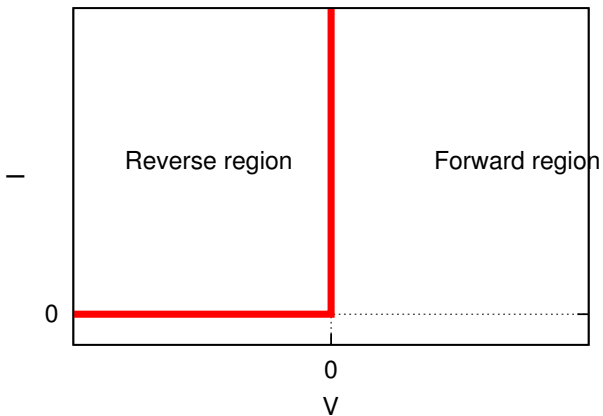
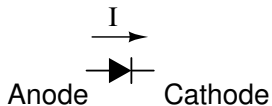
Material:

- 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.

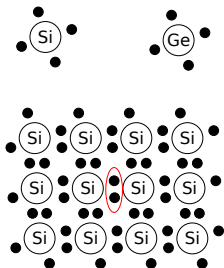
You can skip design exercise preparation prior to the lab. However, at the time of log book submission it must be fully done. Treat it as a home work.

Ideal diode



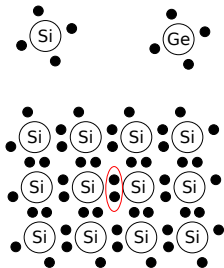
Semiconductors and doping

Pure semiconductor

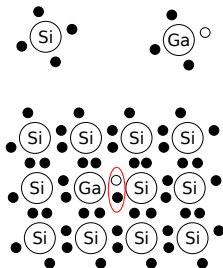


Semiconductors and doping

Pure semiconductor

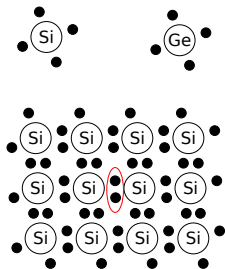


P-doped

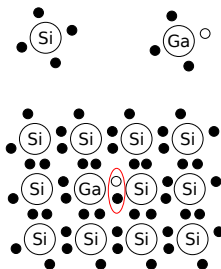


Semiconductors and doping

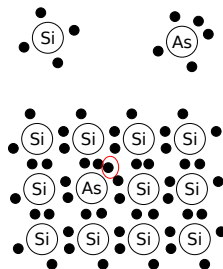
Pure semiconductor



P-doped

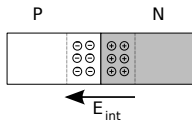


N-doped



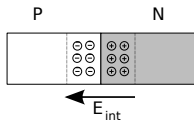
PN-junction

No bias

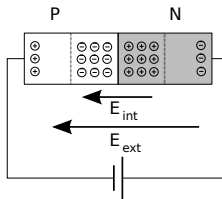


PN-junction

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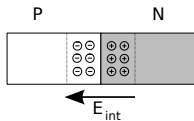


Reverse bias

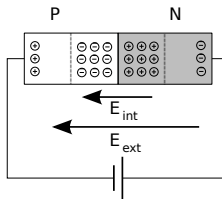


PN-junction

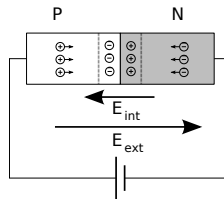
No bias



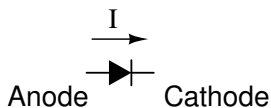
Reverse bias



Forward bias



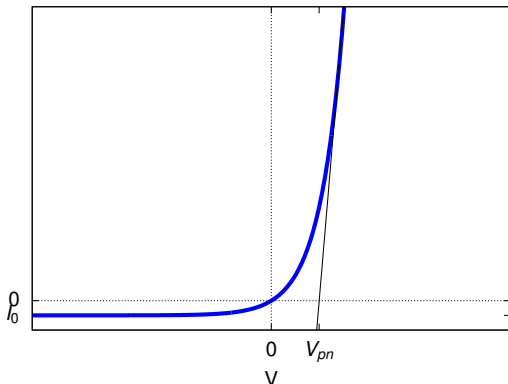
Real diode



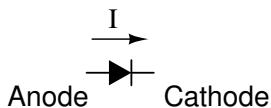
$$I(V) = I_0 \left(e^{V/(nV_T)} - 1 \right)$$

Typical parameters

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



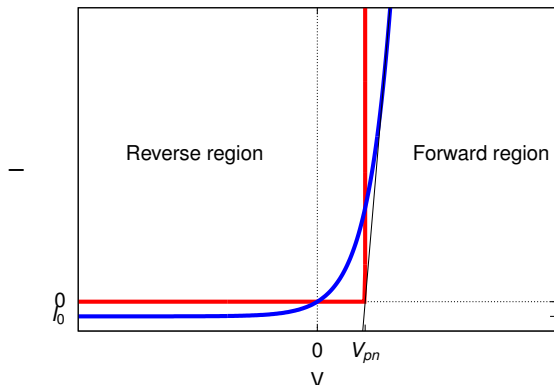
Real diode



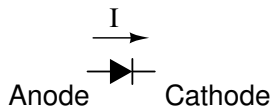
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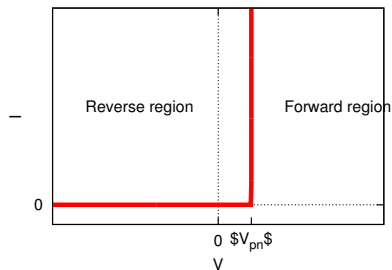


Simplified diode

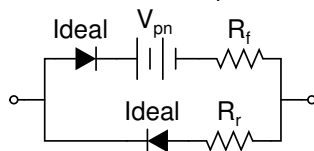


V_{pn} diode P-N junction opening voltage

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



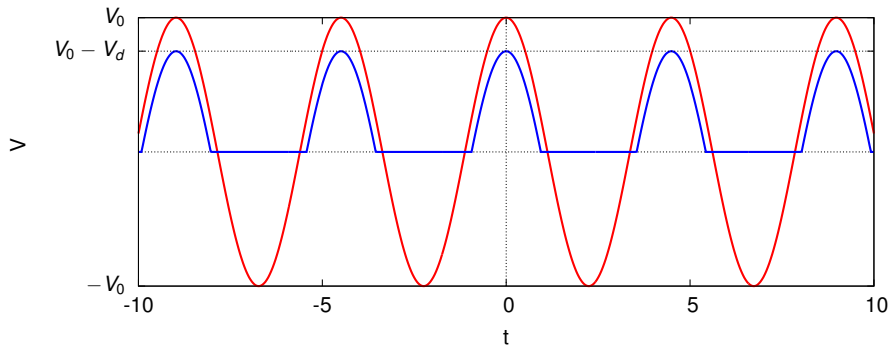
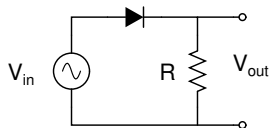
A bit more realistic diode
($R_r \gg R_f$)



Diodes applications

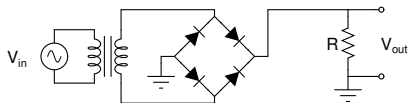
- Circuit Protection
- Rectification
 - current gate
 - half wave rectifier
 - full wave rectifier
 - Power Supplies
- Frequency manipulation
 - Frequency multiplier
 - Mixers
- and more ...
 - Voltage clamps
 - light emitting diodes (LED)
 - photo-diode

Half-wave rectifier, current gate

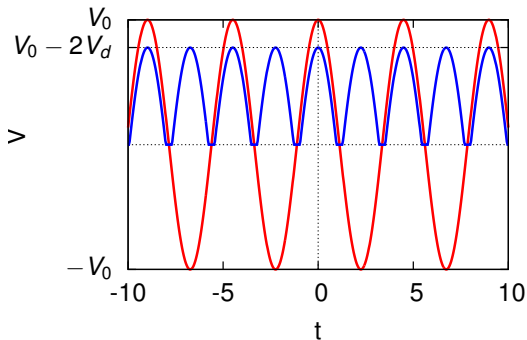


$$V_{in}(t) = V_0 \cos(\omega t) \quad \text{— red —}$$
$$V_{out}(t) \quad \text{— blue —}$$

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

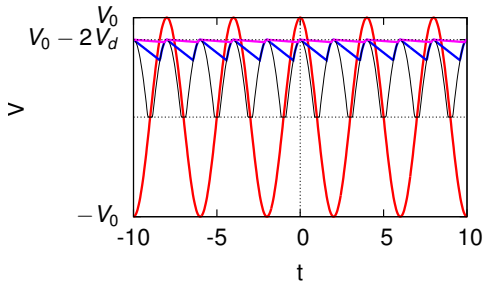
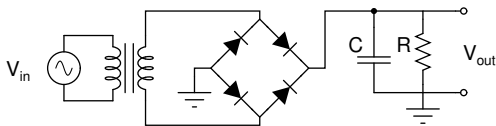


Why
 $\max(V_{out}) = V_0 - 2V_d$?



$$V_{in}(t) = V_0 \cos(\omega t) \quad \text{--- red ---}$$
$$V_{out}(t) \quad \text{--- blue ---}$$

Full-wave rectifier filtered - power supply



$$\begin{aligned}
 V_{in}(t) &= V_0 \cos(\omega t) && \text{— (red)} \\
 V_{out}(t), C1 & && \text{— (blue)} \\
 V_{rec}(t) & && \text{— (grey)} \\
 V_{out}(t), C2 > C1 & && \text{— (magenta)}
 \end{aligned}$$

Ripples size

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

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

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

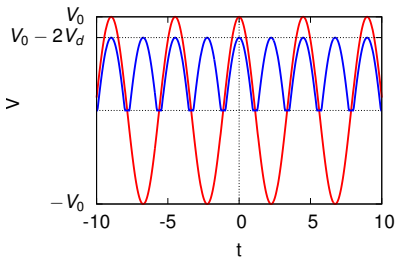
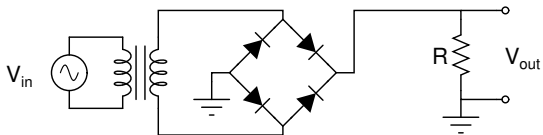
$$I \leq I_{max} = \frac{V_{max}}{R}$$

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

$T \ll RC$

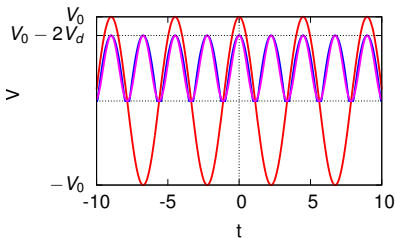
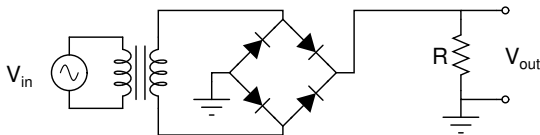
$$\Delta V \leq \frac{V_{max}}{2RCf_{in}}$$

Full-wave rectifier as Frequency doubler



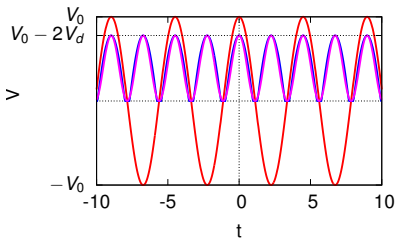
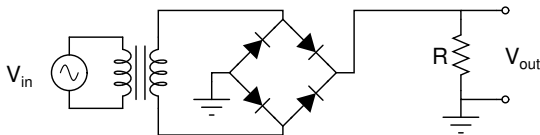
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$$V_{out}(t) \quad \text{— blue —}$$

Full-wave rectifier as Frequency doubler



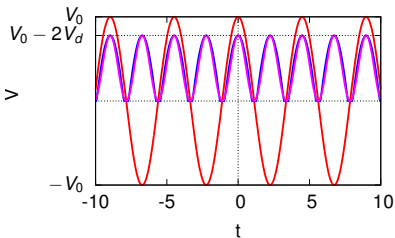
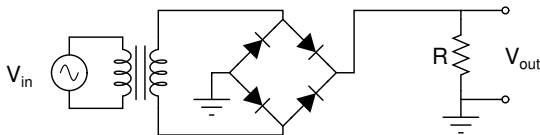
$$\begin{aligned} V_{in}(t) &= V_0 \cos(\omega t) && \text{— red —} \\ V_{out}(t) &= \cos(2\omega t) && \text{— blue —} \\ V_{2nd}(t) &= \cos(2\omega t) && \text{— magenta —} \end{aligned}$$

Full-wave rectifier as Frequency doubler



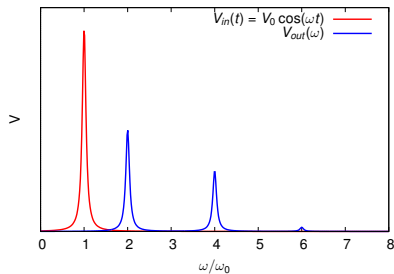
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Full-wave rectifier as Frequency doubler

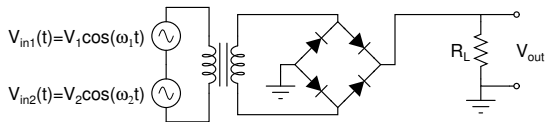


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FFT
→



Full-wave rectifier as Frequency adder



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

Assuming $V_1 \gg V_2$

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