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

Anode  Cathode

Reverce region  Forward region

0 0
Semiconductors and doping

Pure semiconductor

- **Si**
- **Ge**

P-doped

- **Si**
- **Ga**

N-doped

- **Si**
- **As**
Semiconductors and doping

Pure semiconductor

P-doped

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Week 5
Semiconductors and doping

Pure semiconductor

P-doped

N-doped
PN-junction

No bias

\[ E_{\text{int}} \]
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
  
  \[ I_0 = 1 \text{ nA} \]

- thermal voltage
  
  \[ V_T = \frac{kT}{q} = 25.85 \text{ mV at 300 K} \]

- emission coefficient
  
  \[ n = 1..2 \]
Real diode

\[ I(V) = I_0 \left( e^{\frac{V}{nV_T}} - 1 \right) \]

Typical parameters

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

\[ V_{pn} \text{ diode P-N junction opening voltage} \]

- \( V_{pn} = 0.6 \text{ V for Si} \)
- \( V_{pn} = 0.3 \text{ V for Ge} \)

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

\[ V_{\text{in}}(t) = V_0 \cos(\omega t) \]

\[ V_{\text{out}}(t) \]
Full-wave rectifier

\[ V_{\text{in}} \rightarrow \text{Transformer} \rightarrow \text{Diode Bridge} \rightarrow R \rightarrow V_{\text{out}} \]

\[ V_{\text{in}}(t) = V_0 \cos(\omega t) \]

\[ V_{\text{out}}(t) \]

- \( V_0 \)
- \( V_0 - 2V_d \)
- \( -V_0 \)

-10 -5 0 5 10

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Full-wave rectifier filtered - power supply

Ripples size

\[ V(t) = \frac{Q_{\text{max}} - It}{C} = V_{\text{max}} - \frac{It}{C} \]

\[ I \leq I_{\text{max}} = \frac{V_{\text{max}}}{R_L} \]

\[ t \leq T = \frac{1}{2f_{\text{in}}} \]

\[ \Delta V = V_{\text{max}} - V(t) \]

\[ \Delta V \leq \frac{V_{\text{max}}}{2R_L C f_{\text{in}}} \]
Full-wave rectifier as Frequency doubler

\[ V_{\text{in}}(t) = V_0 \cos(\omega t) \]

\[ V_{\text{out}}(\omega) \]

\[ V_{\text{out}}(t) \]

\[ V_{\text{in}} = V_0 \]

\[ V_0 - 2V_d \]

\[ -V_0 \]

\[ t \]

\[ -10 \]

\[ -5 \]

\[ 0 \]

\[ 5 \]

\[ 10 \]

\[ FFT \]

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Full-wave rectifier as Frequency doubler

\[ V_{in}(t) = V_0 \cos(\omega t) \]
\[ V_{out}(t) = V_0 \]
\[ V_{2nd}(t) = \cos(2\omega t) \]

Diagram:

- Input voltage \( V_{in} \)
- Rectifier circuit
- Load resistor \( R \)
- Output voltage \( V_{out} \)

Graph:

- Input voltage waveforms for different conditions
- Output voltage waveform
- Second harmonic waveform
Full-wave rectifier as Frequency doubler

\[ V_{\text{in}}(t) = V_0 \cos(\omega t) \]

\[ V_{\text{out}}(t) = V_2 \cos(2\omega t) \]

\[ \text{FFT} \]

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Full-wave rectifier as Frequency doubler

\[ V_{in}(t) = V_0 \cos(\omega t) \]

\[ V_{2nd}(t) = \cos(2\omega t) \]

FFT \[ \rightarrow \]

\[ V_{in}(t) = \frac{V_0}{2} \cos(\omega t) \]
Full-wave rectifier as Frequency adder

\[ V_{in1}(t) = V_1 \cos(\omega_1 t) \]
\[ V_{in2}(t) = V_2 \cos(\omega_2 t) \]

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

\[ = \sqrt{V_1^2 \cos^2(\omega_1 t) + 2V_1V_2 \cos(\omega_1 t) \cos(\omega_2 t) + V_2^2 \cos^2(\omega_2 t)} \]

Assuming \( V_1 \gg V_2 \)

\[ V_{out}(t) \approx \sqrt{V_1^2 \cos^2(\omega_1 t) + 2V_1V_2 \cos(\omega_1 t) \cos(\omega_2 t) + \frac{V_2^2}{2} \cos^2(\omega_2 t)} \]

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

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