ELL101: Introduction to Electrical Engineering

Madhusudan Singh, Manan Suri, Saif K. Mohammad, Shubhendu Bhasin and A. P. Prathosh

IIT Delhi

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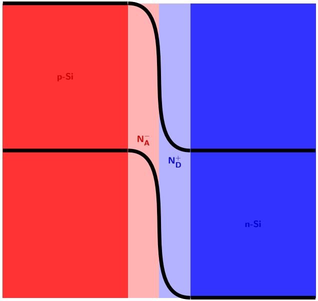
Lecture 14: Zener diodes, diode circuits and rectification

Recap

- Calculation of electron and hole carrier densities from three-dimensional density of states and Fermi function. Effective mass. Fermi level.
- Intrinsic carrier concentration ($3k_BT$ approximation). Intrinsic energy level. Position of the Fermi level as a signature of doping. Peculiarity of physical units used in semiconductor physics.
- Carrier mobility and electric field dependence of carrier velocities. Ohm's law. Conductivity. Resistivity.
- Reading semiconductor properties tables.
- Carrier generation - thermal and optical. Generation rates. Low light level approximation. Recombination time constant.
- Carrier recombination. Electroluminescence.
- pn junctions. Formation of depletion region. Bending of bands. Diffusion and drift. Diode equation. Importance of reporting current density rather than current.

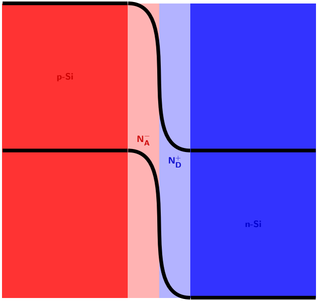
Zener diodes

- Special type of diodes - very heavy doping on both sides.



Zener diodes

- Special type of diodes - very heavy doping on both sides.
- Depletion region narrows, and bands nearly line up. Tunneling is possible at high enough reverse bias.



$$J = qvn \underbrace{\exp\left[-\frac{4}{3q\hbar E}\sqrt{2m^{*}\mathcal{E}_g^3}\right]}_{\text{Tunnel probability}}$$

Zener diodes

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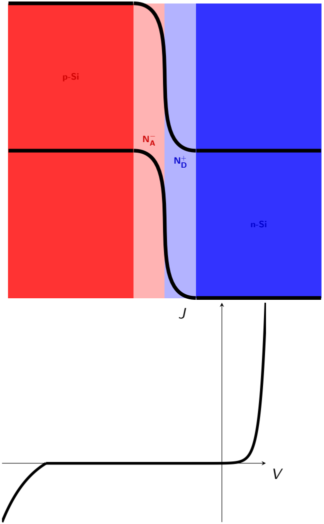
- Depletion region narrows, and bands nearly line up. Tunneling is possible at high enough reverse bias.
- "Designer" breakdown. Reverse bias current rises rapidly at a certain voltage. Can largely maintain that voltage regardless of current.



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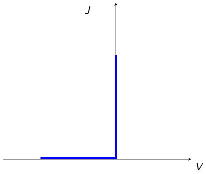
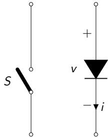
The diode as an ideal switch

- Zero resistance in forward bias.
- Infinite resistance in reverse bias.





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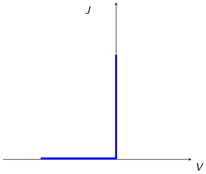

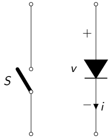

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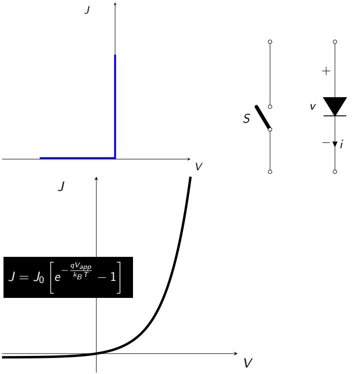

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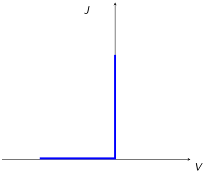
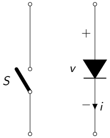
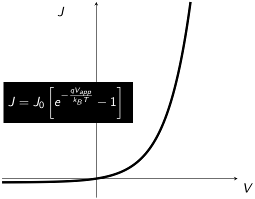
- Si: 0.7 V. Ge: 0.5 V. Knee voltage.







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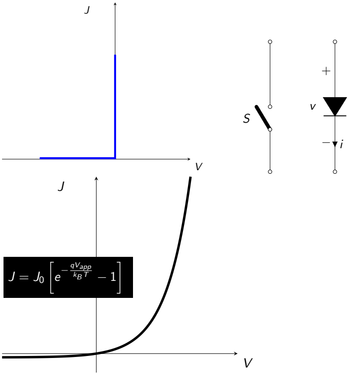
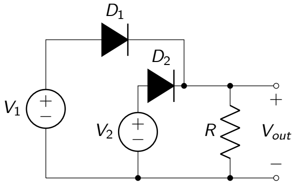
- Several applications:
  - AC-DC conversion: rectifier.
  - Peak detection, DC restoration: clamper.
  - Wave shaping: clipper.



Worked example 1



- The IC employs Si technology with junction potential 0.7 V. $V_1 = 5V$ and $V_2 = 0V$. Find V_{out}.

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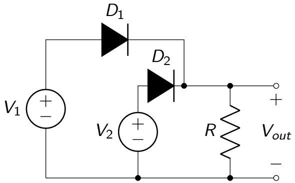

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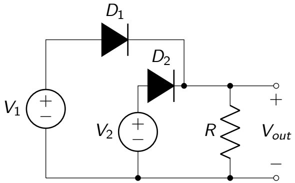

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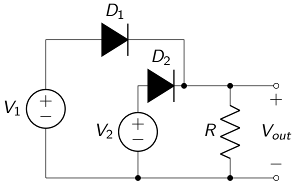

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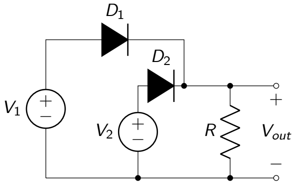

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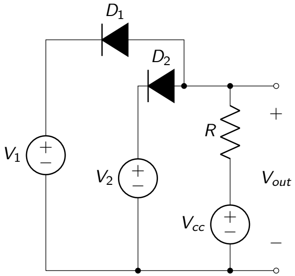
  3. $V_{out} < 0$: Both diodes are FB. V_{out} is overspecified.

Worked example 2



- Si technology with junction potential 0.7 V. $V_1 = 5V$, $V_2 = 0V$ and $V_{cc} = 6V$. Find V_{out}.

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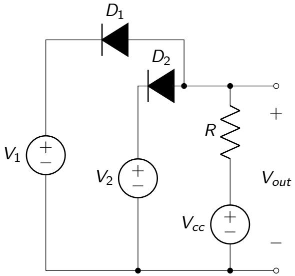

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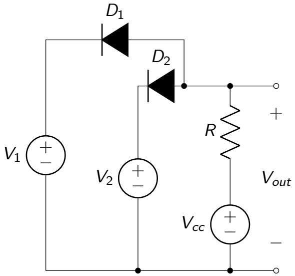

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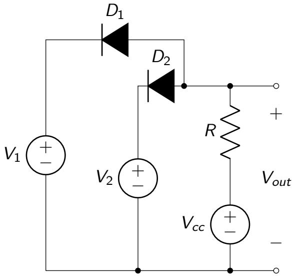

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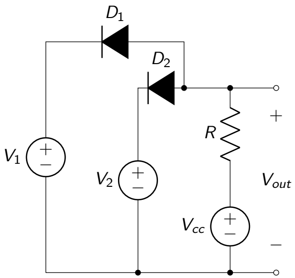

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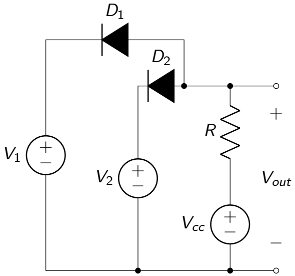

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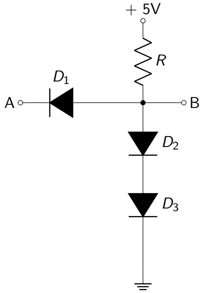
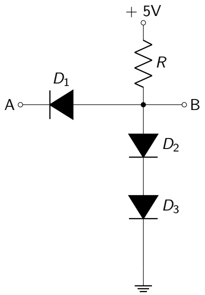
  4. D_1 is RB ($V_{out} < 5V$) and $D_2 > 0V$. Possible. $V_{out} = 0 + 0.7 = 0.7V$

Worked example 3



- Si technology. Find V_B for $V_A = -1, 0, 1$ and $2V$



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	D_2, D_3: FB	D_2, D_3: RB

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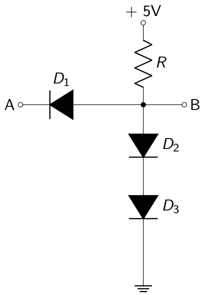

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	D_2, D_3: FB	D_2, D_3: RB
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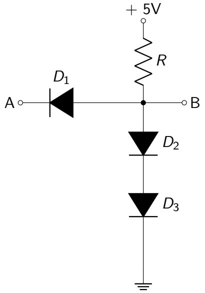

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D_1: FB	$V_B > V_A$, $V_B > 0$, $V_B = \min(V_A + 0.7, 1.4)$	$V_A < V_B < 0$ $V_B = V_A + 0.7$

Rectification

- Conversion of an AC current to unidirectional pulsating current by using an asymmetric device (for instance a diode).
- Two types:
  1. Half-wave rectifier: uses only half of an AC signal.
  2. Full-wave rectifier: uses both halves of an AC signal.

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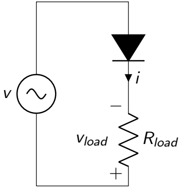
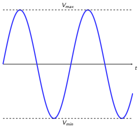
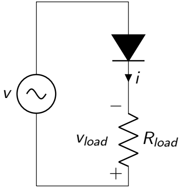
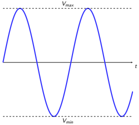
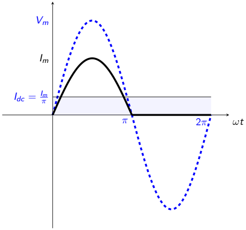




Half-Wave Rectifier







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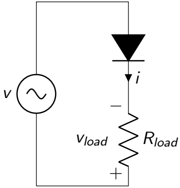

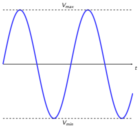

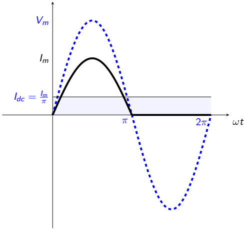

- The DC value of current can be estimated using ideal switch behaviour for the diode.

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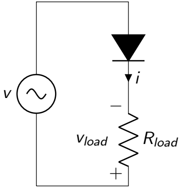

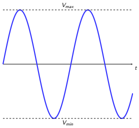

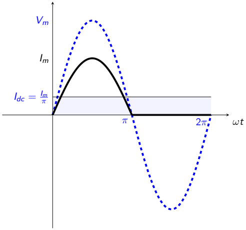

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- It is the time average over one full cycle.

$$i = \frac{v}{R_{load}} = \begin{cases} \frac{V_m \sin \omega t}{R_{load}} & 0 \leq \omega t \leq \pi \\ 0 & \pi \leq \omega t < 2\pi \end{cases}$$

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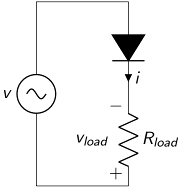

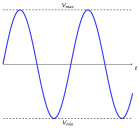

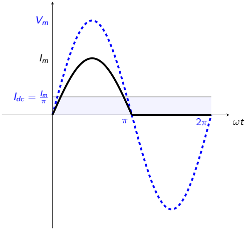

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- Second half cycle drops out. Approx. 32% for both current and load voltage.

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$$I_{dc} = \frac{1}{2\pi} \int_0^{2\pi} i d(\omega t) = \frac{1}{2\pi} \int_0^{\pi} \frac{V_m \sin \omega t}{R_{load}} d(\omega t)$$

$$I_{dc} = \frac{V_m}{\pi R_{load}} \equiv \frac{I_m}{\pi}; \text{ and, } V_{dc} = \frac{V_m}{\pi}$$

Discussion

- RMS value of load voltage (v_{load}) is given by

$$V_{rms} = \sqrt{\frac{1}{2\pi} \int_{0}^{\pi} \left(V_m \sin \omega t \right)^2 d\left(\omega t \right)} = \frac{V_m}{2}$$

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- Application: two position lamp dimmer switch.