VE311 Mid Review - Diode

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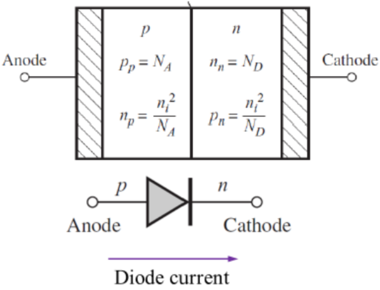
Overview

PN Junction Diode



N_A, N_D: doping densities
n_i: intrinsic carrier concentration

hole in p:

$$p_p = N_A \tag{1}$$

electron in p:

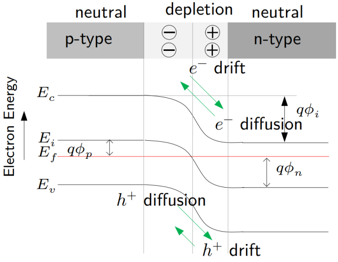
$$n_p = \frac{{n_i}^2}{N_A} \tag{2}$$

electron in n:

$$n_n = N_D \tag{3}$$

hole in n:

$$p_n = \frac{{n_i}^2}{N_D} \tag{4}$$



built-in potential:

$$V_{bi} = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right) \quad (5)$$

- Some electrons/holes in the neutral regions with sufficient energy continuously diffuse to the opposite sides. $\rightarrow$ Formation of diffusion
- Some electrons/holes wandering into the in the depletion region get swept by the built-in electric field. $\rightarrow$ Formation of drift current
- Diffusion current cancels drift current. **No net current flowing.**

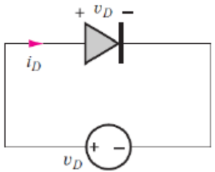
Diode Equation

- Forward Bias: Diode is on. Current flows from p to n.
- Reverse Bias: Diode is off. Current doesn't flow, but saturation current exists.

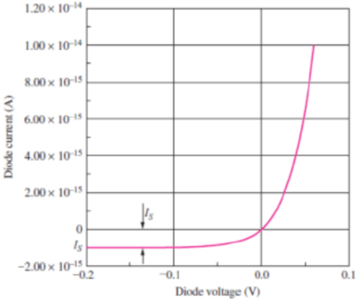
$$I_D = I_S\left(e^{\frac{qV_D}{KT}} - 1\right) = I_S\left(e^{\frac{V_D}{V_T}} - 1\right) \tag{6}$$

Note:

- k = Boltzmann's constant, 8.62 × 105 eV/K
- $\frac{kT}{q}$ = 0.026(0.025875)V at 300K when calculation.



IV Characteristics of Diode

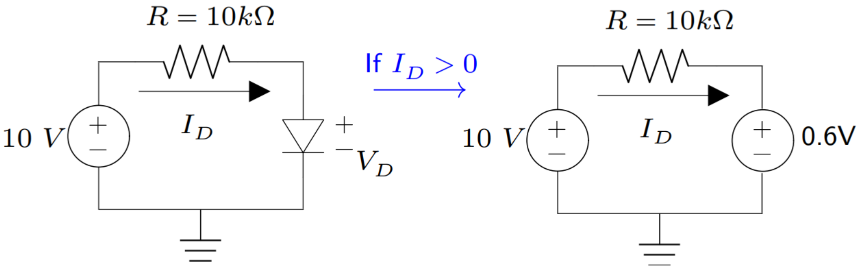


Non-linear, or rectifying, behavior

- **Non-linear** behavior
- turn-on voltage $> V_{bi}$

Diode Simplification

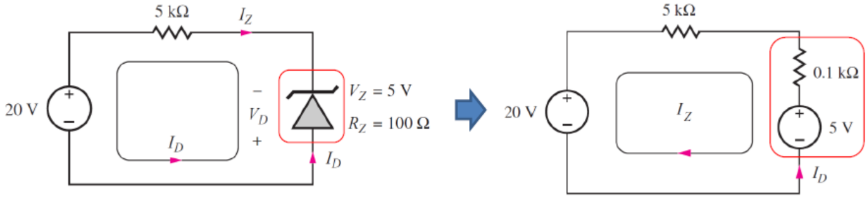
- Ideal Diode Model: **Short circuit** for Forward Bias and **Open Circuit** for Reverse Bias
- Constant Voltage Drop Model: **Replace Diode with a voltage source** for Forward Bias and **Open Circuit** for Reverse Bias.



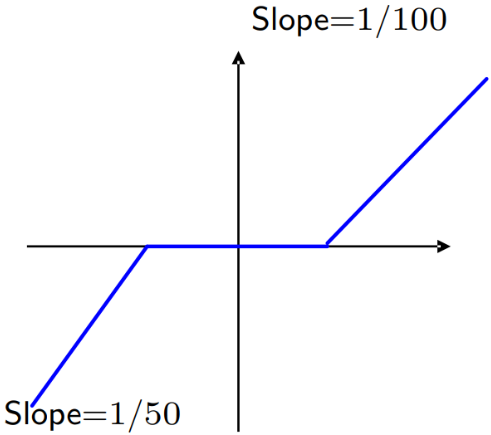
Diode Simplification

1. Identify the model for simplification.
2. Assume the voltage applied on the diode
3. Transform the diode to source and resistor according to the assumption.
4. Validate that the assumption is correct or not.

Method: Replace the Diode with a "Reverse" voltage source and a resistance.

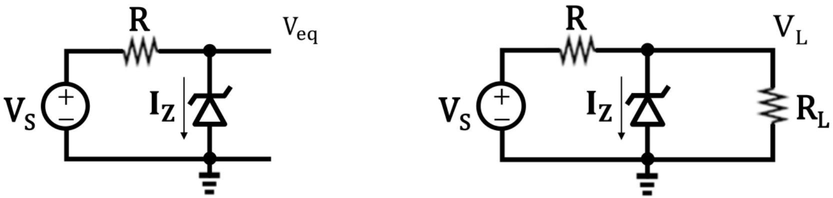


When $V_D < V_{break}$, voltage source is V_{break}, slope is $\frac{1}{R_Z}$.



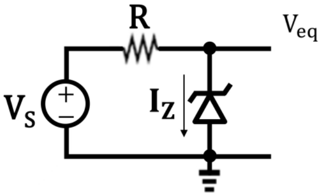
Voltage Regulator

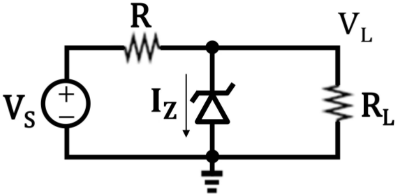
Assume the zener diode operates in reverse breakdown region.



$$V_{eq} = V_{break} + \frac{V_s - V_{break}}{R + R_Z} R_Z \tag{7}$$

$$V_L = V_{eq} \frac{R_L}{(R||R_Z) + R_L} \tag{8}$$

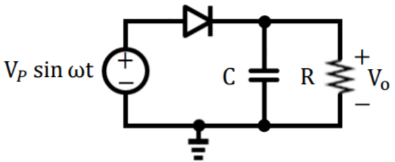


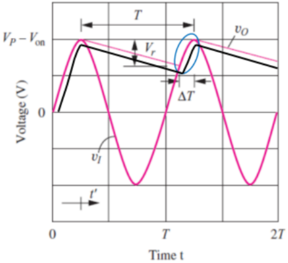


$$\text{Line Regulation} = \frac{dV_L}{dV_S} = \frac{R_Z}{R + R_Z} (R_L = \infty) \tag{9}$$

$$\text{Load Regulation} = \frac{dV_L}{dI_L} = R \parallel R_Z \tag{10}$$

The basic rectifier circuit converts an AC voltage to a pulsating DC voltage.





$V_p \sin \omega t > V_O$

Diode ON

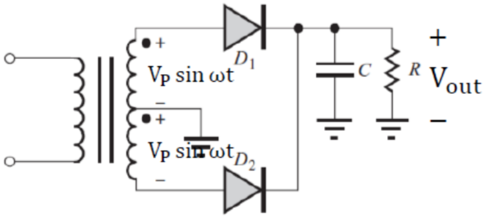
Half-Wave Rectifier

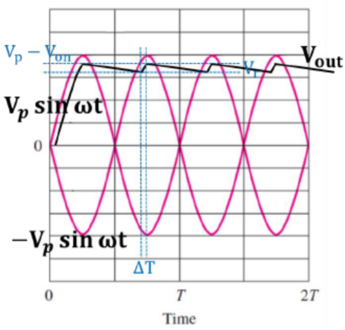
CTPP Time!

1. $V_{dc} = V_s - V_{on}$
2. $I_{dc} = \frac{V_{dc}}{R}$
3. Ripple Voltage: $V_r = V_{dc}(1 - e^{\frac{T-\Delta T}{RC}}) \approx V_{dc}\frac{T}{RC}$
4. Conduction Angle: $\theta_c = \sqrt{\frac{2V_r}{V_S}}$
5. Conduction Interval: $\Delta T = \frac{\theta_c}{\omega}$
6. Diode Current: $I_{peak} = \frac{2I_{dc}T}{\Delta T}$
7. Surge Current: $I_{surge} = C\frac{dV}{dt} = \omega C V_S(t = 0)$
8. Peak Inverse Voltage (PIV): $PIV = 2V_s - V_{on}$

Full-Wave Rectifier

Full-wave rectifier circuits cut the capacitor discharge time in half and offer the advantage of requiring only one-half the filter capacitance to achieve a given ripple voltage





Full-Wave Rectifier

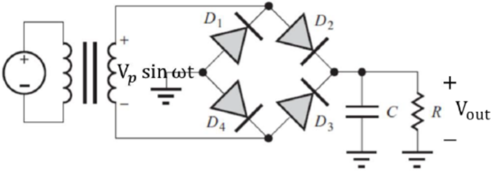
CTPP Time!

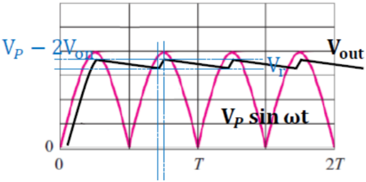
Just replace T with $\frac{T}{2}$ in the Half-Wave rectifier.

1. $V_{dc} = V_s - V_{on}$
2. $I_{dc} = \frac{V_{dc}}{R}$
3. Ripple Voltage: $V_r = V_{dc}(1 - e^{\frac{T/2-\Delta T}{RC}}) \approx V_{dc}\frac{T}{2RC}$
4. Conduction Angle: $\theta_c = \sqrt{\frac{2V_r}{V_S}}$
5. Conduction Interval: $\Delta T = \frac{\theta_c}{\omega}$
6. Diode Current: $I_{peak} = \frac{I_{dc}T}{\Delta T}$
7. Surge Current: $I_{surge} = C\frac{dV}{dt} = \omega CV_S(t = 0)$
8. Peak Inverse Voltage (PIV): $PIV = 2V_s - V_{on}$

Full-Wave Bridge Rectifier

- For $v_I > 0$, D_2 and D_4 will be on and D_1 and D_3 will be off.
- For $v_I < 0$, D_2 and D_4 will be off and D_1 and D_3 will be on.





Full-Wave Bridge Rectifier

CTPP Time!

Just replace V_{on} with $2V_{on}$ in the Full-Wave rectifier and change PIV.

1. $V_{dc} = V_s - 2V_{on}$
2. $I_{dc} = \frac{V_{dc}}{R}$
3. Ripple Voltage: $V_r = V_{dc}(1 - e^{\frac{T/2-\Delta T}{RC}}) \approx V_{dc}\frac{T}{2RC}$
4. Conduction Angle: $\theta_c = \sqrt{\frac{2V_r}{V_S}}$
5. Conduction Interval: $\Delta T = \frac{\theta_c}{\omega}$
6. Diode Current: $I_{peak} = \frac{I_{dc}T}{\Delta T}$
7. Surge Current: $I_{surge} = C\frac{dV}{dt} = \omega C V_S(t = 0)$
8. Peak Inverse Voltage (PIV): $PIV = V_s - V_{on}$

Good Luck!