Diode current equation

$$I_D = I_o(e^{V_D/\eta V_T} - 1)$$

$$= I_o e^{V_D/\eta V_T} - I_o$$

- I_D is diode current
- I_o is reverse saturation current
- V_D is voltage across diode
- V_T is thermal voltage = T / 11600
- η is a constant = 1 for Ge and 2 for Si

η = Ideality Factor – indicates the nearness with which the considered diode behaves with respect to the ideal diode

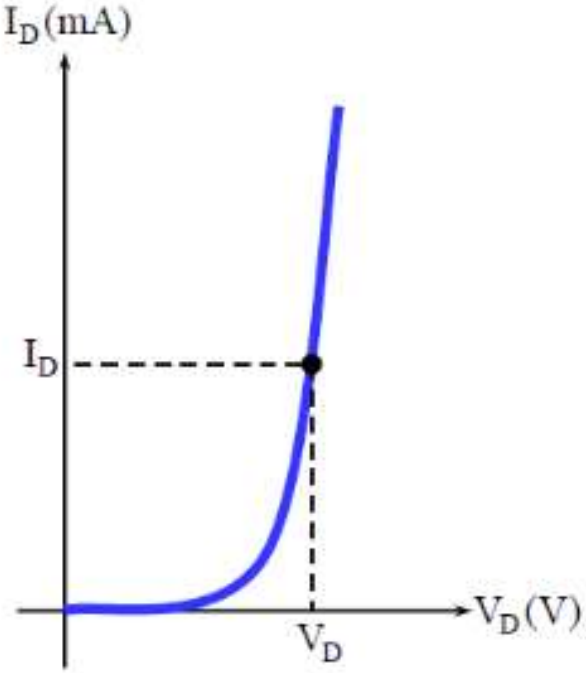
If it is 1, diode considered behaves as exactly as ideal diode

If it increases from 1, behavior of considered diode deviates from the ideal diode, greater is the deviation , greater is the value of η

Diode resistances

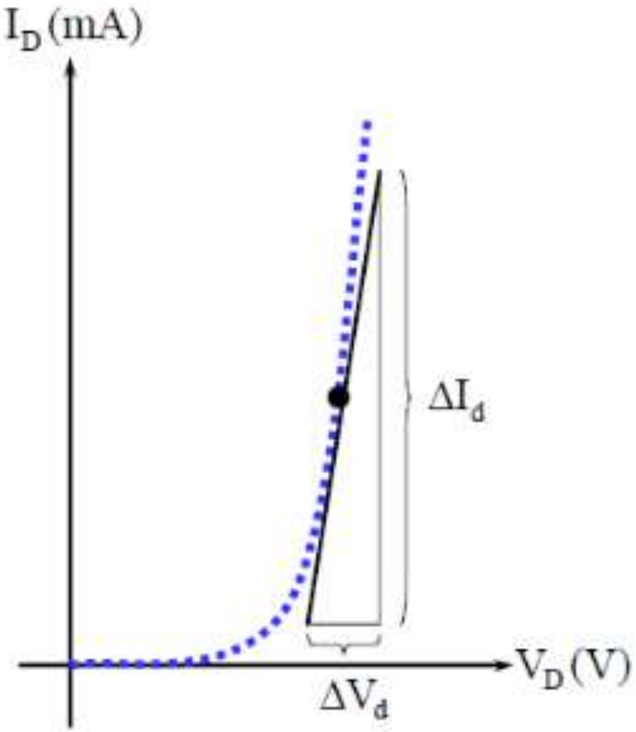
- **Static or DC resistance:**
  - ratio of diode voltage and diode current

$$R_D = \frac{V_D}{I_D}$$



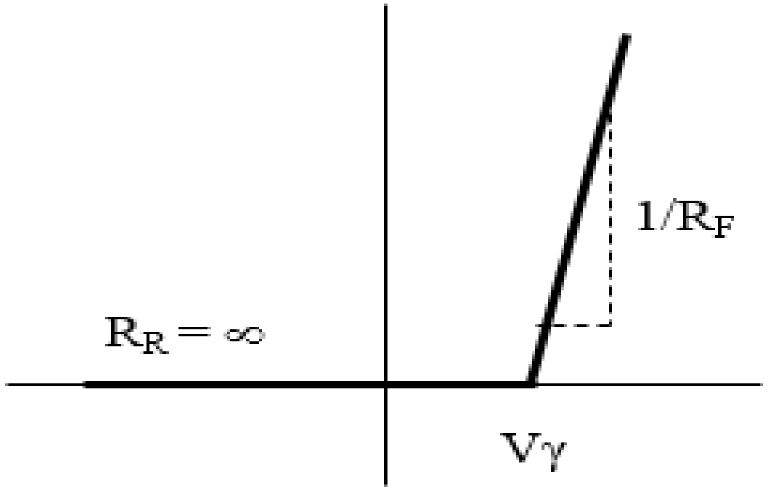
AC resistance:

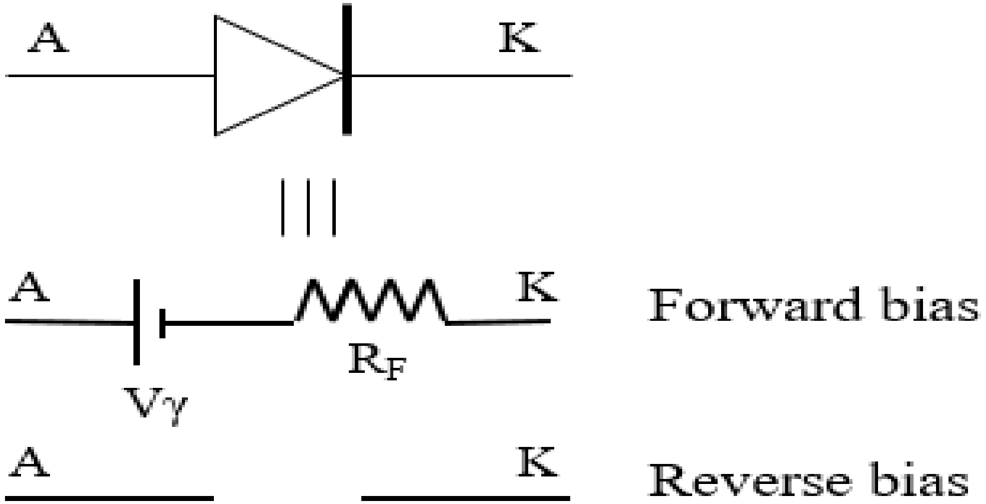
$$r_d = \frac{\Delta V_D}{\Delta I_D} \qquad r_d = \frac{\Delta V_D}{\Delta I_D} \approx \frac{\eta V_T}{I_D}$$



Diode Equivalent Circuit

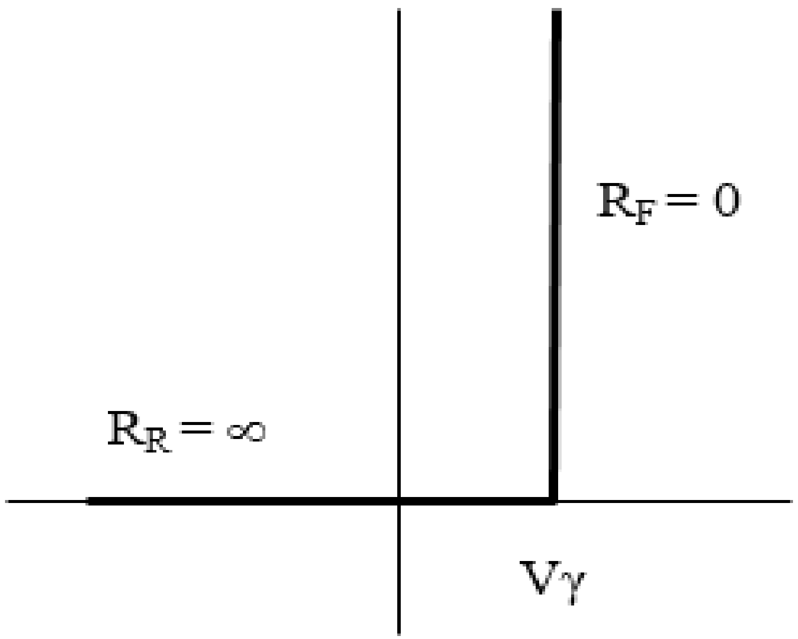
- Used during circuit analysis
- Characteristic curve replaced by straight-line segments

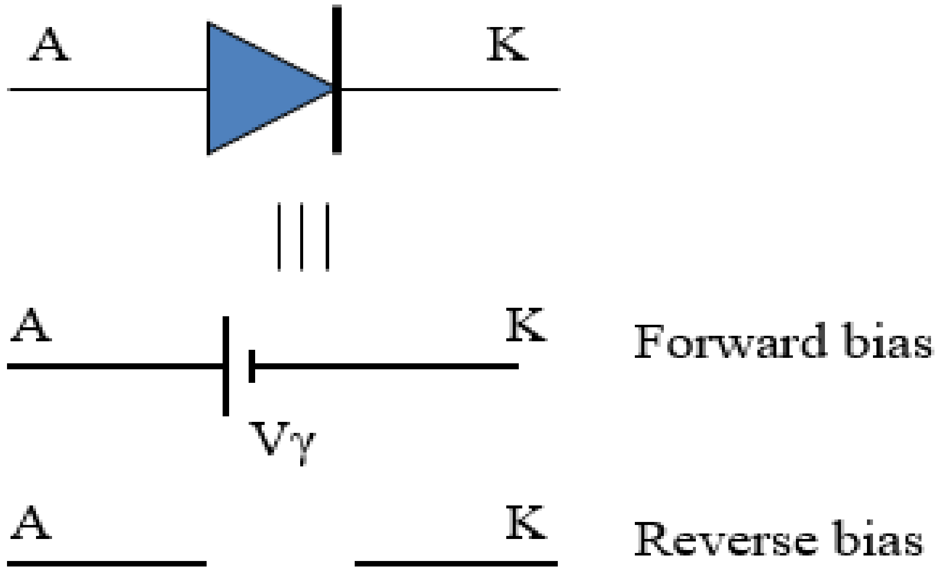




Diode Equivalent Circuit

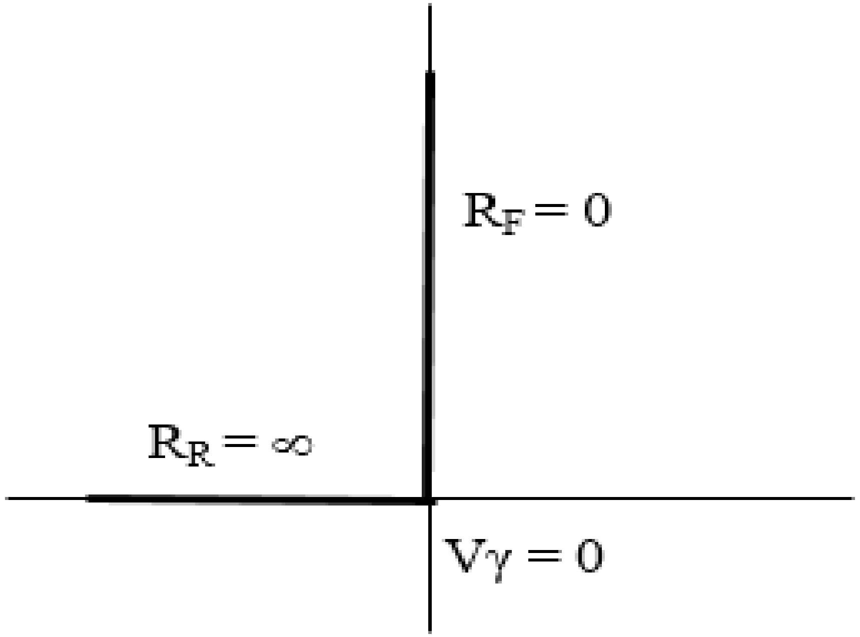
- As further approximation, we can neglect the slope of the characteristic i.e., $R_F = 0$

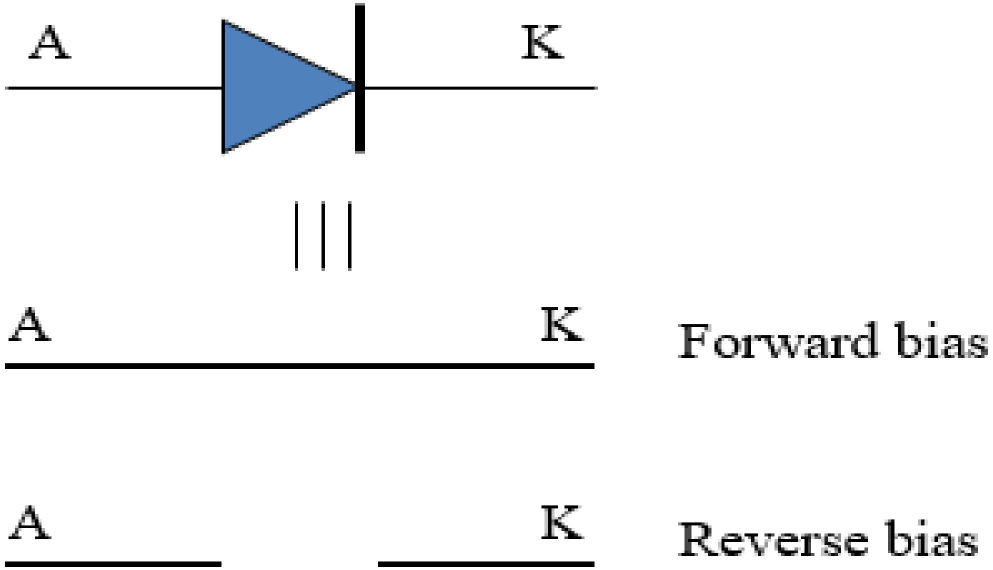




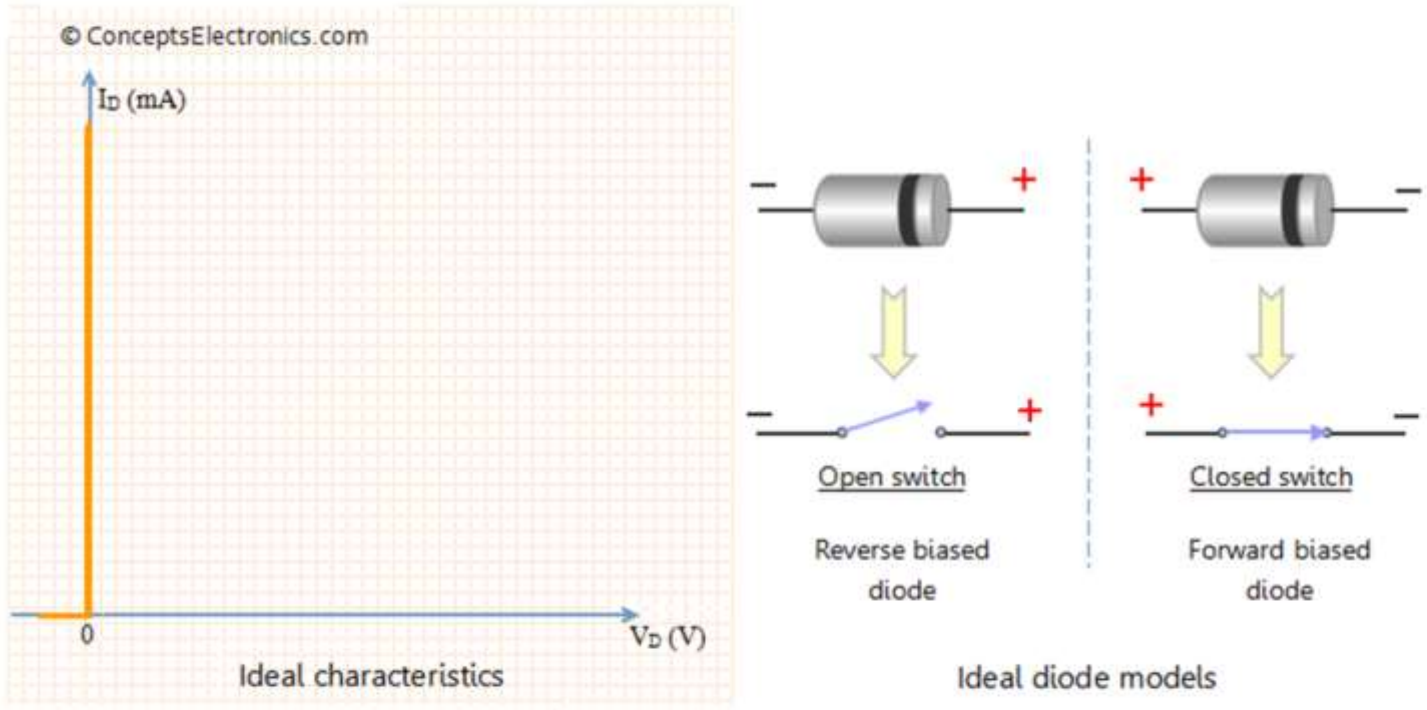
Diode Equivalent Circuit

- As third approximation, even the cut-in voltage can be neglected (Ideal diode)





Ideal diode : V-I characteristics



V-I characteristic of Ideal diode and ideal models

[http://conceptselectronics.com/diodes/diode-equivalent-models/].

Effect of Temperature on the Reverse current

Reverse saturation current approximately **doubles** for every **10 degree rise** in temperature.

$$I_{o2} = I_{o1} 2^{(T_2 - T_1)/10}$$

I_{O1} = Reverse saturation current at temperature T_1

I_{O2} = Reverse saturation current at temperature T_2

Note: Rise in temperature increases conductivity and thus increase in current

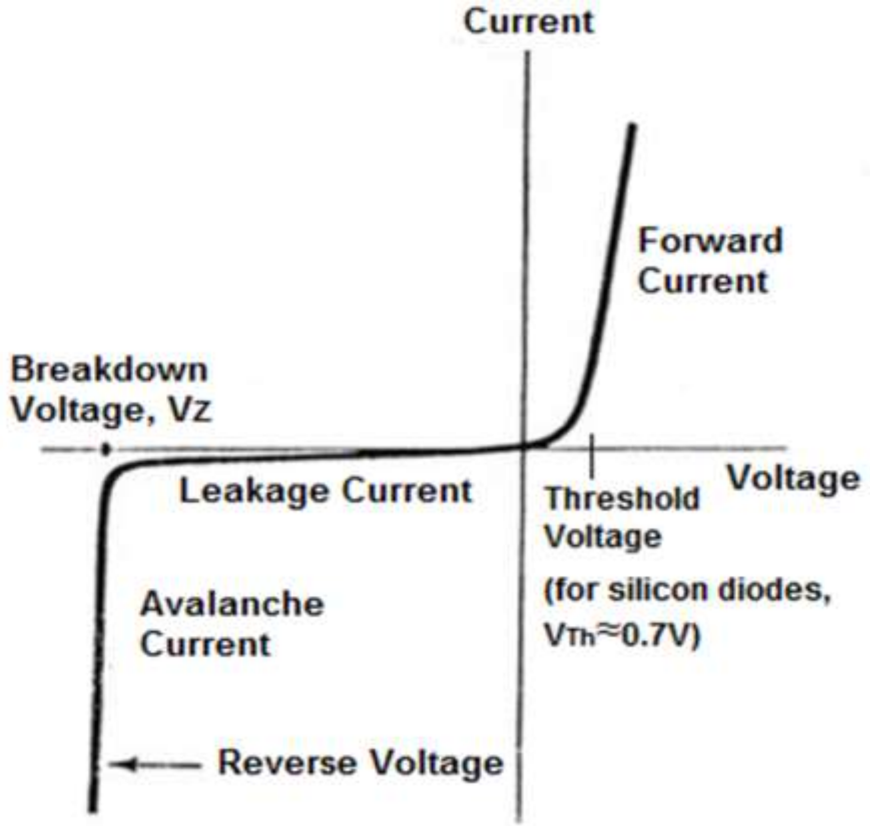
Breakdown in Reverse Biased Diodes

Large reverse current can damage the diode: this effect is called breakdown of diode

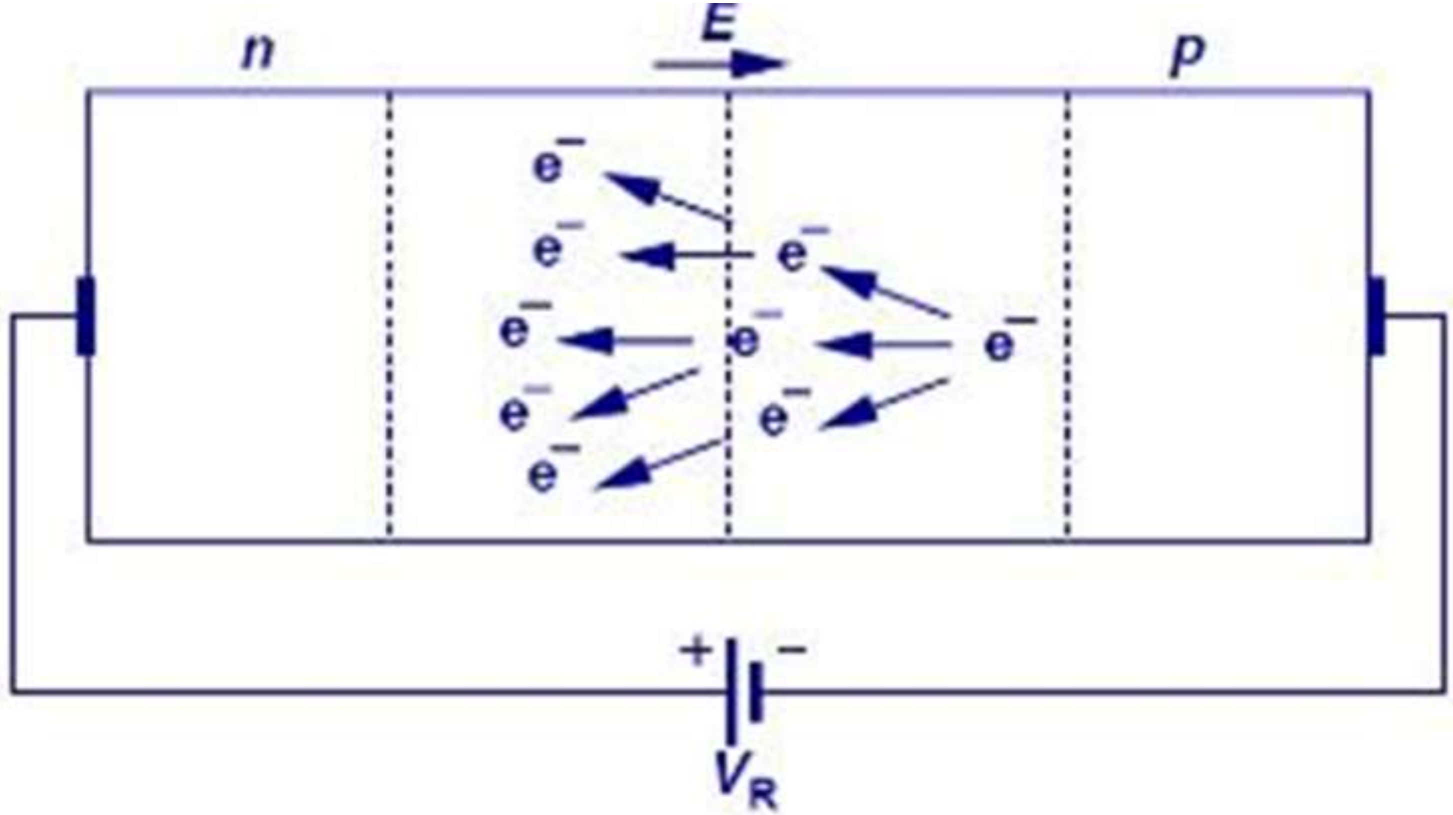
Two breakdown mechanisms:

- **Avalanche breakdown :**
  - Occurs in Lightly doped diodes,
  - Occurs at high reverse Voltage.

- **Zener Breakdown:**
  - Occurs in heavily doped diodes.
  - at lower reverse bias voltages.



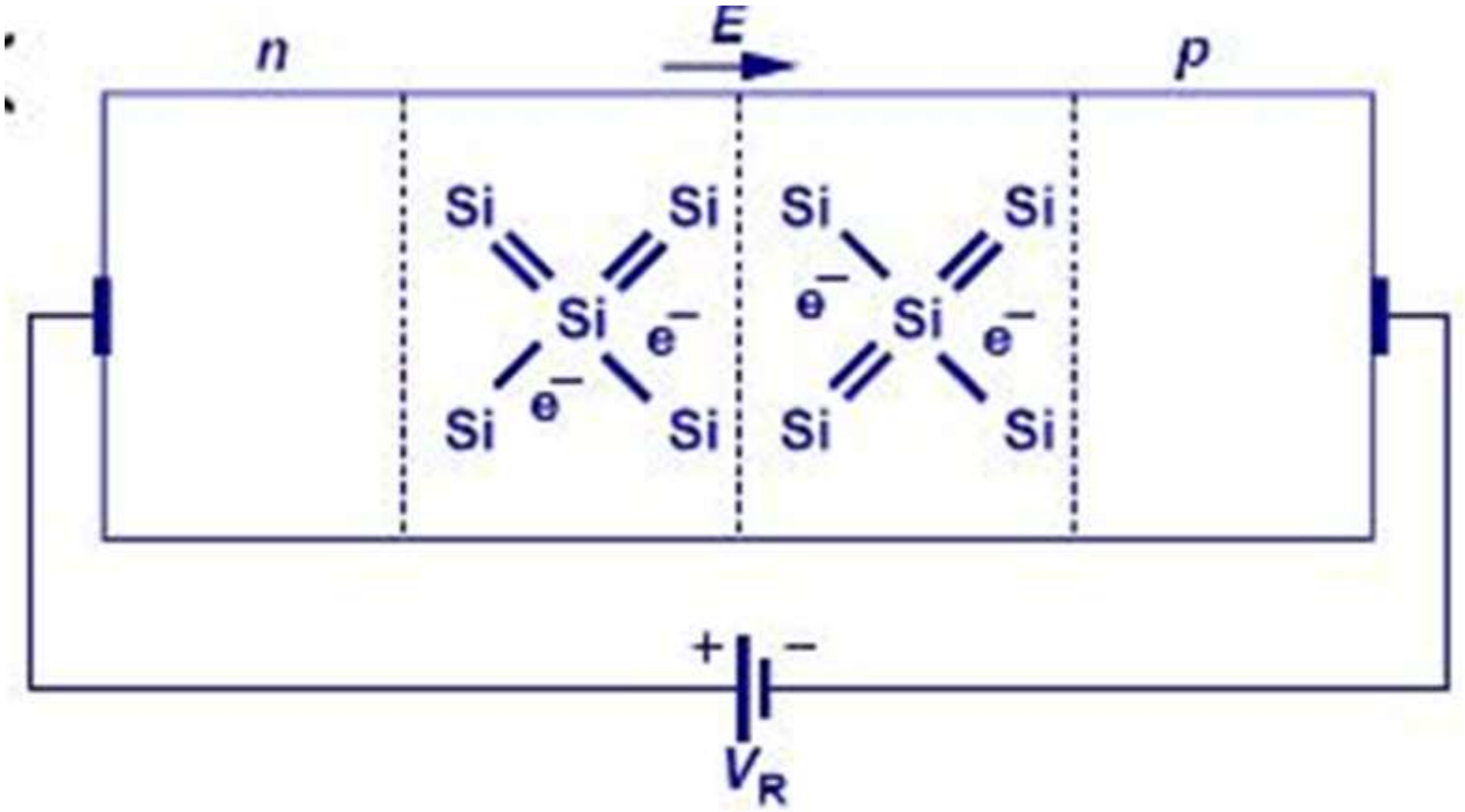
Avalanche Breakdown



Schematic of Avalanche phenomenon

http://shrdocs.com/presentations/12656/index.html

Zener Breakdown



Schematic of Zener phenomenon

http://shrdocs.com/presentations/12656/index.html

P-N Junction Diode

1. A Silicon diode has a saturation current of 1pA at 20^{0}C. Determine (a) Diode bias voltage when diode current is 3mA (b) Diode bias current when the temperature changes to 100^{0}C, for the same bias voltage.

a.

$$I_D = I_0\left(e^{\frac{V_D}{\eta V_T}} - 1\right)$$

$$V_T = \frac{T}{11600} = \frac{293}{11600} = 25.25\,mV$$

$$V_D = \eta V_T \ln\left(1 + \frac{I_D}{I_0}\right) = 1.103V$$

b.

$$I_{02} = I_{01}2^{(T_2 - T_1)/10} = 10^{-12}\left(2^{\frac{(100-20)}{10}}\right) = 256\,pA$$

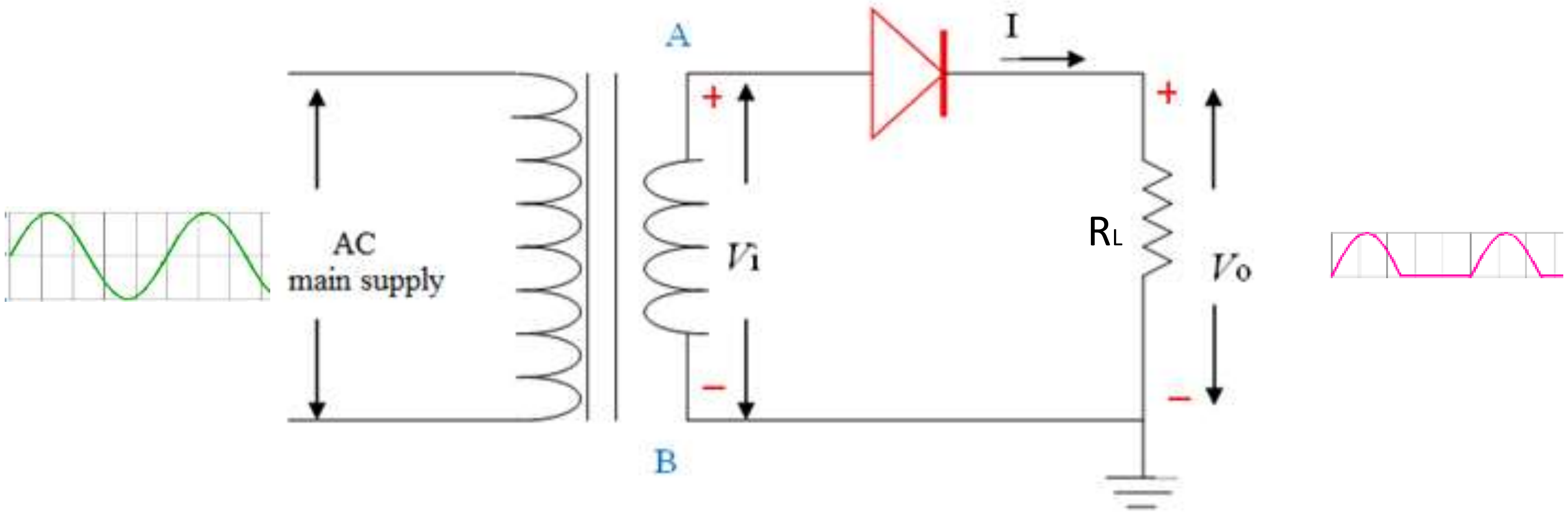
$$I_D = I_0\left(e^{\frac{V_D}{\eta V_T}} - 1\right)$$

$$\mathrm{I_D} = 256x10^{-12}\left(e^{\frac{1.103}{(2x32.15x10^{-3}-1)}}\right) = 7.21mA$$

RECTIFIER

- Converts AC signal to pulsating DC
- Primary element: Diode
- Two types of rectifiers are: Half wave rectifier (HWR)
  Full wave rectifier (FWR)
- Full wave rectifier
  - Center-tapped transformer FWR
  - Bridge FWR

Half Wave Rectifier (HWR)

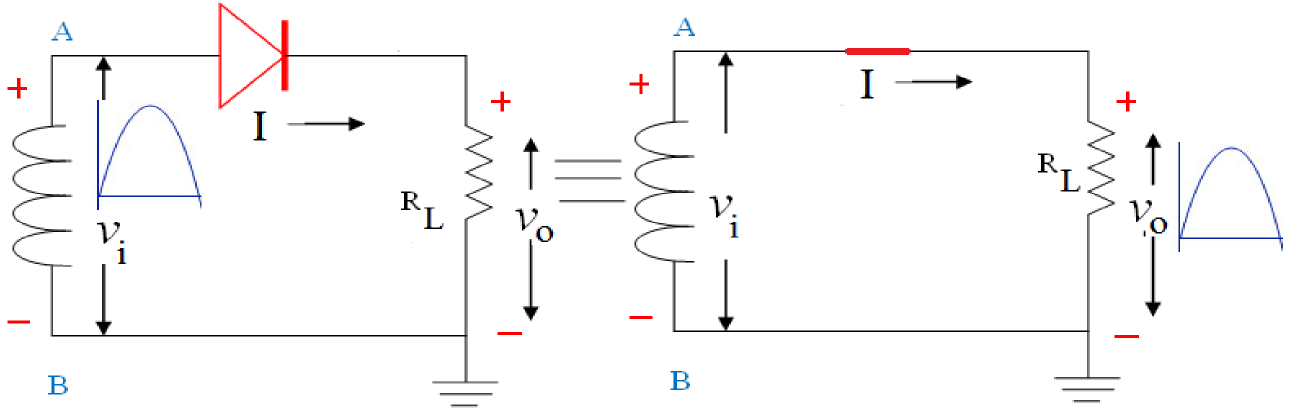


Circuit Diagram of HWR

- In HWR, the rectifying element conducts only during one half cycle of the input. Mostly during positive half cycle.
- Diode passes current only for half of the signal time period. Hence the name HWR.

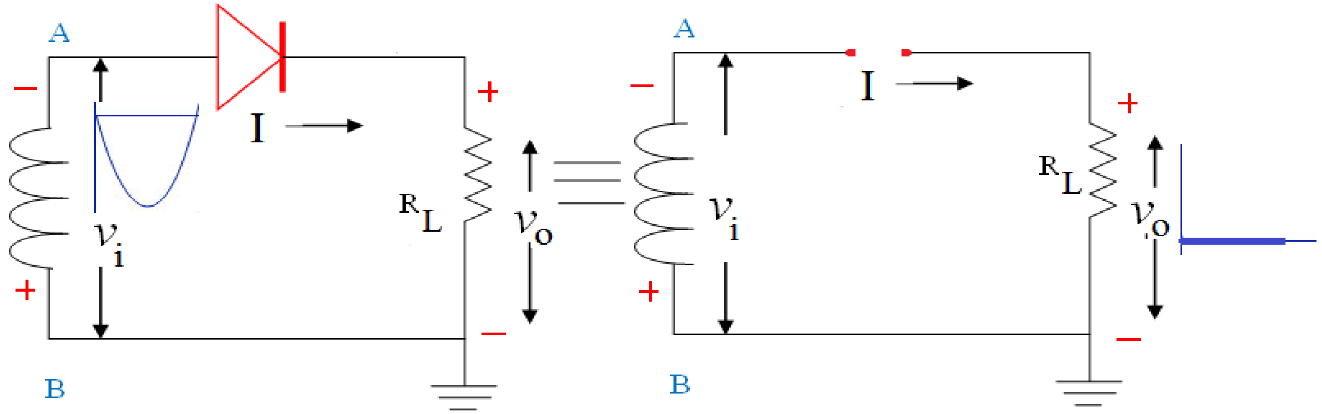
Half Wave Rectifier (HWR)

For positive half cycle



Equivalent Circuit of HWR, when node A is positive w.r.t node B

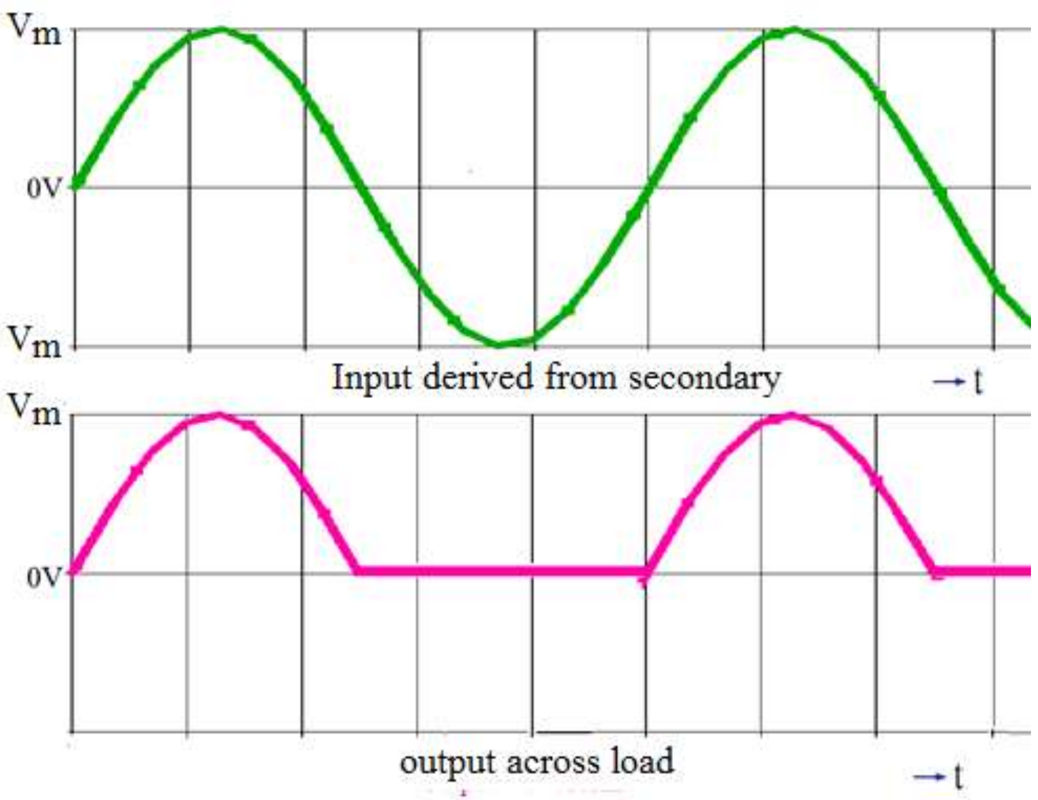
For negative half cycle



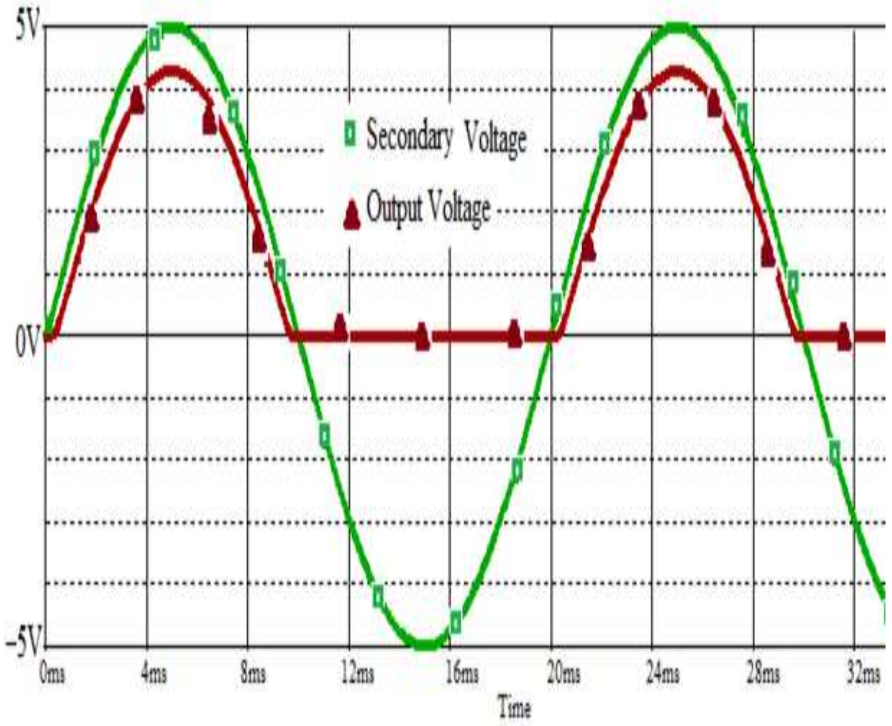
Equivalent Circuit of HWR, when node A is negative w.r.t node B

Note: Current through load exist only for one half cycle

Half Wave Rectifier (HWR)



Input and rectified output with ideal diode



Input and rectified output with practical diode

Half Wave Rectifier (HWR)

Performance of Rectifiers is measured using the following parameters:

- During positive half cycle of the input, $i_L = I_m \sin(\omega t)$, 0 to π

Peak current (I_m)

$$I_m = \frac{V_m - V_\gamma}{R_L + R_F} \approx \frac{V_m}{R_L}$$

- During negative half cycle of the input, $i_L = 0$, π to 2π

Average value of load current in half wave rectifier is non zero.

$$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i_L \, d(\omega t) = \frac{I_m}{\pi}$$

Half Wave Rectifier (HWR)

Average value of load current :

$$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i_L \, d(\omega t)$$

$$= \frac{1}{2\pi}\left[\int_0^{\pi} I_m \sin\omega t \, d\omega t + \int_{\pi}^{2\pi} 0 \, d\omega t\right]$$

$$= \frac{1}{2\pi}\int_0^{\pi} I_m \sin\omega t \, d\omega t$$

$$= \frac{I_m}{2\pi}\left[-\cos(\omega t)\right]_0^{\pi}$$

Half Wave Rectifier (HWR)

43

$$= \frac{-I_m}{2\pi}\left[\cos(\pi) - \cos(0)\right]$$

$$= \frac{-I_m}{2\pi}\left[-1 - 1\right] = \frac{-I_m}{\cancel{2}\pi}(-\cancel{2})$$

$$I_{dc} = \frac{I_m}{\pi}$$

Half Wave Rectifier (HWR)

- Average output voltage is $$V_{dc} = I_{dc} R_L$$

- RMS value of load current in half wave rectifier is:

$$I_{rms} = \left[\frac{1}{2\pi} \int_0^{2\pi} i_L^2 \, d(\omega t) \right]^{1/2} = \frac{I_m}{2}$$

- RMS output voltage is $$V_{rms} = I_{rms} R_L$$

Half Wave Rectifier (HWR)

Rms value of Load current (I_{rms})

$$I_{rms} = \left[\frac{1}{2\pi}\int_0^{2\pi} i_L^2 \, d(\omega t)\right]^{1/2}$$

$$= \left[\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2(\omega t) \, d\omega t\right]^{1/2}$$

$$= \left[\frac{I_m^2}{2\pi}\int_0^{\pi} \frac{1-\cos 2\omega t}{2} \, d\omega t\right]^{1/2}$$

$$= \left[\frac{I_m^2}{4\pi}\int_0^{\pi} (1-\cos 2\omega t) \, d\omega t\right]^{1/2}$$

$\cos 2\theta = 1 - 2\sin^2\theta$

$-1 + \cos 2\theta = -2\sin^2\theta$

$\sin^2\theta = \frac{1-\cos 2\theta}{2}$

(4A)

$$= \frac{I_m}{2}\left[\frac{1}{\pi}\left(\omega t - \frac{\sin 2\omega t}{2}\right)_0^{\pi}\right]^{1/2}$$

$$= \frac{I_m}{2}\left\{\frac{1}{\pi}\left(\pi - \frac{\sin 2\pi}{2} - 0 + \frac{\sin(0)}{2}\right)\right\}^{1/2}$$

$\sin 2\pi = \sin 0 = 0$

$$= \frac{I_m}{2}\left[\frac{1}{\cancel{\pi}}\left(\cancel{\pi}\right)\right]^{1/2}$$

$$\boxed{I_{rms} = \frac{I_m}{2}}$$

If FF = 1 w/f is pure dc

FF = 10

= 50

Half Wave Rectifier (HWR)

Ripple Factor (γ) :

It helps in the measure of ripples (pulsating components) present in the output of rectifier.

It tells how smooth is the output. Smaller the ripple factor closer is the output to pure D.C

Ripple Factor $= \dfrac{RMS\ value\ of\ A.C\ component\ of\ output}{Average\ (or)\ D.C\ component\ of\ output} = \dfrac{I_{ac}}{I_{dc}}$

I_{ac} = RMS value of A.C component present in output

I_{dc} = D.C component present in output

I_{rms} = RMS value of total output current

Half Wave Rectifier (HWR)

$$I_{rms} = \sqrt{I_{ac}^2 + I_{dc}^2}$$

$$I_{rms}^2 = I_{ac}^2 + I_{dc}^2$$

$$I_{ac}^2 = I_{rms}^2 - I_{dc}^2$$

$$I_{ac} = \sqrt{I_{rms}^2 - I_{dc}^2}$$

$$\gamma = \frac{\sqrt{I_{rms}^2 - I_{dc}^2}}{I_{dc}}$$

Half Wave Rectifier (HWR)

$$= \sqrt{\frac{I_{rms}^2}{I_{dc}^2} - \frac{I_{dc}^2}{I_{dc}^2}} = \sqrt{\frac{I_{rms}^2}{I_{dc}^2} - 1}$$

$$= \sqrt{\left(\frac{\frac{I_m}{2}}{\frac{I_m}{\pi}}\right)^2 - 1} = \sqrt{\left(\frac{\pi}{2}\right)^2 - 1}$$

$\gamma = 1.21$ [$\because$ γ is independent of load ct and i/p vr]

Half Wave Rectifier (HWR)

D.C Power O/P (P_{dc})

$$P_{dc} = I_{dc}^2 R_L$$

$$= \left(\frac{I_m}{\pi}\right)^2 R_L = \frac{I_m^2}{\pi^2} R_L$$

A.C i/p power (P_{ac})

$$P_{ac} = I_{\cancel{ac}}^2 (R_L + R_F)$$

$$= I_{rms}^2 (R_L + R_F)$$

$$P_{ac} = \left(\frac{I_m}{2}\right)^2 (R_L + R_F) = \frac{I_m^2}{4} (R_L + R_F)$$

R_L = load resis
R_F = diode resistan

Half Wave Rectifier (HWR)

Rectifier Efficiency (η)

$$\eta = \frac{\text{dc power delivered to the load}}{\text{ac power supplied by the secondary of transformer}}$$

$$= \frac{P_{dc}}{P_{ac}}$$

$$\eta = \frac{\frac{I_m^2}{\pi^2} R_L}{\frac{I_m^2}{4}(R_L + R_F)} = \frac{\frac{4}{\pi^2}}{\frac{R_L + R_F}{R_L}} = \frac{0.406}{\left(1 + \frac{R_F}{R_L}\right)}$$

For Ideal $R_F =$

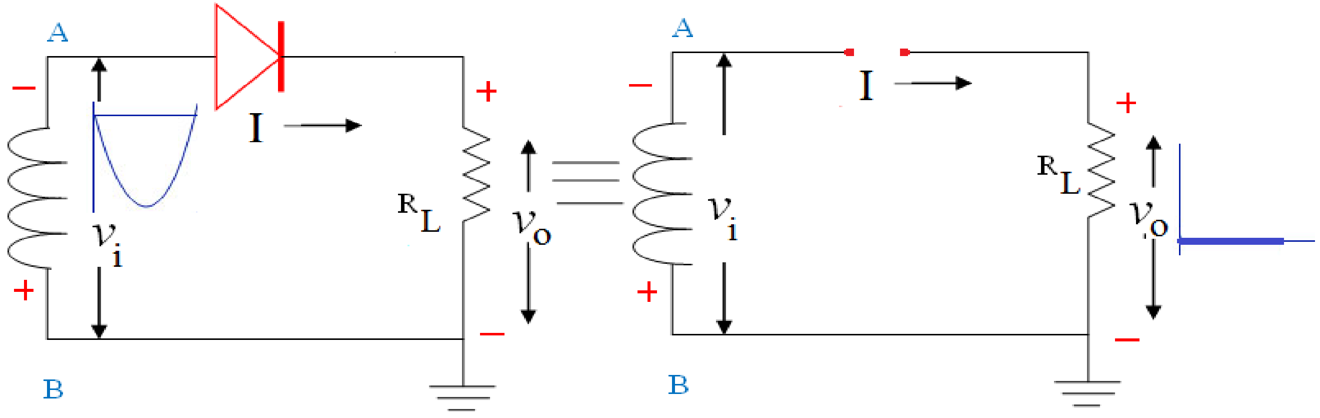
$\eta = 40.6\%$

Half Wave Rectifier (HWR)

Peak Inverse Voltage (PIV):

PIV is the peak voltage across the diode in the reverse biased condition

Reverse biased condition



PIV = V_m

Half Wave Rectifier (HWR)

Advantages of HWR

- Simple circuit
- Single diode
- PIV rating is V_m

Disadvantages of HWR

- High ripple factor
- Low efficiency

Half Wave Rectifier (HWR)

1. A half wave rectifier circuit is supplied from a 230V, 50Hz supply with a step-down ratio of 2:1 to a resistive load of 10kΩ. The diode forward resistance is 75Ω while transformer secondary resistance is 10Ω. Calculate maximum, average & RMS values of current, DC o/p voltage, rectification efficiency and ripple factor

Half Wave Rectifier (HWR)

Solution:

Given

I/P primary voltage $V_{p(RMS)} = 230\,V$

T/F ratio $\frac{N_1}{N_2} = \frac{3}{1}$

$R_L = 10\,K$

$R_f = 75\,\Omega$, $R_s = 10\,\Omega$

$\frac{V_1}{V_2} = \frac{V_p}{V_s} = \frac{N_1}{N_2}$

$V_s = V_p \left(\frac{N_2}{N_1}\right) = 230 \times 1/3$

$V_{s(RMS)} = V_s = 76.667\,V$

(V_m) Peak value of secondary ac V_r $= \sqrt{2}\, V_s = \sqrt{2} \times 76.667$

$V_m = 108.423\,V$

Half Wave Rectifier (HWR)

Maximum ct:

$$I_m = \frac{V_m - V_f}{R_s + R_f + R_L} = \frac{108.432}{10.476 + 10\times10^3}$$

0.3

$$I_m = 0.010750\ A = \underline{\underline{10.75\ mA}}$$

Average ct:

$$I_{dc} = \frac{I_m}{\pi}$$

$$= \frac{10.75\times10^{-3}}{\pi} = \underline{\underline{3.42\ mA}}$$

Half Wave Rectifier (HWR)

RMS o/p

$I_{rms} = \frac{I_m}{2}$

$= \frac{11.55 \times 10^{-3}}{2} = 5.775\ mA$

DC o/p volt.

$V_{dc} = I_{dc} R_L$

$= 3.42 \times 10^{-3} \times 10 \times 10^{3}$

$V_{dc} = 34.2\ V$

Half Wave Rectifier (HWR)

Rectification Efficiency (η)

$$\eta\ (\text{in }\%) = \frac{P_{dc}}{P_{ac}} \times 100$$

$$P_{dc} = V_{dc} I_{dc}$$

$$= (11.2)(3.42 \times 10^{-3})$$

$P_{dc} = 0.\ [illegible]$ W

Half Wave Rectifier (HWR)

$$P_{ac} = (I_{rms})^2 (R_s + R_F + R_L)$$

$$= ([illegible] \cdot 27.5 \times 10^{-3})^2 ([illegible])$$

$$P_{ac} = 0.2475\ W$$

$$\eta = \frac{P_{dc}}{P_{ac}} \times 100$$

$$= \frac{0.11396}{0.2477} \times 100 = \underline{\underline{40.5\ \%}}$$

<u>Ripple Factor</u>

$$\underline{\gamma = 1.21}$$

Half Wave Rectifier (HWR)

A sinusoidal voltage of peak value [illegible] frequency [illegible] is applied to [illegible]. If the load resistance is [illegible] and diode forward resistance [illegible] calculate

i) peak value of load current [illegible]

ii) Average load current [illegible]

Half Wave Rectifier (HWR)

c) RMS load ct (6.2 mA)

d) Average o/p vt (3.15 V)

e) RMS o/p vt (4.96 V)

f) Efficiency (40.2 %)

g) Ripple factor (1.21)