ECC-01

Module 3: Diode Circuits

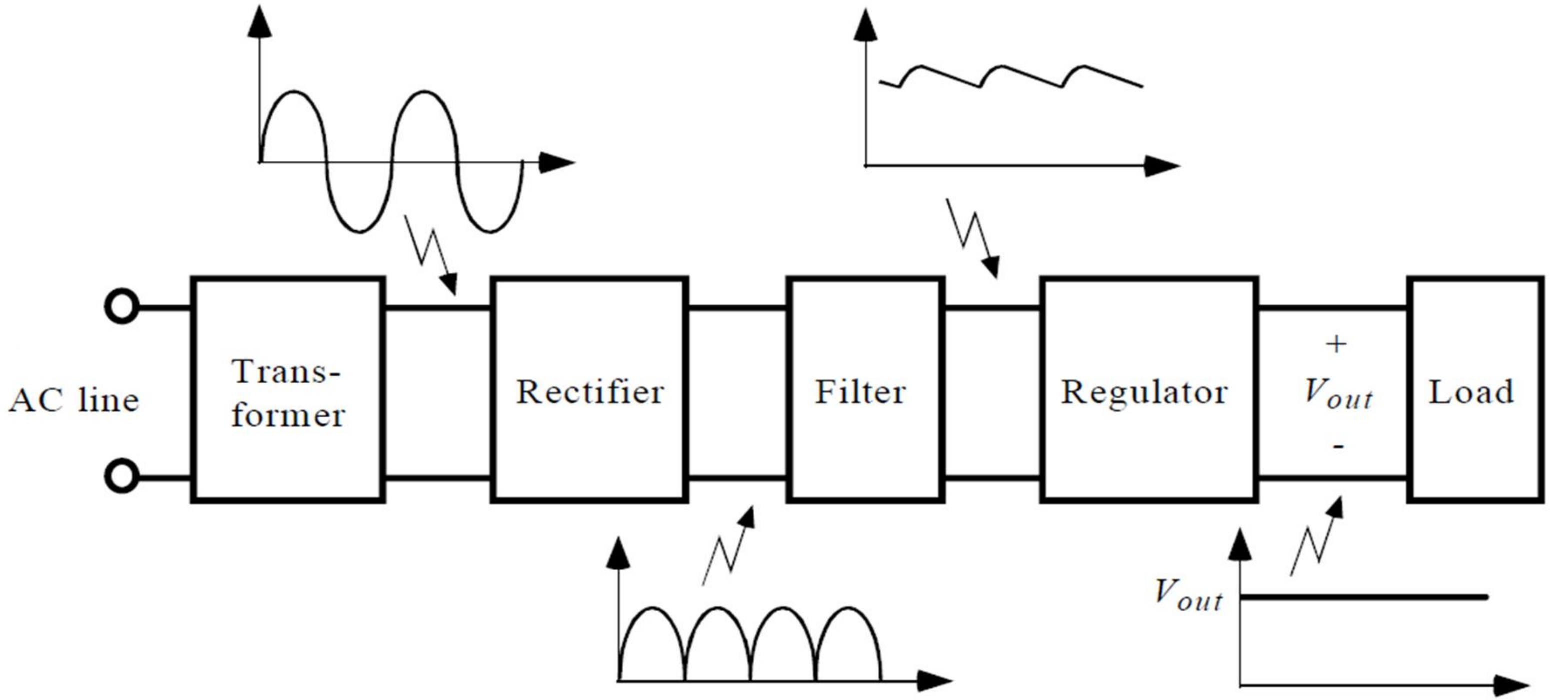
Diode Circuits [3 Hours]

3.1 Diode rectifier
- 3.1.1 Half wave rectifier
- 3.1.2 Full wave rectifier : centre tap and bridge rectifier
- 3.1.3 Capacitive filter and DC power supply (Numerical problems)

3.2 Special Diodes
- 3.2.1 Zener diode : Avalanche breakdown and Zener breakdown and characteristics.
- 3.2.2 Zener diode as a voltage regulator
- 3.2.3 Display devices : LED and LCD

Rectifier

A rectifier is an electrical device that converts AC (alternating current) to Pulsating DC (direct current), which is in only one direction, a process known as rectification.



Basic Block Diagram of Regulated power Supply

Need of Rectification

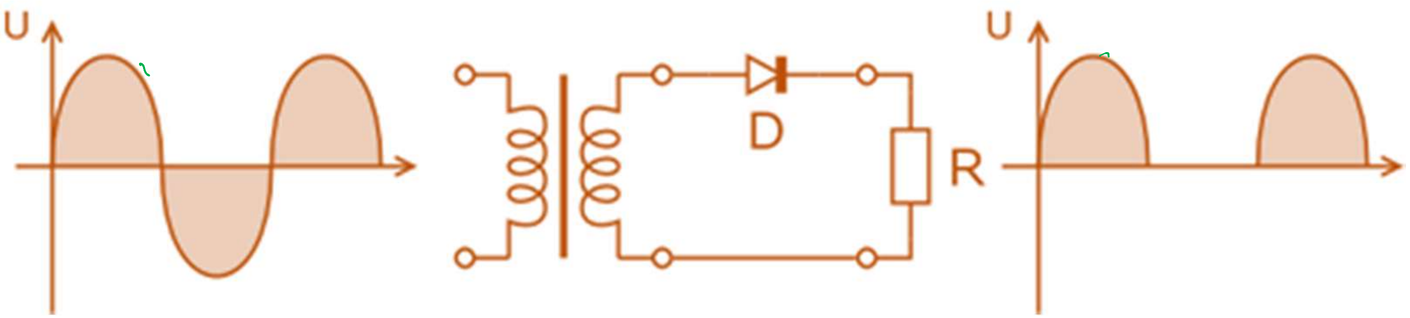
- Every electronic circuit such as amplifiers, needs a DC power source for its operation.
- This DC voltage has to be obtained from AC supply.
- For this the AC supply has to be reduced or Stepped down first using a Step down transformer and then converted to dc by using rectifier.

Types of Rectifiers

- Half wave Rectifier
- Full wave Rectifier
- Bridge Rectifier

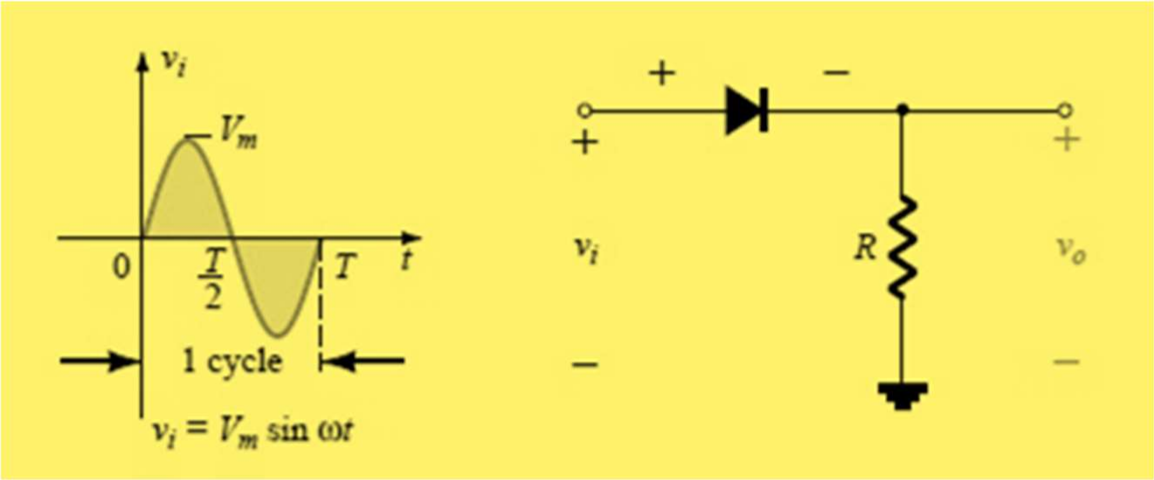
Half wave Rectifier

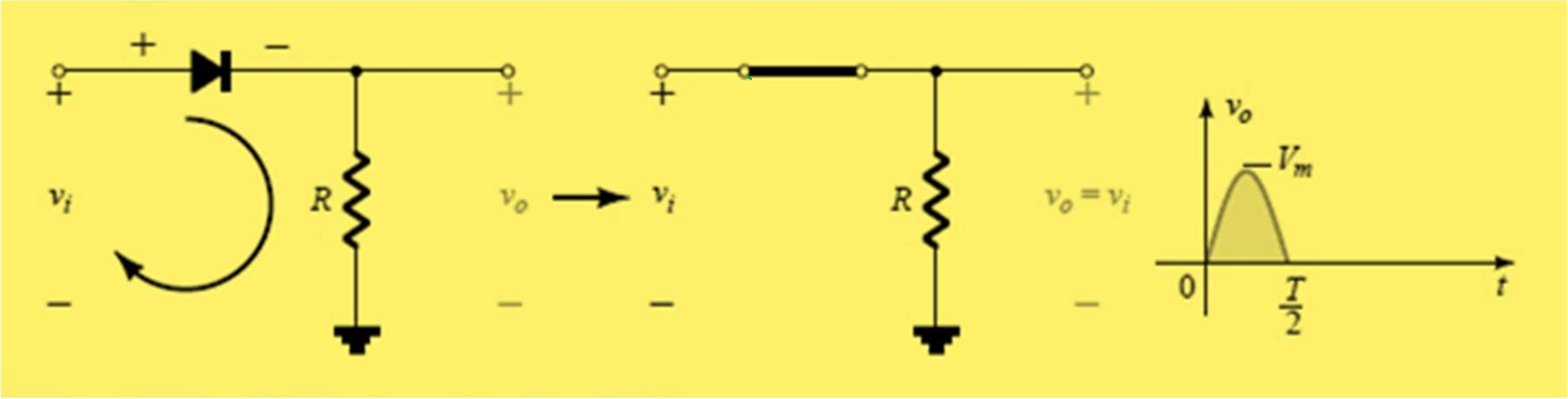
- In half wave rectification, either the positive or negative half of the AC wave is passed, while the other half is blocked.
- Because only one half of the input waveform reaches the output, it is very inefficient if used for power transfer.



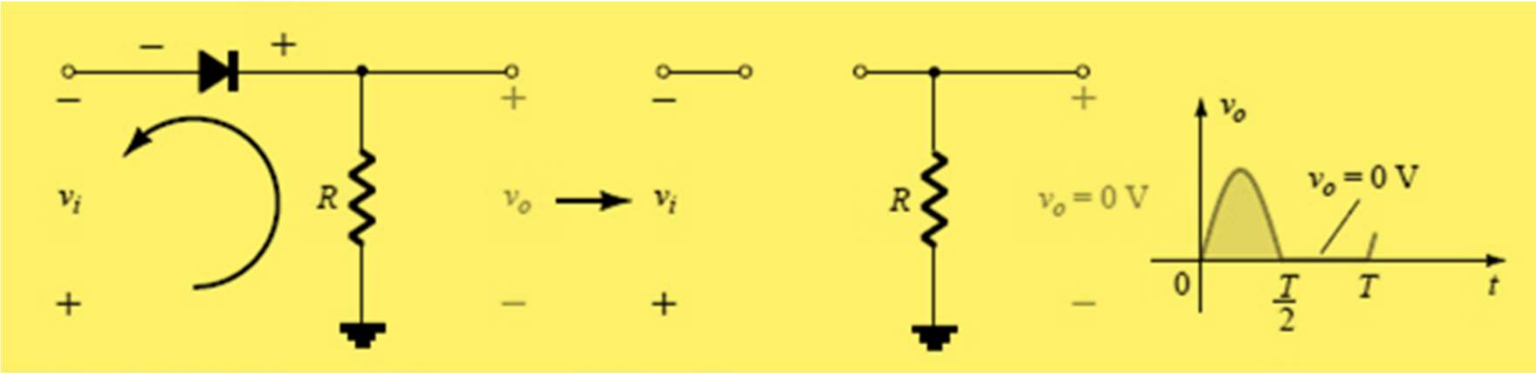
Half wave Rectifier (Cont...)

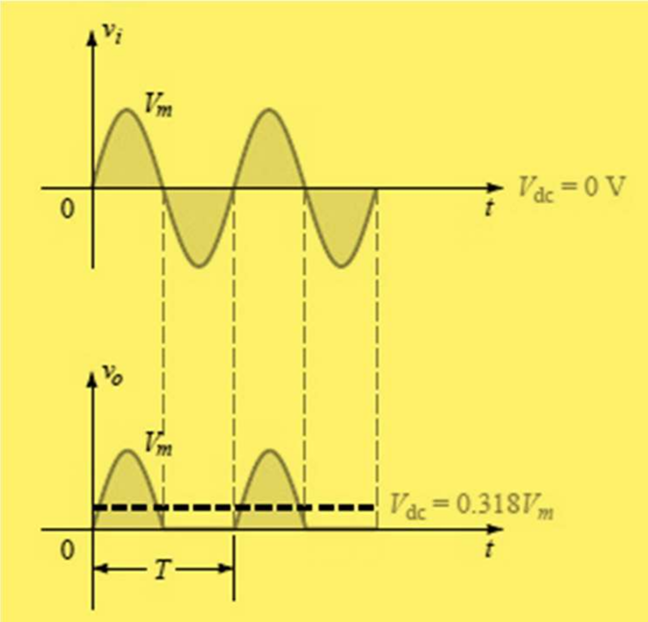
Operation





Half wave Rectifier (Cont...)





Parameters of Half Wave Rectifier

The current i_L in the diode or load R_L is given by

$i_L = I_m \sin \omega t$ when $0 \le \omega t \le \pi$

$= 0$ when $\pi \le \omega t \le 2\pi$

1. Average or dc value of the load current:

$$I_{av} = I_{dc} = \frac{\text{area under the } i_L \text{ curve over a cycle}}{\text{base}} = \frac{\int_0^{\pi} i_L \, d(\omega t)}{2\pi}$$

$$= \frac{1}{2\pi}\int_0^{\pi} i_L \, d(\omega t) = \frac{1}{2\pi}\int_0^{\pi} \frac{V_m \sin wt \; d(\omega t)}{R_f + R_L}$$

$$= \frac{V_m}{2\pi(R_f + R_L)} \int_0^{\pi} \sin \omega t \; d(\omega t)$$

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

$$= \frac{V_m}{2\pi(R_f + R_L)} \times 2 = \frac{V_m}{\pi(R_f + R_L)}$$

$$= \frac{I_m}{\pi} \left(\because I_m = \frac{V_m}{R_f + R_L} \right)$$

Parameters of Half Wave Rectifier (Cont...)

2. RMS value of the load current

The rms value of current flowing through the load R_L in a Half –wave rectifier is given by,

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i_L^2 \; d(\omega t)}$$

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

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

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

Parameters of HW rectifier (Cont...)

3. Ripple factor:

- **The pulsating load current i_L is the combination of dc and ripple (ac) components.** The instantaneous value of the ripple (ac) component i is the difference between the instantaneous value of i_L and the dc value of current I_{dc}. Therefore, the instantaneous value of the ripple components is given by--

$$i = i_L - I_{dc}$$

- Therefore , the rms value of the ripple (ac) current of Half – wave rectifier is given by,

$$I_{\text{ripple, rms}} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i^2 \; d(\omega t)}$$

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

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

$$I_{\text{ripple, rms}} = \sqrt{i_{rms}^2 - I_{dc}^2}$$

The ripple factor γ is given by

$$\therefore \gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1} \quad \text{(or)} \quad \therefore \gamma = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1}$$

$$\therefore \gamma = \sqrt{\left(\frac{I_m/2}{I_m/\pi}\right)^2 - 1} = \sqrt{\left(\frac{\pi}{2}\right)^2 - 1} = 1.21$$

$$\Rightarrow \gamma = 1.21$$

Parameters of HW rectifier (Cont...)

4. Form Factor:

The ratio of the root mean square value to the average value of an alternating quantity (current or voltage) is called **Form Factor.**

i.e $\quad F.F = \frac{Rms\ value}{average\ value}$

So for hwr,

$$F.F = \frac{(I_L)rms}{I_{DC}}$$

$$= \frac{\frac{I_m}{2}}{\frac{I_m}{\Pi}} = 1.57$$

5. Peak Inverse Voltage:

It is the maximum voltage that the rectifying diodes has to withstand, when it is reversed-biased.

$$PIV = V_m \text{ for HWR}$$

Diode operates safely if, PIV < Breakdown voltage

Parameters of HW rectifier (Cont...)

6. Rectification Efficiency:

$$\eta = \frac{P_{dc}}{P_i} X\ 100\ \% \qquad where\ P_{dc} = {I_{dc}}^2 R_L$$

$$P_i = \frac{1}{2\pi}\int_0^{2\pi} v i_L\, d(wt) \qquad where\ v = i_L(R_f + R_L)$$

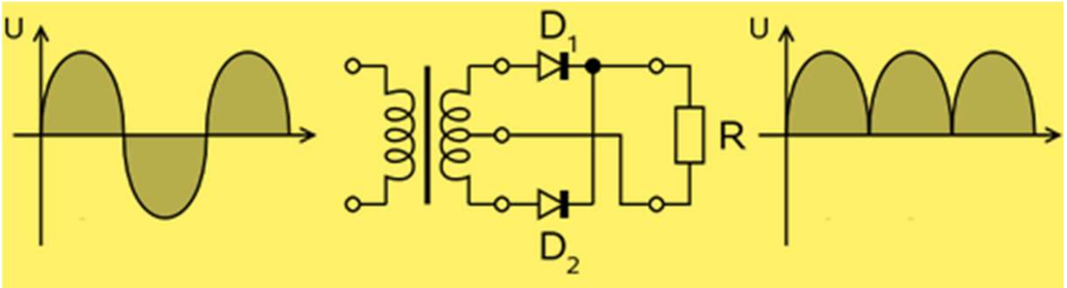
$$= (R_f + R_L){I_{rms}}^2$$

$$\eta = \left(\frac{{I_{dc}}^2}{{I_{rms}}^2}\right)\left(\frac{1}{1 + \frac{R_f}{R_L}}\right) X\ 100\ \%$$

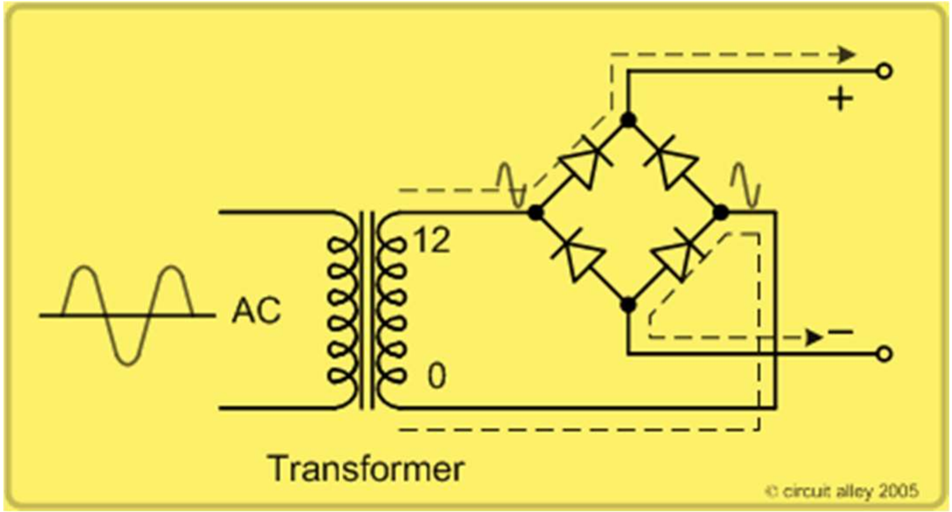
$$= \frac{40.6}{1+\frac{R_f}{R_L}}$$

Full wave Rectifier

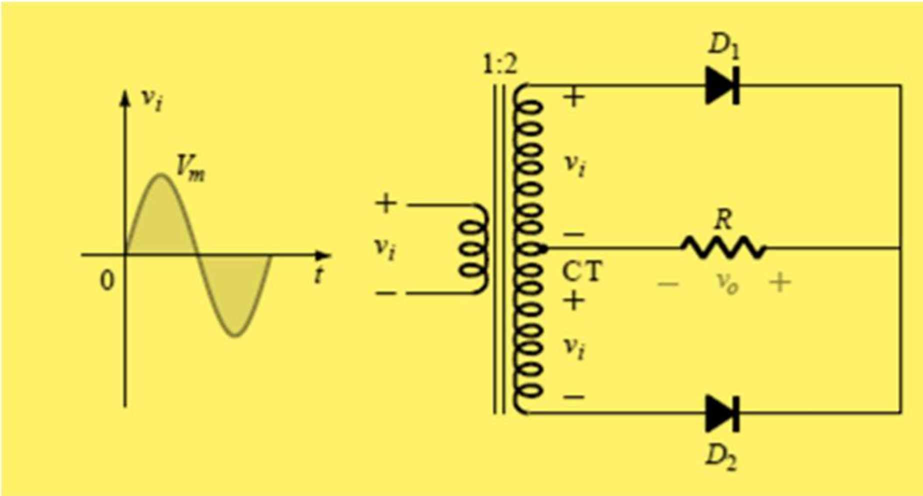
- For single-phase AC, if the transformer is center-tapped, then two diodes back-to-back (i.e. anodes-to-anode or cathode-to-cathode) can form a full-wave rectifier.

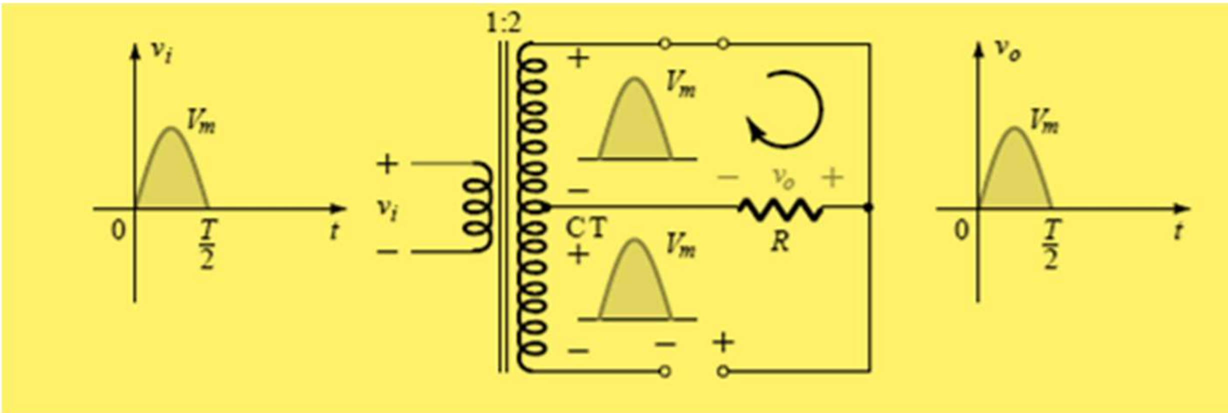


- In a circuit with a non - center tapped transformer, four diodes are required instead of the one needed for **half-wave rectification**.

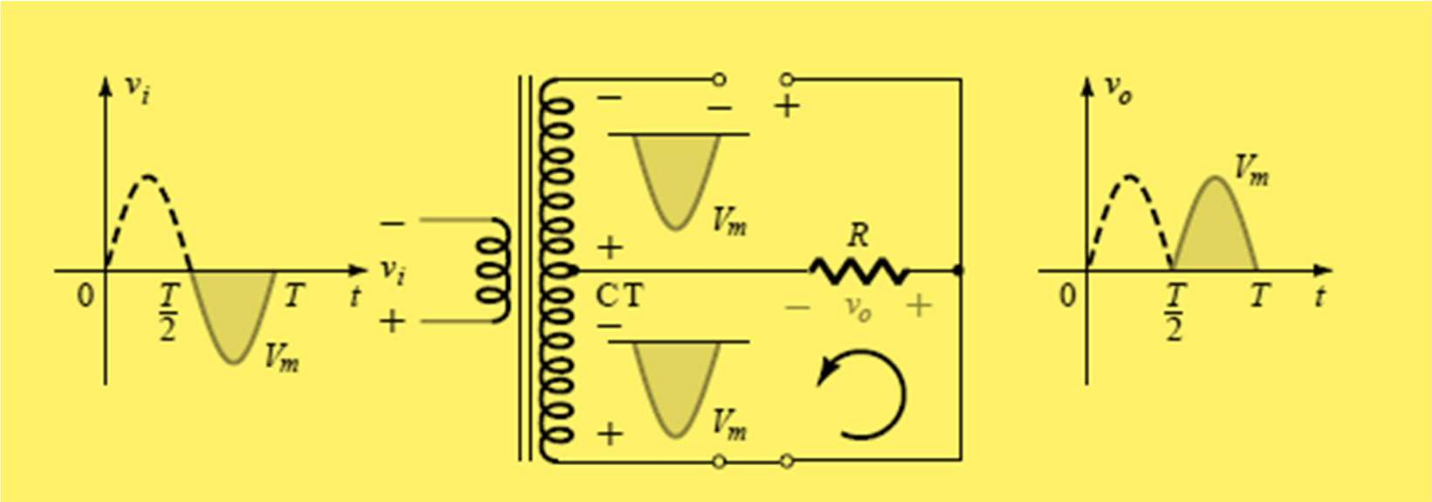


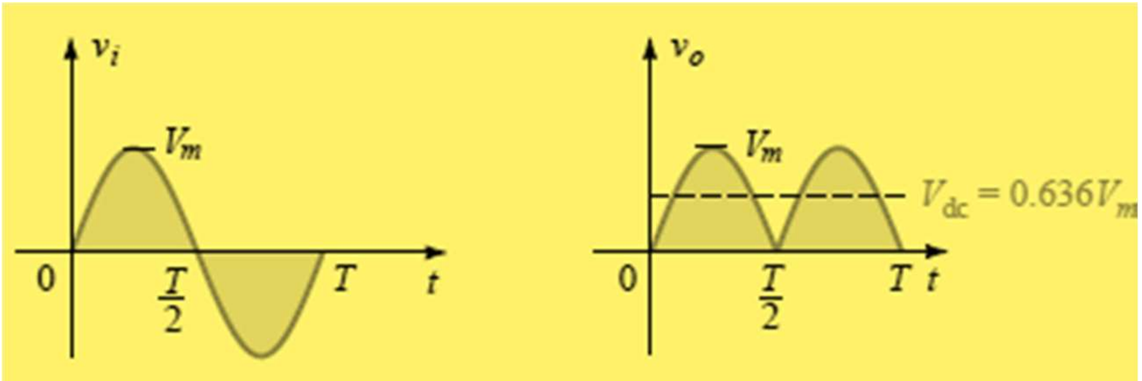
Full wave Rectifier (Center Tapped)





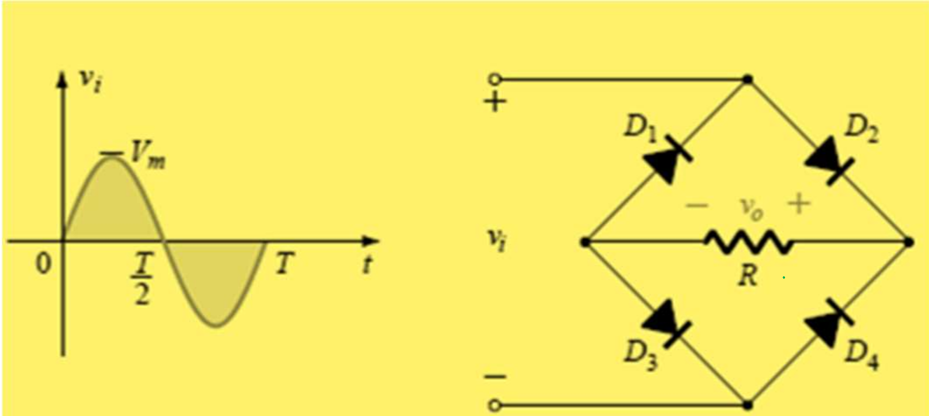
Full wave Rectifier (Center Tapped) (Cont..)



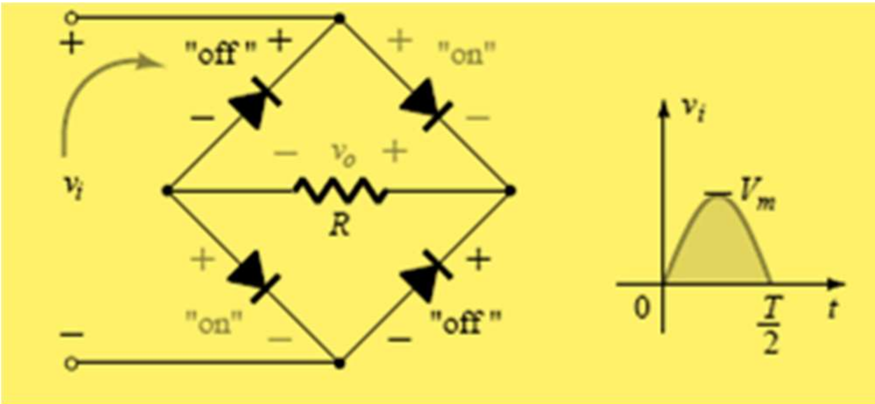


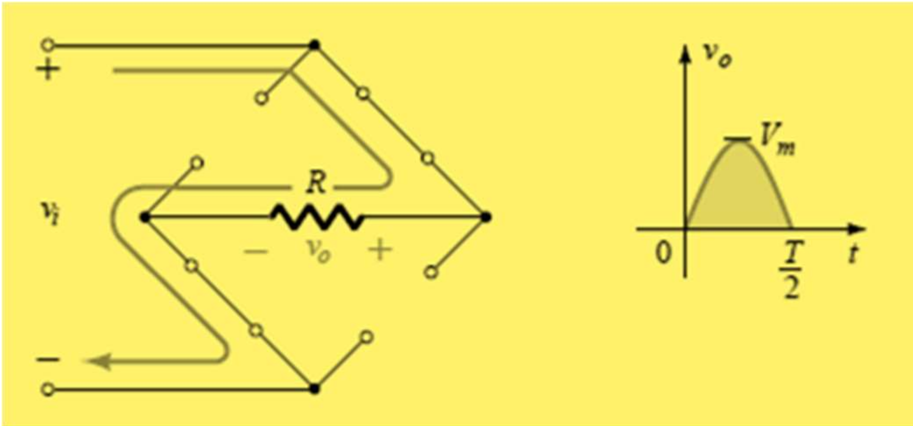
Input output waveform

Full wave Rectifier (Bridge)



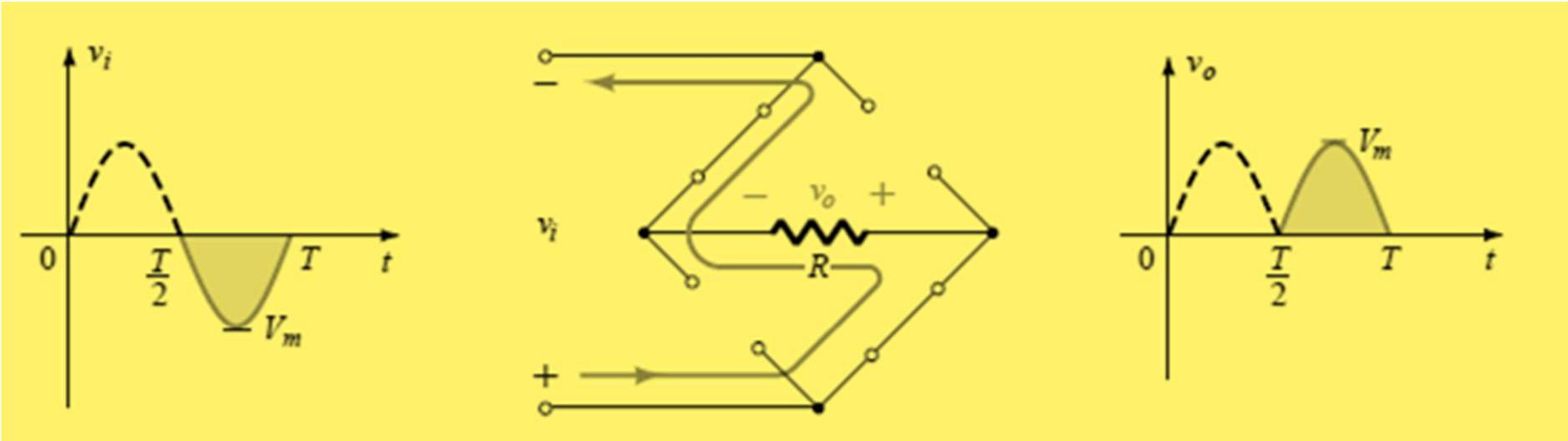
Full-wave bridge rectifier.



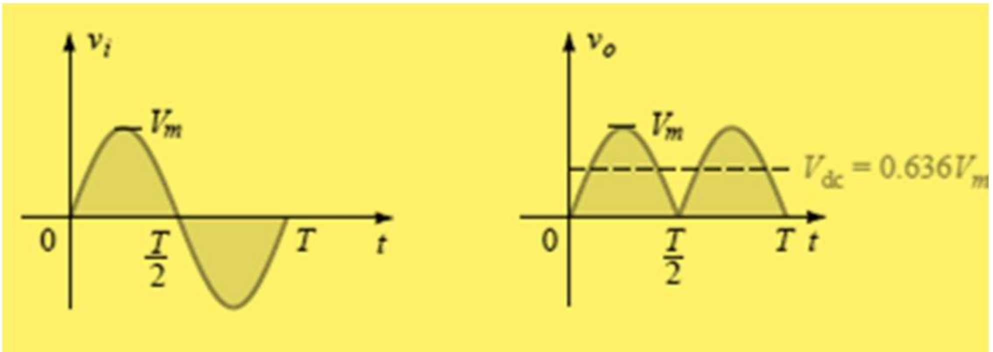


Conduction path for the positive region of v_i.

Full wave Rectifier (Bridge)



Conduction path for the negative region of v_i.



Input and output waveforms for a full-wave rectifier.

Parameters of FW rectifier

The current i_L in the diode or load R_L is given by

$$i_L = I_m \sin \omega t \qquad \text{when } 0 \le \omega t \le \pi$$

$$= I_m \sin \omega t \qquad \text{when } \pi \le \omega t \le 2\pi$$

1. Average or dc value of the load current:

$I_{av} = I_{dc}$

$$Average\ Value = (\frac{1}{\pi}) \int_0^{\pi} Imsin\omega td(wt)$$

$$= (\frac{Im}{\pi}) \int_0^{\pi} sin\omega td(wt)$$

$$= \left(\frac{Im}{\pi}\right)[cos0 - cos\pi]$$

$$= (2\frac{Im}{\pi})$$

$$= 0.637Im$$

2. RMS value of the load current

$$I_{rms} = \sqrt{\frac{1}{2\pi} \int_0^{2\pi} {I_m}^2\, Sin(wt)d(wt)}$$

$$= \frac{I_m}{\sqrt{2}}$$

Parameters of FW rectifier (Cont...)

3. Ripple factor:

$$Ripple\ Factor = \frac{\sqrt{(Irms)^2 - (Idc)^2}}{Idc}$$

$$= \frac{\sqrt{(0.707Im)^2 - (0.637Im)^2}}{(0.637Im)}$$

$$= \frac{\sqrt{(0.707Im)^2 - (0.637Im)^2}}{(0.637Im)}$$

$$= 0.482$$

4. Form Factor:

The ratio of the root mean square value to the average value of an alternating quantity (current or voltage) is called **Form Factor.**

$$\text{Form Factor} = \frac{I_{r.m.s}}{I_{av}} = \frac{I_m/\sqrt{2}}{2I_m/\pi} = \frac{\pi I_m}{2\sqrt{2}I_m} = 1.11$$

Parameters of FW rectifier (Cont...)

5. Peak Inverse Voltage:

It is the maximum voltage that the rectifying diodes has to withstand, when it reversed-biased.

PIV = $2V_m$ for FWR (Center Tapped)

PIV = V_m for FWR (Bridge)

Diode operates safely if, PIV<Breakdown voltage

6. Rectification Efficiency:

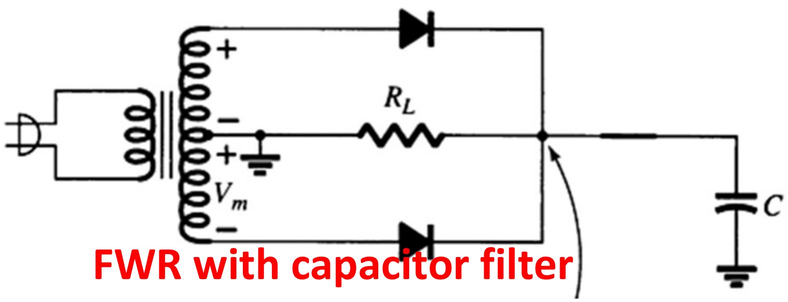
$$\eta = \left(\frac{{I_{dc}}^2}{{I_{rms}}^2}\right)\left(\frac{1}{1+\frac{R_f}{R_L}}\right) X\ 100\ \%$$

$$= \frac{81.2}{1+\frac{R_f}{R_L}}$$

Filter Circuits

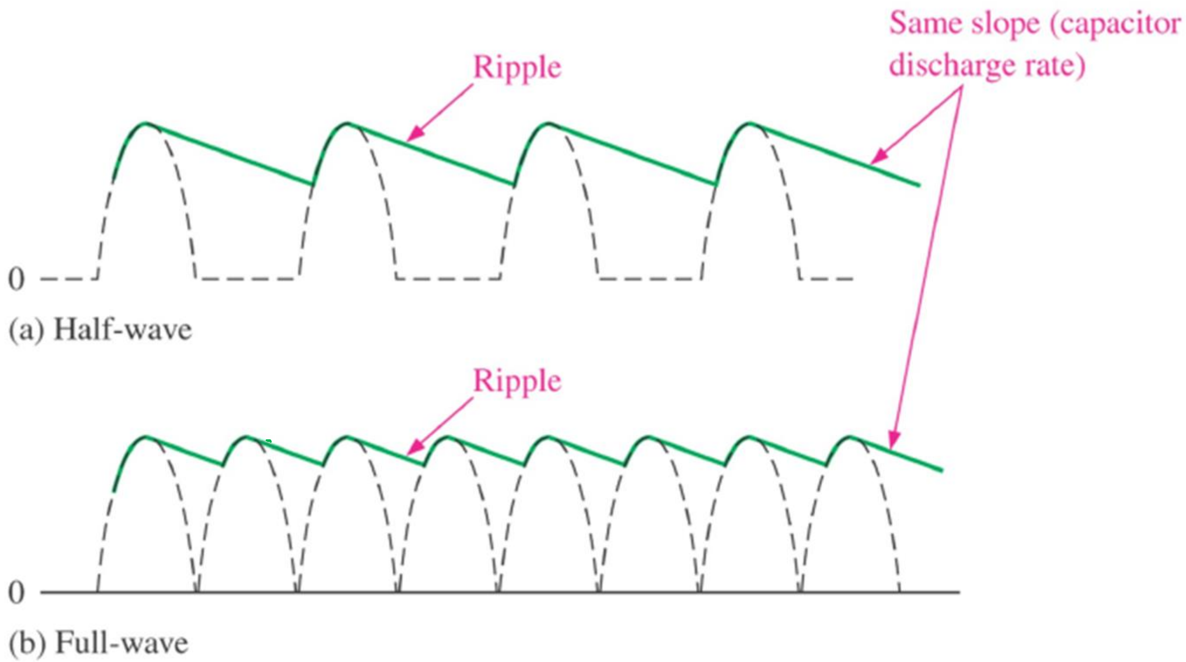
- The output from the rectifier section is a pulsating DC.
- The filter circuit reduces the peak-to-peak pulses to a small ripple voltage.
- The commonly used filters a

Capacitor Filter



FWR with capacitor filter

$$\boldsymbol{Ripple\ voltage(peak\ to\ peak)} = \frac{V_m}{fR_LC}$$



Regulator

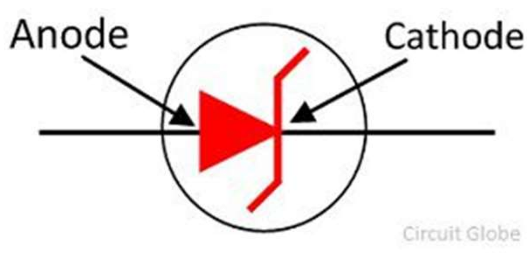
- A voltage regulator regulates the voltage, regardless of the adjustments in the input voltage or connected load.

❖ Zener Diode as a voltage regulator:

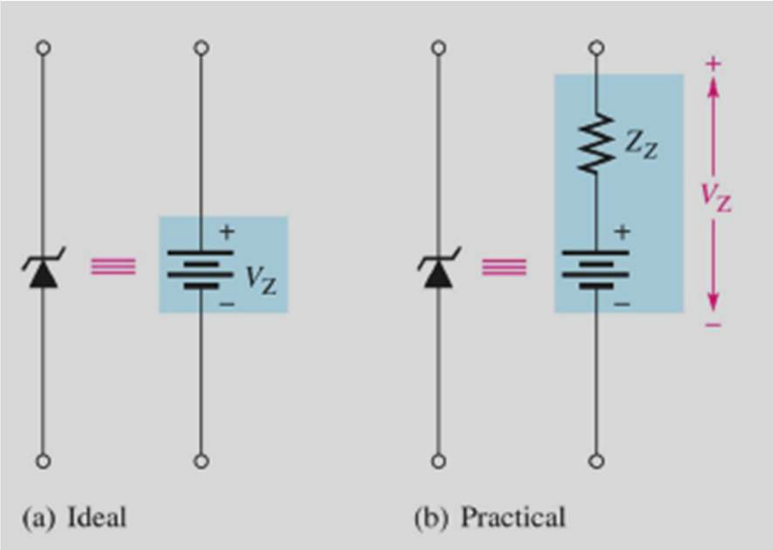
The zener diode is used to provide an output reference voltage that is stable despite changes in input voltage

– Used as a reference in regulated power supplies

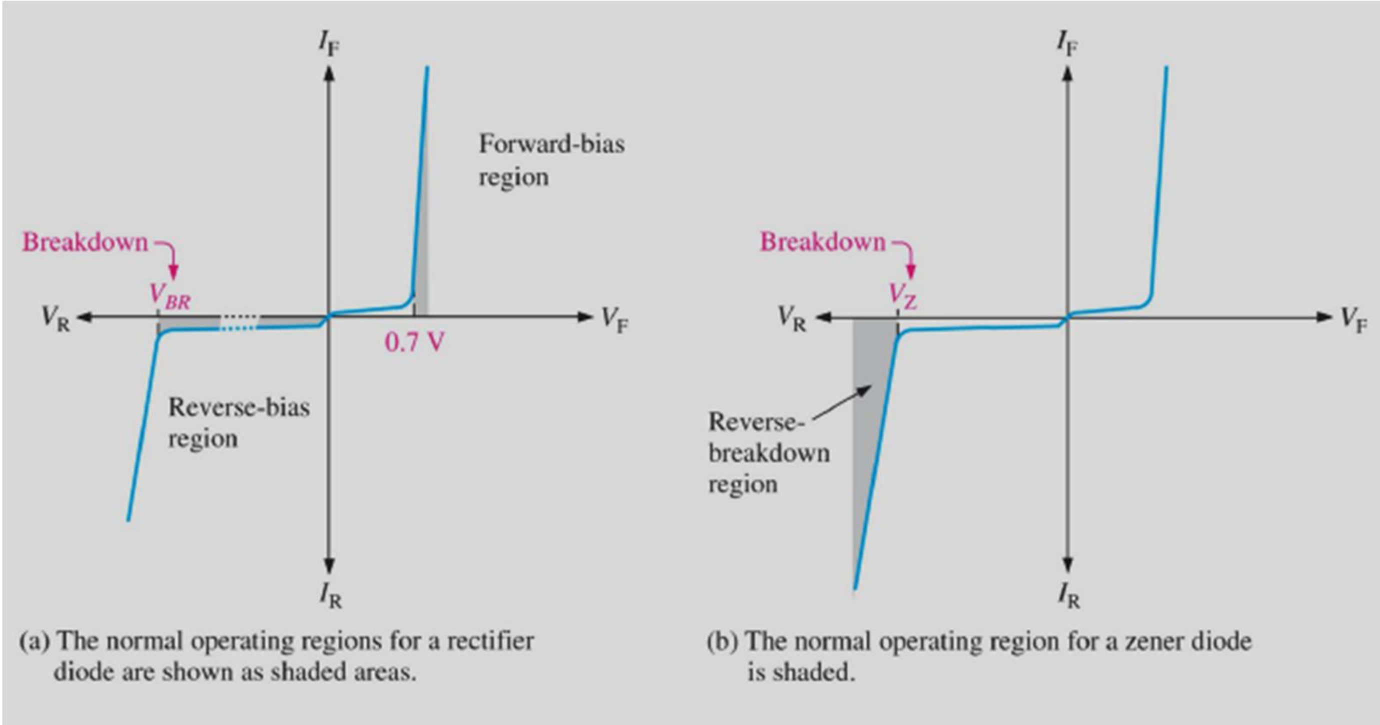
– The zener diode is designed for operation in the reverse breakdown region, where the voltage remains almost constant over a wide range of reverse current values



Zener Diode

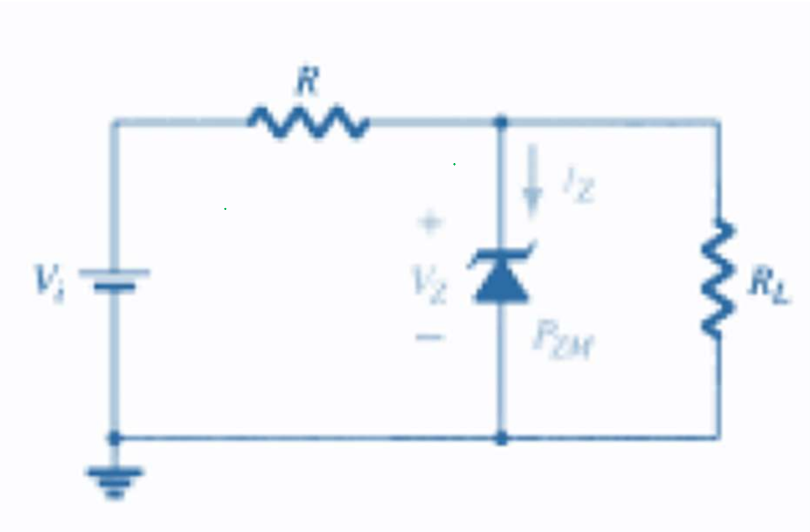


Zener diode equivalent circuit



Diode V-I characteristic

Zener Regulator



If $V \geq V_Z$, the Zener diode is "on"

$$\boxed{V_L = V_Z}$$

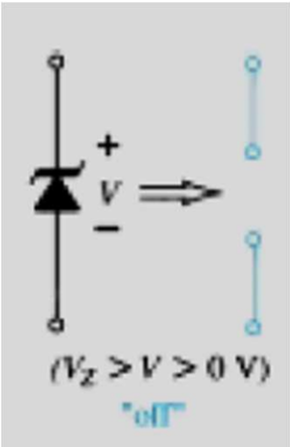
$$I_R = I_Z + I_L$$

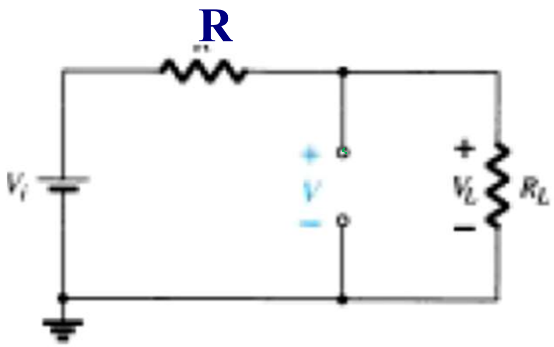
$$\boxed{I_Z = I_R - I_L}$$

$$I_L = \frac{V_L}{R_L} \quad and \quad I_R = \frac{V_R}{R} = \frac{V_i - V_L}{R}$$

The power dissipated by the Zener diode is determined by

$$\boxed{P_Z = V_Z I_Z}$$





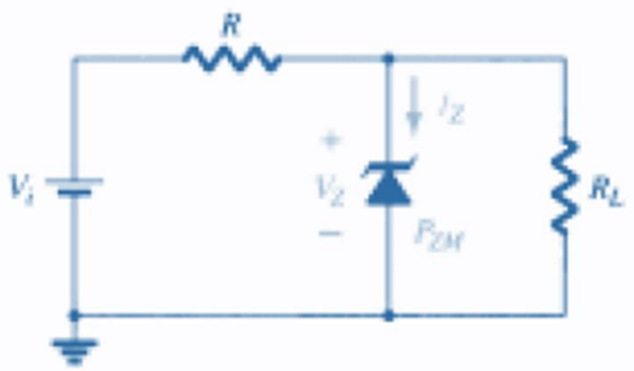
$$\boxed{V = V_L = \frac{R_L V_i}{R + R_L}}$$

If $V < V_Z$, the diode is "off"

Vi > Vz (1 +R/RL) => Vo = Vz

Fixed V_i, Variable R_L

To find minimum R_L



$$V_L = V_Z = \frac{R_L V_i}{R_L + R}$$

$$\boxed{R_{L_{\min}} = \frac{R V_Z}{V_i - V_Z}}$$

$$\boxed{I_{L_{\max}} = \frac{V_L}{R_L} = \frac{V_Z}{R_{L_{\min}}}}$$

Once the diode is in the "on" state, the voltage across R remains fixed at

$$\boxed{V_R = V_i - V_Z}$$

and I_R remains fixed at

$$\boxed{I_R = \frac{V_R}{R}}$$

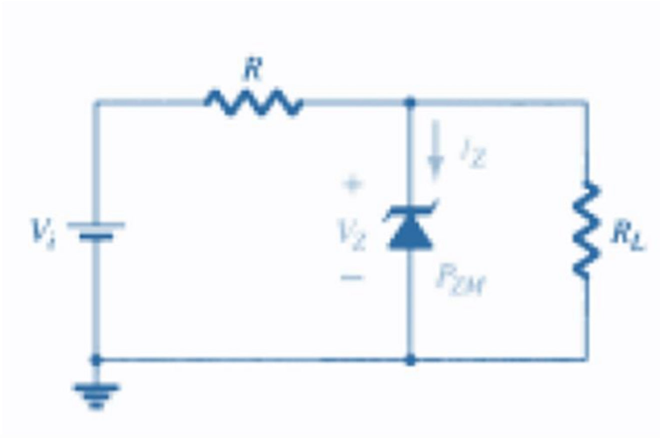
The Zener current

$$\boxed{I_Z = I_R - I_L}$$

$$\boxed{I_{L_{\min}} = I_R - I_{ZM}}$$

$$\boxed{R_{L_{\max}} = \frac{V_Z}{I_{L_{\min}}}}$$

Fixed R_L, Variable V_i



The minimum turn-on voltage $V_i = V_{i_{min}}$ is determined by

$$V_L = V_Z = \frac{R_L V_i}{R_L + R}$$

$$\boxed{V_{i_{min}} = \frac{(R_L + R)V_Z}{R_L}}$$

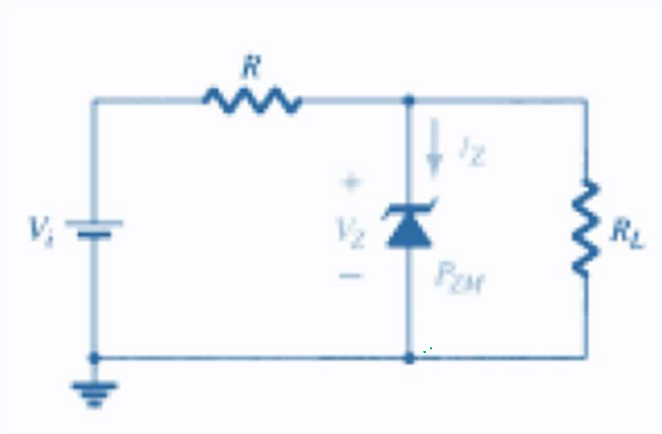
The maximum value of V_i is limited by the maximum Zener current I_{ZM}. Since $I_{ZM} = I_R - I_L$,

$$\boxed{I_{R_{max}} = I_{ZM} + I_L}$$

Since I_L is fixed at V_Z/R_L and I_{ZM} is the maximum value of I_Z, the maximum V_i is defined by

$$V_{i_{max}} = V_{R_{max}} + V_Z$$

$$\boxed{V_{i_{max}} = I_{R_{max}} R + V_Z}$$



R = 220Ω
Vz = 10V
Pz max = 400 mW
Vi = 20 V

i. Find V_L. I_L, I_Z, and I_R if R_L = 180Ω
ii. Repeat if R_L = 470Ω
iii. Find R_L that will establish max power
iv. Find the min. R_L to ensure that Zener diode is ON.

i. $\boxed{V = V_L = \frac{R_L V_i}{R + R_L}}$ **= 9V**

If $V < V_Z$, the diode is "off"

I_z = 0

I_L = I_R = 20/ (220+180) = 50mA

ii. $\boxed{V = V_L = \frac{R_L V_i}{R + R_L}}$ **= 13.62V**

If $V \geq V_Z$, the Zener diode is "on"

V_L = Vz = 10V

I_L = VL/RL = 10/470 = 21.28 mA

VR = 20-10 = 10V

IR = VR/R = 10/220 = 45.45 mA

I_Z = I_R – IL = 24.17 mA

iii. P_z max = 400 mW = V_z x I_z = 10 x $I_{z,max}$

$I_{z,max}$ = 40mA

$I_{L,min}$ = I_R-$I_{z,max}$ = 45.45-40 = 5.45mA

R_L = $V_L/I_{L,min}$ = 10V/5.45mA = 1834.86 Ohm

iv. $$\boxed{R_{L_{\min}} = \frac{RV_Z}{V_i - V_Z}}$$ **= 220 ohm**

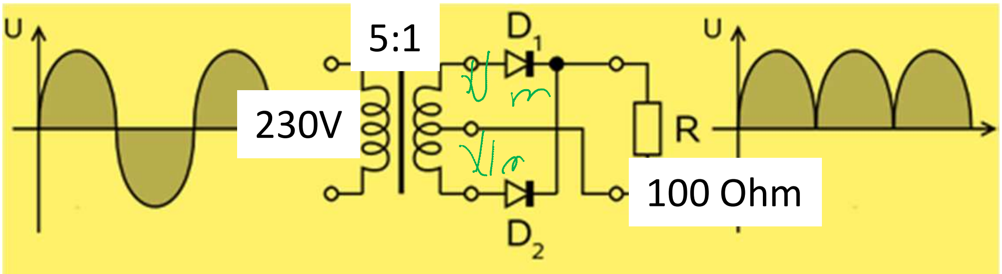
Voltage Regulation:

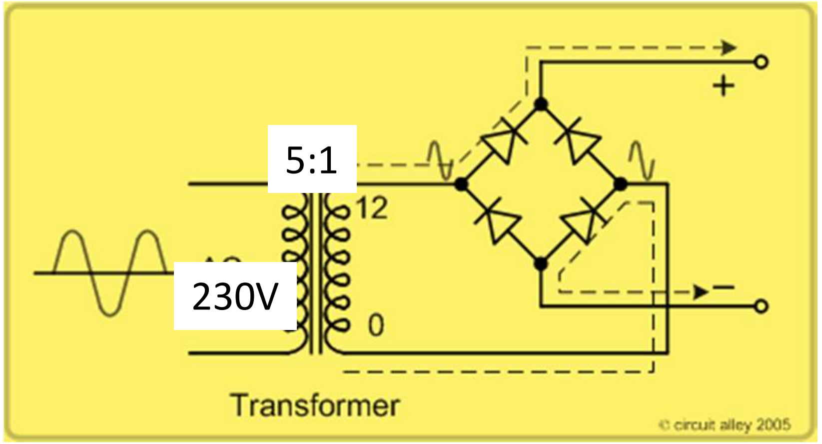
Line regulation is a measure of the circuit's ability to maintain the specified output voltage with varying input voltage. Line regulation is defined as

Line regulation = $\delta Vo/\delta Vi$

Load regulation is a measure of the circuit's ability to maintain the specified output voltage under varying load conditions. Load regulation is defined as

Load regulation = $\delta Vo/\delta Io$





Find DC voltage

Centre Tap Rectifier

RMS secondary voltage = 230 x 1/5 = 46V
Max or peak voltage across secondary = $46\sqrt{2}$ **= 65V**

Max voltage appearing across half secondary (Vm) = 65/2 = 32.5 V

$I_{DC} = 2I_m/\pi = 2V_m/\pi R_L$

$V_{DC} = I_{DC} \times R_L = 2V_m/\pi = 20.7V$

Bridge Rectifier

Vm = 65V

$V_{DC} = I_{DC} \times R_L = 2V_m/\pi = 41.4V$