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اسم المادة: الكترونيك القدرة

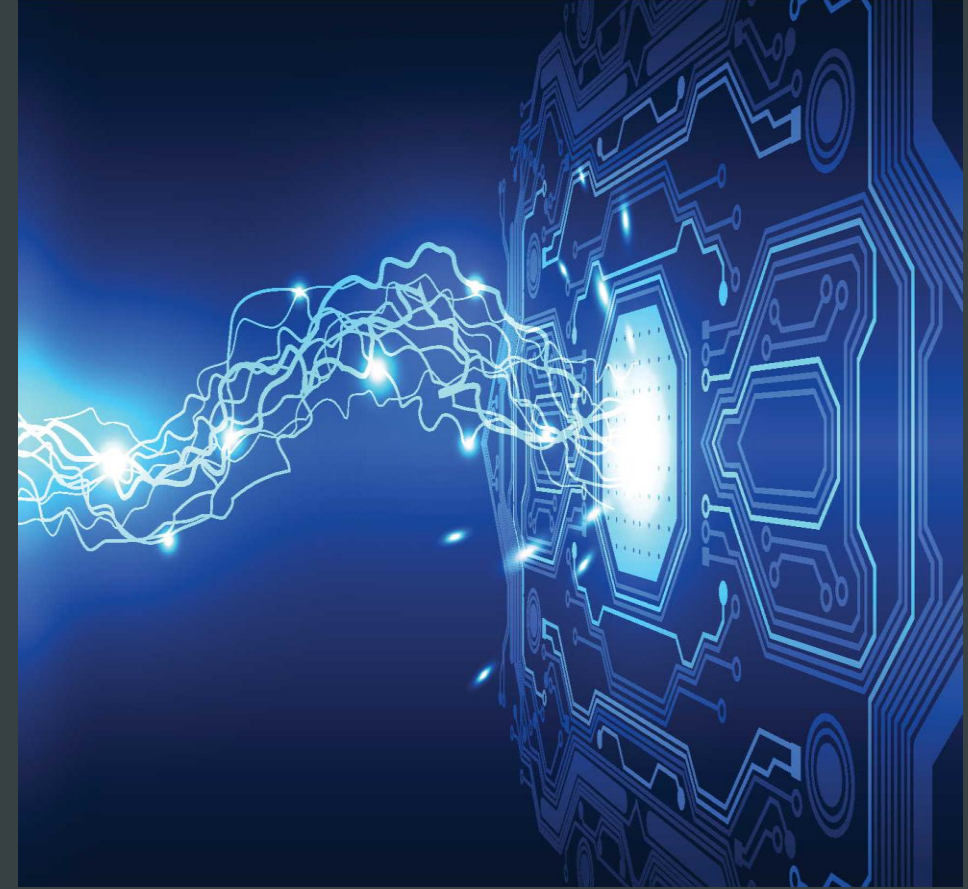
القسم: قسم تقنيات الكهرباء والطاقة المتجددة

المرحلة: الثانية

وزارة التعليم العالي والبحث العلمي
جامعة الفرات الاوسط التقنية
المعهد التقني النجف

Lecture 1

Power Electronic



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Agenda

- Introduction to power electronic science.
- Main tasks of power electronic
- Diode construction, characteristics, specifications
- Half wave rectifier circuit
- Final tips & takeaways

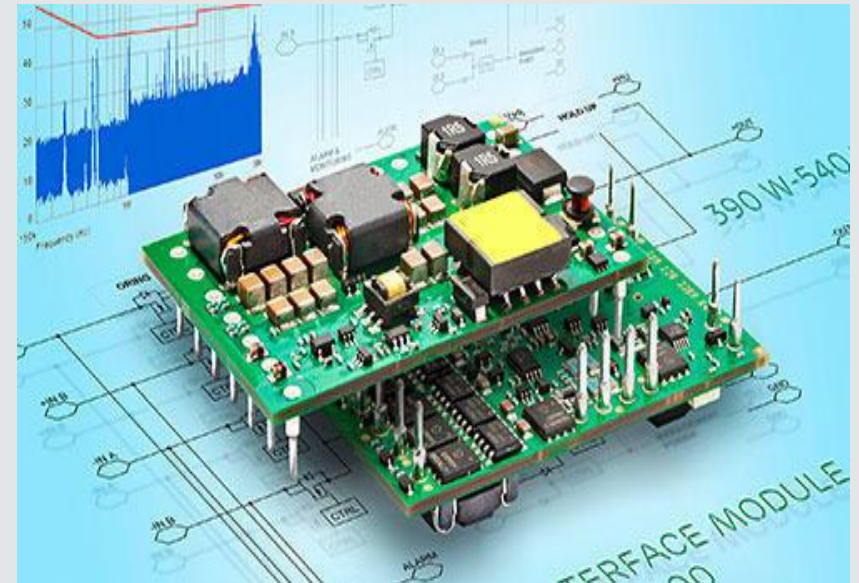
Preliminary test

Q: what is the power electronic study as engineering science?

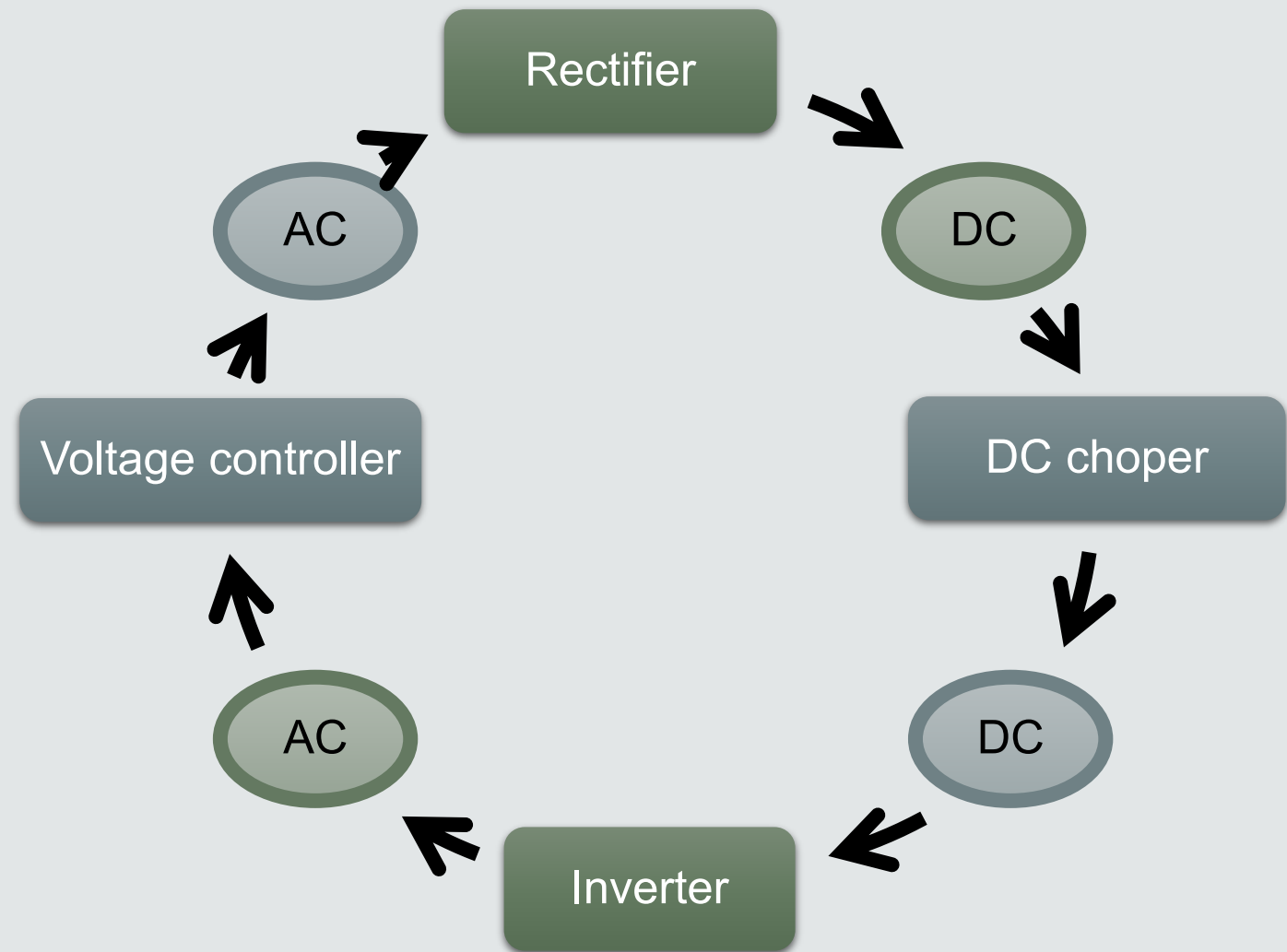
Power electronic : is the field of engineering science which combines between **power** and **electronic & control** system.

Power : deals with static or rotating **power equipments** for generation, transmission or distribution of electric power.

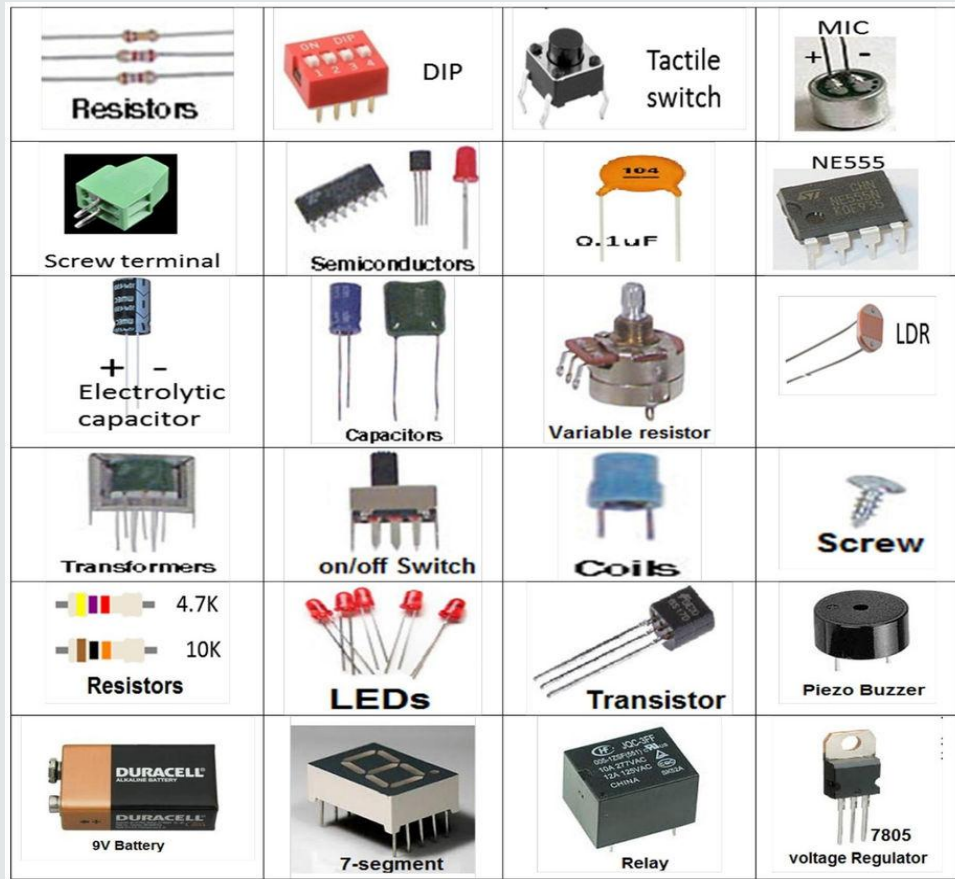
Electronic : it deals with solid state **semiconductors power devices** & circuit for **power conversion** to meet the desired control objectives.



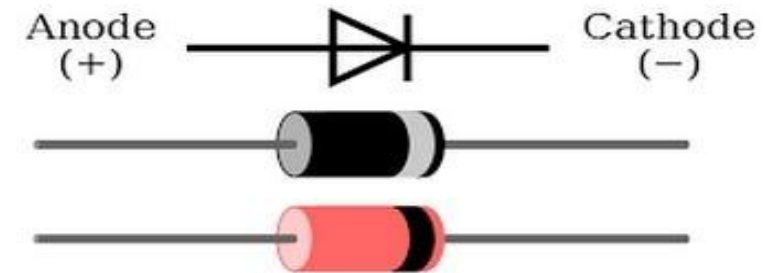
Power electronic functions



Powerdiode



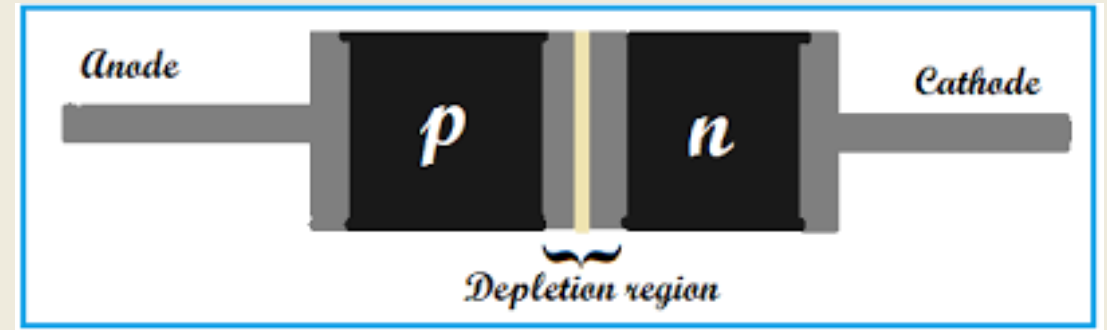
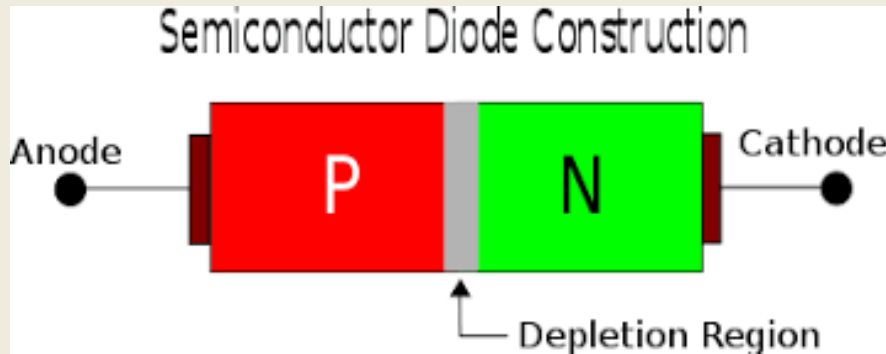
Diode



الصمام الثنائي

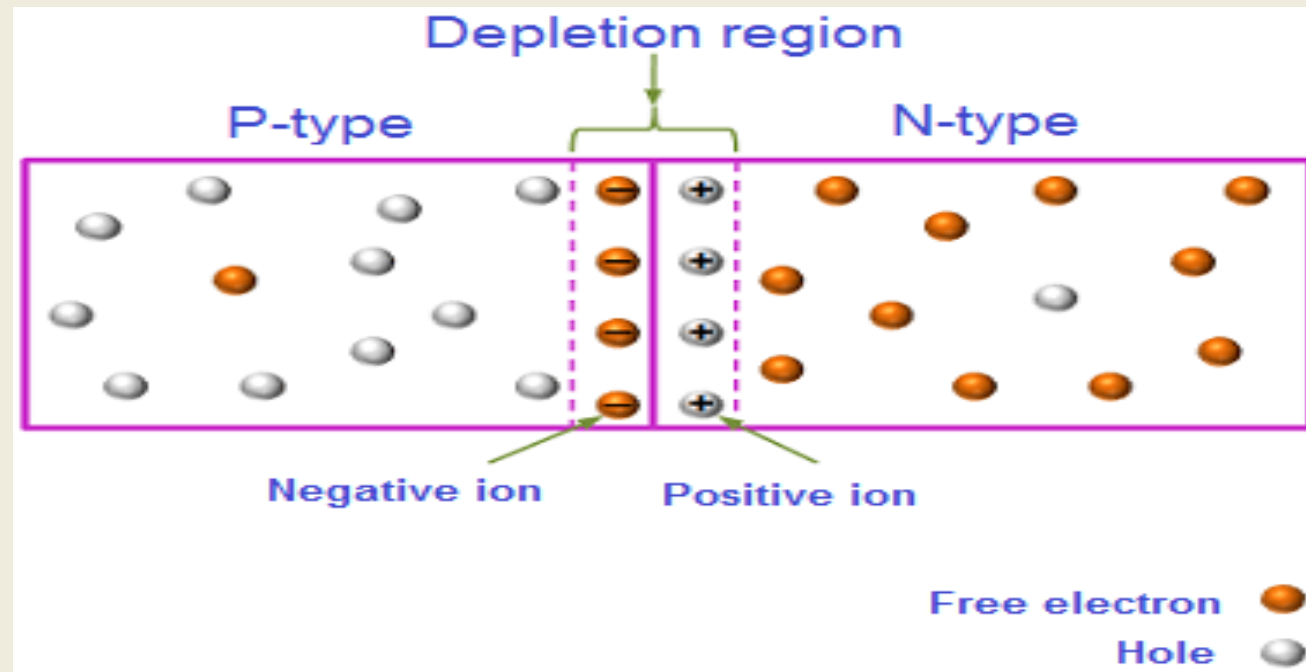
- _ The current will pass through the circuit when diode will be forward bias.
- _ Diode will work as opened switch when it will be reverse bias.

Diode's construction



- DIODE IS AN ELECTRONIC DEVICE WHICH CONTAIN TWO PARTS CALLED **ANODE** & **CATHODE** ARE JOINED TOGETHER.
- DEPLETION LAYER IS THE REGION WHERE THE **ELECTRONS** AND **HOLES** ARE MEETING.

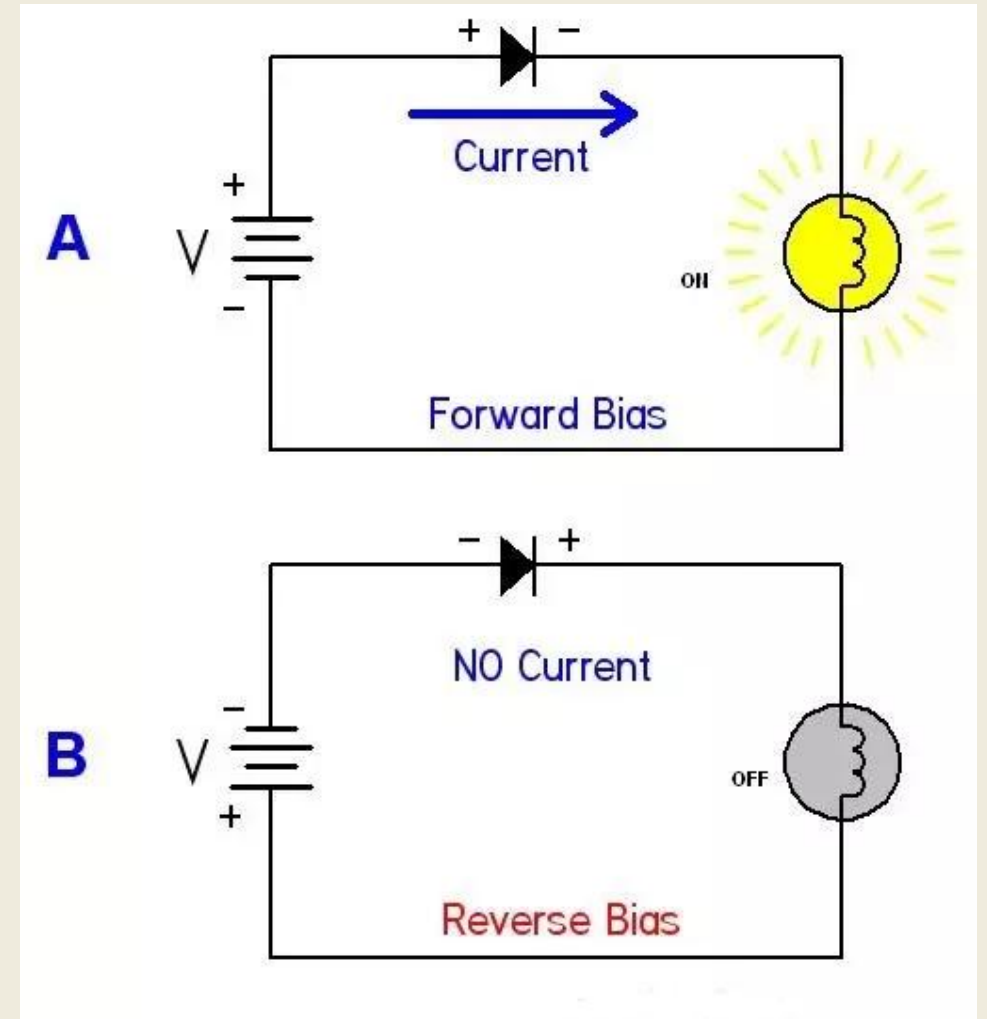
- THE CONDUCTION PRINCIPLE IS DEPENDING ON THE BIAS OF THE DEVICE WHICH WILL MOVE THE ELECTRONS & HOLES TOGETHER TO THE DEPLETION REGION OR MOVE AWAY FROM THAT REGION.



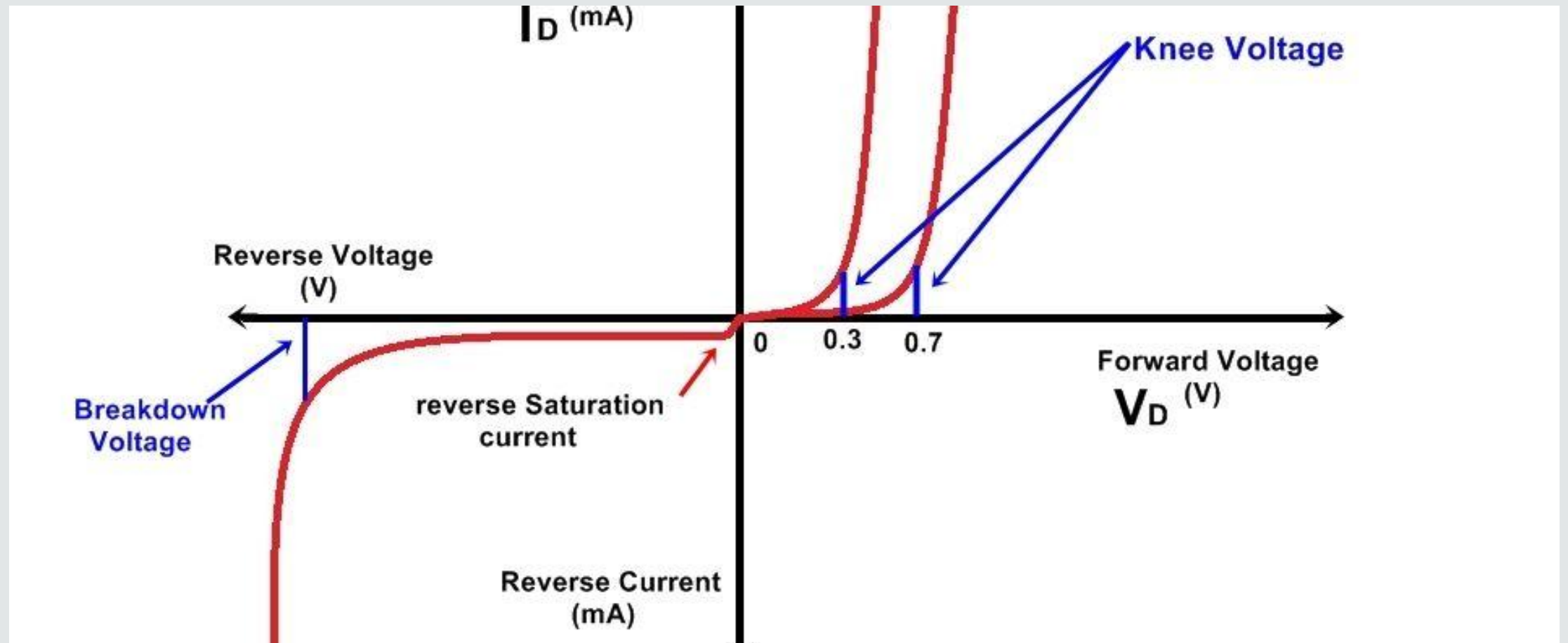
Forward & Reverse bias

(A) The bulb will be ON when the device in forward state which means the current will pass through the switch.

(B) Where the bulb will be OFF when the device in reverse bias which means the circuit will be open and there is no current will pass through it.



V-I DIODE'S CHARACTERSTIC



The specifications of the diode

Thermal reliability

High peak inverse voltage

Low reverse current

Low forward voltage drop

High efficiency

compactness

Half wave rectifier

The main purpose of this circuit is to provide DC current from AC power source.

$$V_o = \frac{1}{2\pi} \int_0^{2\pi} V_m \cdot \sin(\omega t)$$

$$V_o = \frac{1}{2\pi} \left(\int_0^\pi V_m \sin(\omega t) \, dt + \int_\pi^{2\pi} V_m \sin(\omega t) \, dt \right)$$

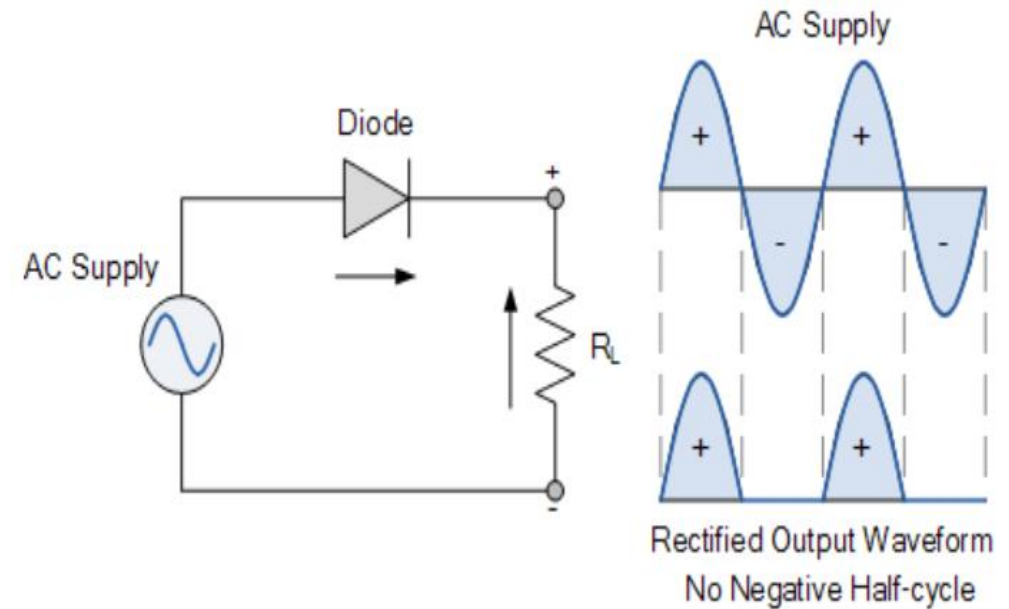
Part (ii) in the above waveform is zero because from π to 2π the output waveform is zero.

$$V_o = \frac{1}{2\pi} \left(\int_0^\pi V_m \cdot \sin(\omega t) + 0 \right)$$

$$V_o = \frac{V_m}{2\pi} * [-\cos(\omega t)]_0^\pi$$

$$V_o = \frac{V_m}{2\pi} * [-\cos(\pi) + \cos(0)]$$

$$V_o = \frac{V_m}{2\pi} * 2 = \frac{V_m}{\pi}$$



R.M.S Calculations

$$V_{or} = \frac{V_m}{\sqrt{2\pi}} \left[\int_0^\pi (\sin(\omega t))^2 \cdot dt + 0 \right]^{\frac{1}{2}}$$

$$V_{or} = \frac{V_m}{\sqrt{2\pi}} \left[\frac{1}{2} \left\{ \int_0^\pi 1 \cdot dt - \int_0^\pi \cos(2\omega t) \cdot dt \right\} \right]^{\frac{1}{2}} \quad \left(\sin^2(\omega t) = \frac{1 - \cos 2(\omega t)}{2} \right)$$

$$V_{or} = \frac{V_m}{2\sqrt{\pi}} \left[[t]_0^\pi + \frac{1}{2} [\sin(2\omega t)]_0^\pi \right]^{\frac{1}{2}}$$

$$V_{or} = \frac{V_m}{2\sqrt{\pi}} \left[(\pi - 0) + \frac{1}{2} [\sin(2\pi) - \sin(0)] \right]^{\frac{1}{2}}$$

$$V_{or} = \frac{V_m}{2\sqrt{\pi}} * [\pi]^{\frac{1}{2}} = \frac{V_m}{2}$$

$$V_{dc} = V_m / \pi \quad , \quad I_{dc} = I_m / \pi$$

$$V_{r.m.s} = V_m / 2 \quad , \quad I_{r.m.s} = I_m / 2$$

$$P_{dc} = V_{dc} * I_{dc} \quad (\text{DC Power})$$

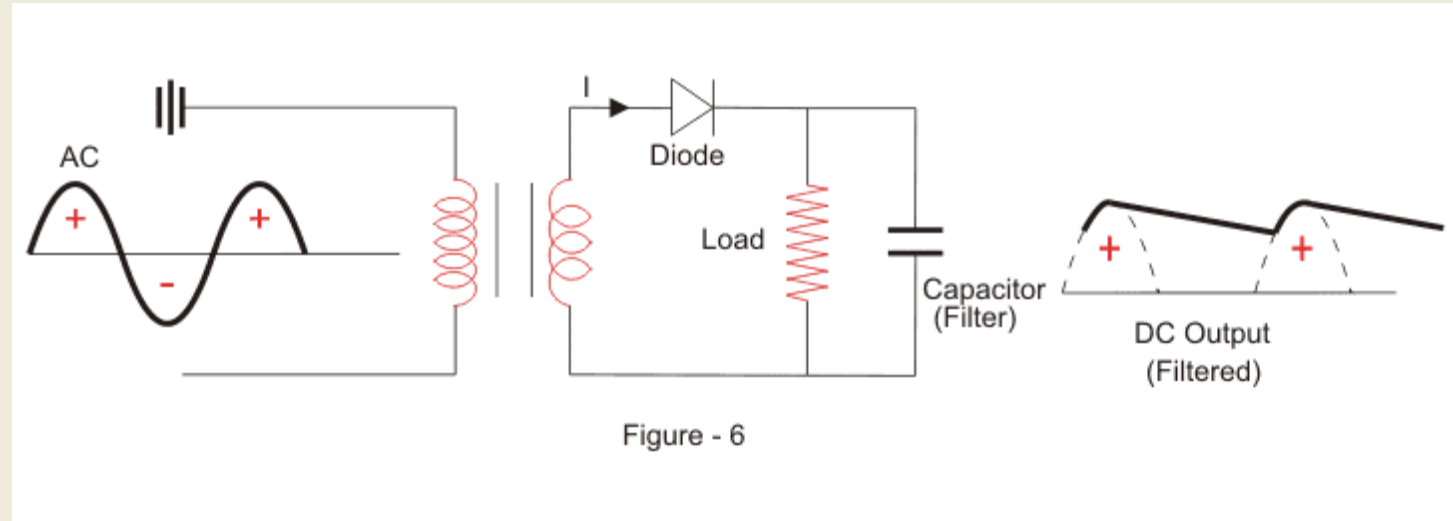
$$P_{total} = V_{r.m.s} * I_{r.m.s}$$

$$F_o = F_s \text{ (frequency)}$$

D.C, R.M.S values & efficiency

- $P_{total} = V_{r.m.s} * I_{r.m.s}$
- $\eta = P_{dc} / P_{ac}$ (Efficiency)
- $\eta = (I_{dc})^2 / (I_{r.m.s})^2 = 4 / (\pi)^2 = 0.4$
- $FF = V_{r.m.s} / V_{dc}$ (Form factor)
- $RF = V_{ac} / V_{dc}$ (Ripple factor)

H.W.R with capcitive filter



The capacitor effect (charging & discharging effect) will make the output of the circuit smoother by decreasing the ripple of the output wave.

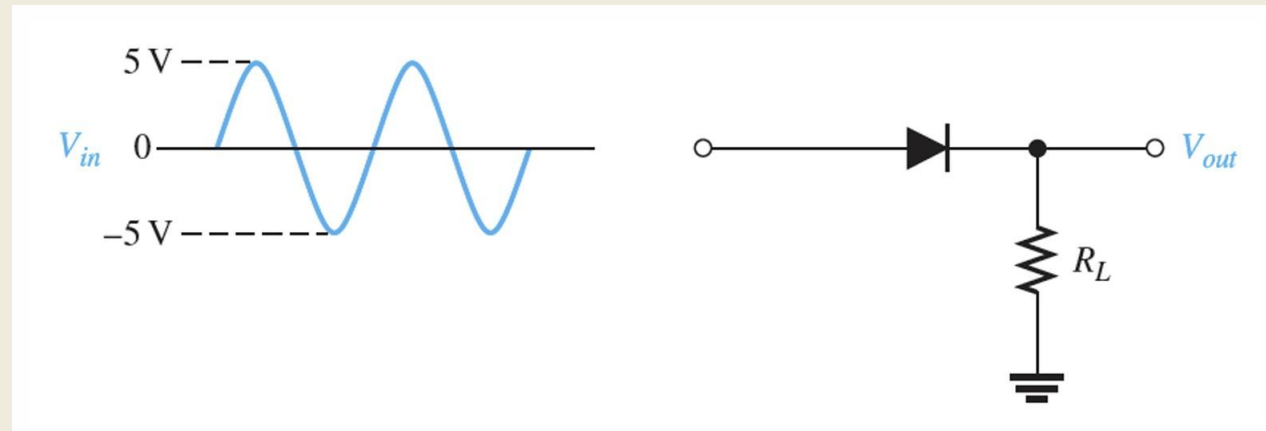
Advantages of half wave rectifier:

1. Simple construction
2. Low cost
3. Easy Mathematical analysis

Disadvantages:

1. High ripple factor
2. Low rectification efficiency

EX: Determine the peak output voltage and the average value of the output voltage of the rectifier in Fig. below for the indicated input voltage.

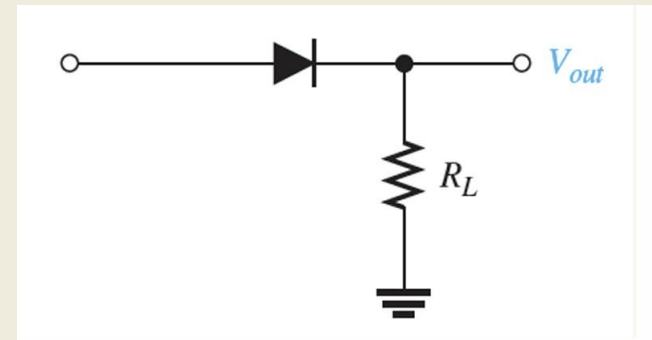


Solution:

$$V_{p(out)} = V_{p(in)} - V_B = 5 - 0.7 = 4.3 \text{ V}$$

$$V_{AVG} = V_{p(out)} / \pi = 4.3 / 3.14 = 1.37 \text{ V}$$

EX: Determine the peak output voltage for the rectifier in if the $V_{p.p}$ is 30V



Solution:

$$V_{p(in)} = V_{p.p}/2 = 30 / 2 = 15 \text{ V}$$

$$V_{p(out)} = V_{p(in)} - V_B = 15 - 0.7 = 14.3 \text{ V}$$

$$V_{AVG} = V_{p(out)} / \pi = 14.3 / 3.14 = 4.55$$

EX: The applied input a.c. power to a half-wave rectifier is 100 watts. The d.c. output power obtained is 40 watts.

- (i) What is the rectification efficiency ?
- (ii) What happens to remaining 60 watts ?

Solution :

(i)
$$\text{Rectification efficiency} = \frac{\text{d.c. output power}}{\text{a.c. input power}} = \frac{40}{100} = 0.4 = 40\%$$

(ii) 40% efficiency of rectification does not mean that 60% of power is lost in the rectifier circuit. In fact, a crystal diode consumes little power due to its small internal resistance. The 100 W a.c. power is contained as 50 watts in positive half-cycles and 50 watts in negative half-cycles. The 50 watts in the negative half-cycles are not supplied at all. Only 50 watts in the positive half-cycles are converted into 40 watts.

$$\therefore \text{Power efficiency} = \frac{40}{50} \times 100 = 80\%$$

Although 100 watts of a.c. power was supplied, the half-wave rectifier accepted only 50 watts and converted it into 40 watts d.c. power. Therefore, it is appropriate to say that efficiency of rectification is 40% and not 80% which is power efficiency.

EX: An a.c. supply of 230 V r.m.s is applied to a half-wave rectifier circuit through a transformer of turn ratio 10 : 1. Find (i) the output d.c. voltage and (ii) the peak inverse voltage. Assume the diode to be ideal.

Solution :

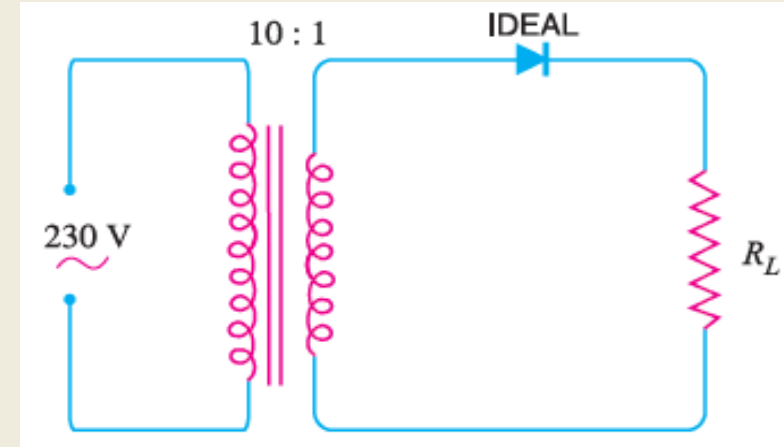
Primary to secondary turns is

$$\frac{N_1}{N_2} = 10$$

$$\begin{aligned}\text{R.M.S. primary voltage} \\ &= 230 \text{ V}\end{aligned}$$

∴ Max. primary voltage is

$$\begin{aligned}V_{pm} &= (\sqrt{2}) \times \text{r.m.s. primary voltage} \\ &= (\sqrt{2}) \times 230 = 325.3 \text{ V}\end{aligned}$$



Max. secondary voltage is $325.3/10 = 32.53 \text{ V}$
(i)

$$I_{d.c.} = \frac{I_m}{\pi}$$

$$V_{dc} = \frac{I_m}{\pi} \times R_L = \frac{V_{sm}}{\pi} = \frac{32.53}{\pi} = 10.36 \text{ V}$$

(ii) During the negative half-cycle of a.c. supply, the diode is reverse biased and hence conducts no current. Therefore, the maximum secondary voltage appears across the diode.

$$\therefore \text{Peak inverse voltage} = 32.53 \text{ V}$$

EX: A half-wave rectifier is used to supply 50V d.c. to a resistive load of 800 Ω . The diode has a resistance of 25 Ω . Calculate a.c. voltage required?

Solution :

Output d.c. voltage, $V_{dc} = 50 \text{ V}$

Diode resistance, $r_f = 25 \Omega$

Load resistance, $R_L = 800 \Omega$

Let V_m be the maximum value of a.c. voltage required.

$$\begin{aligned}\therefore V_{dc} &= I_{dc} \times R_L \\ &= \frac{I_m}{\pi} \times R_L = \frac{V_m}{\pi(r_f + R_L)} \times R_L \quad \left[\because I_m = \frac{V_m}{r_f + R_L} \right]\end{aligned}$$

$$\text{or} \quad 50 = \frac{V_m}{\pi(25 + 800)} \times 800$$

$$\therefore V_m = \frac{\pi \times 825 \times 50}{800} = \mathbf{162 \text{ V}}$$

Hence a.c. voltage of maximum value 162 V is required.

EX: A half wave rectifier is connected to a transformer with turns ratio 4:1

find its average DC output voltage, PIV of diode and ripple frequency

if input voltage is 200 V rms, 50 Hz mains supply?

(Ans : $V_{DC}=22.52$ V, PIV of diode $=70.72$ V Ripple freq. $=50$ Hz)

Pre-test

Q: Draw the main function of power electronic science?

Thank
you

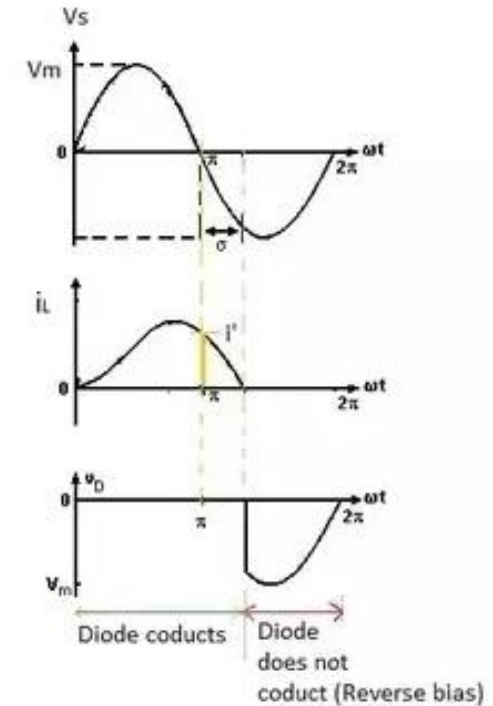
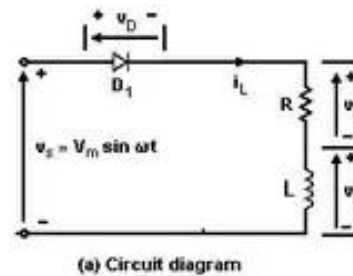
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PRELIMINARY TEST

Q: give a practical example of rectifier circuit?

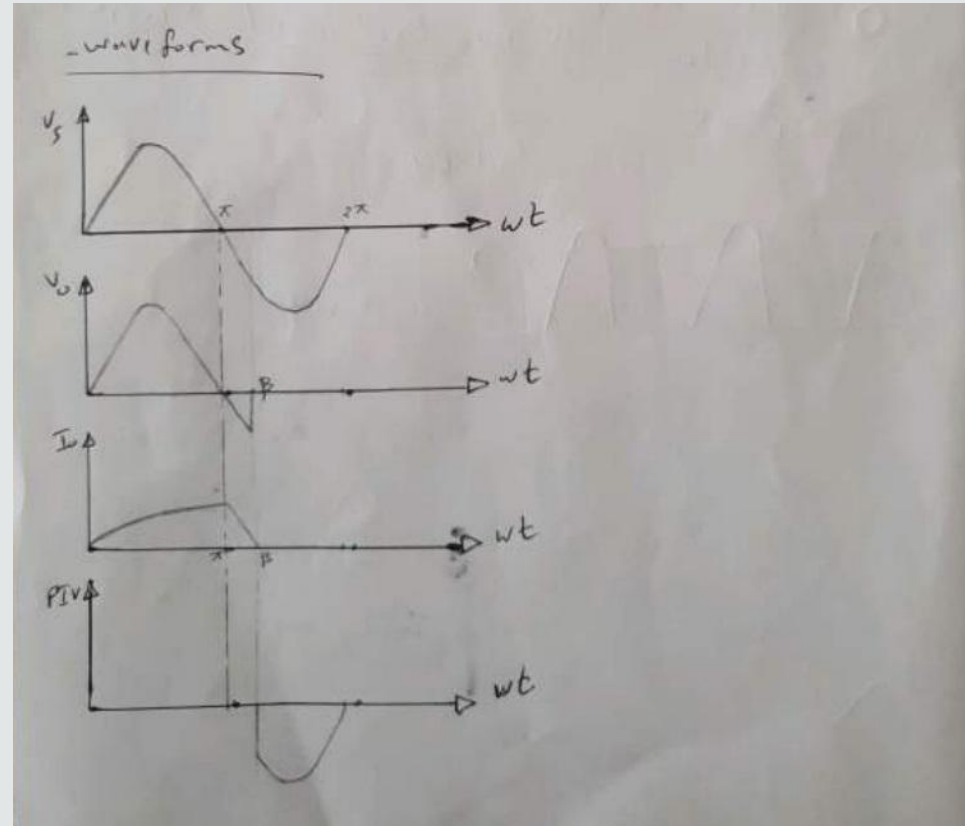
SINGLE PHASE (H.W.R) WITH INDUCTIVE LOAD

- Because of the effect of the inductance the conduction period will continue up to complete discharge of the inductance .

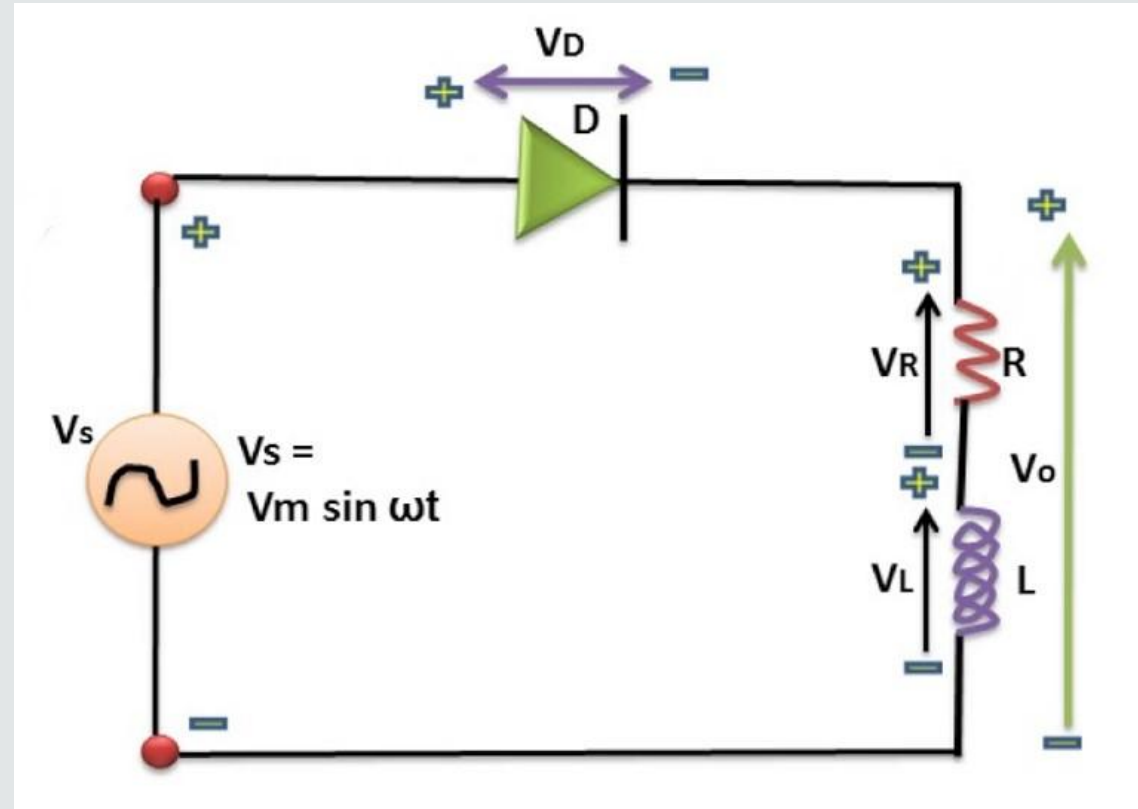


WAVE FORMS

- β : it is the angle where the
- inductance completely
- discharged .
- It can be noticed that the current
- will Continue pass through the
- circuit up to this angle.
- Peak inverse voltage (PIV) it is
- clearly Start from this angle up
- to 2π .



VOLTAGE OF THE SOURCE AND VOLTAGE ON THE RESISTANCE TERMINAL



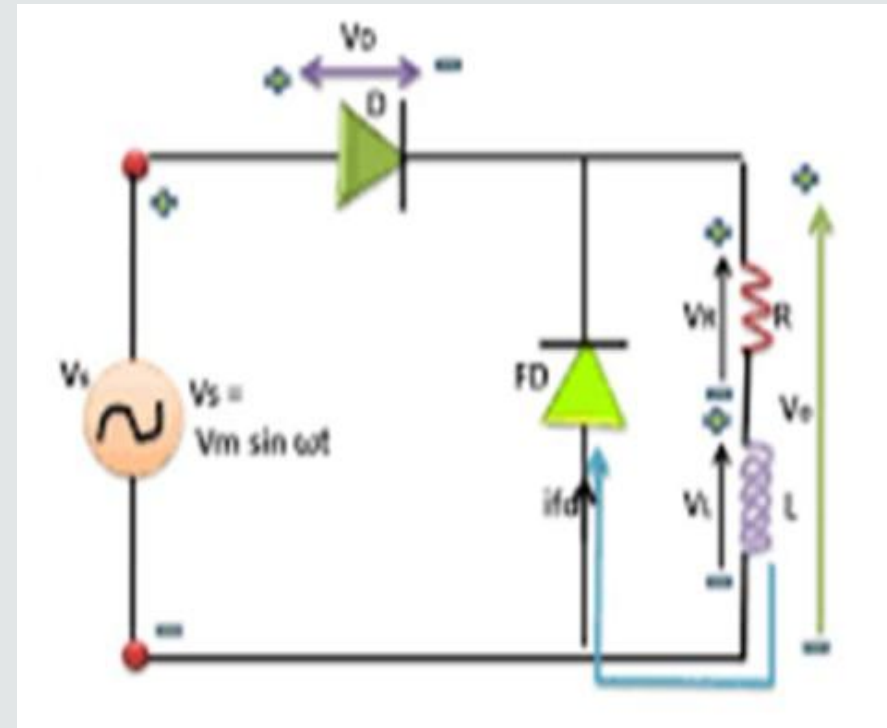
VOLTAGE AND CURRENT CALCULATION

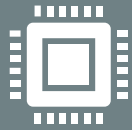
- DC, RMS voltages & currents
- Can be calculated as shown below.

$$\begin{aligned} V_{dc} &= \frac{V_m}{2\pi} \int_0^{\beta} \sin \omega t \, d\omega t \\ &= \frac{V_m}{2\pi} (1 - \cos \beta) \\ V_{r.m.s} &= \sqrt{\frac{1}{2\pi} \int_0^{\beta} (V_m \sin \omega t)^2 d\omega t} \\ &= \frac{V_m}{2\sqrt{\pi}} \sqrt{\beta + 0.5(1 - \sin(2\beta))} \\ I_{dc} &= \frac{V_{dc}}{R} = \frac{V_m}{2\pi R} (1 - \cos \beta) \end{aligned}$$

SINGLE PHASE H.W.R INDUCTIVE LOAD WITH FREE WHEELING DIODE

- *It is a diode connected across inductive load terminals to prevent the development of high voltage across the switch.*



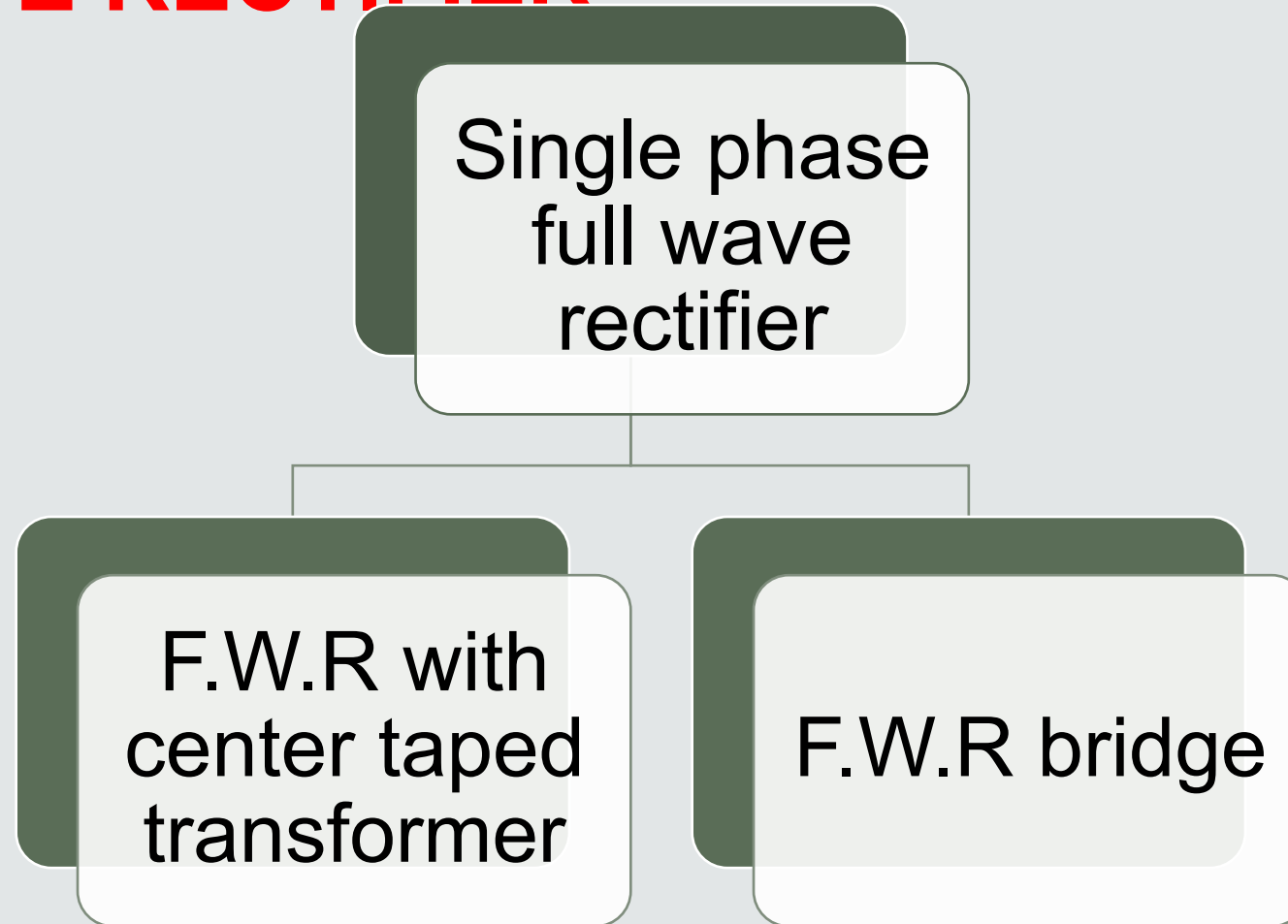


When the inductive circuit is switched off, this diode gives short circuit path for the flow of inductor decay current and hence dissipation of stored energy in the inductor.



The main purpose of free wheeling or “flyback” diode is to free wheel the stored energy in the inductor

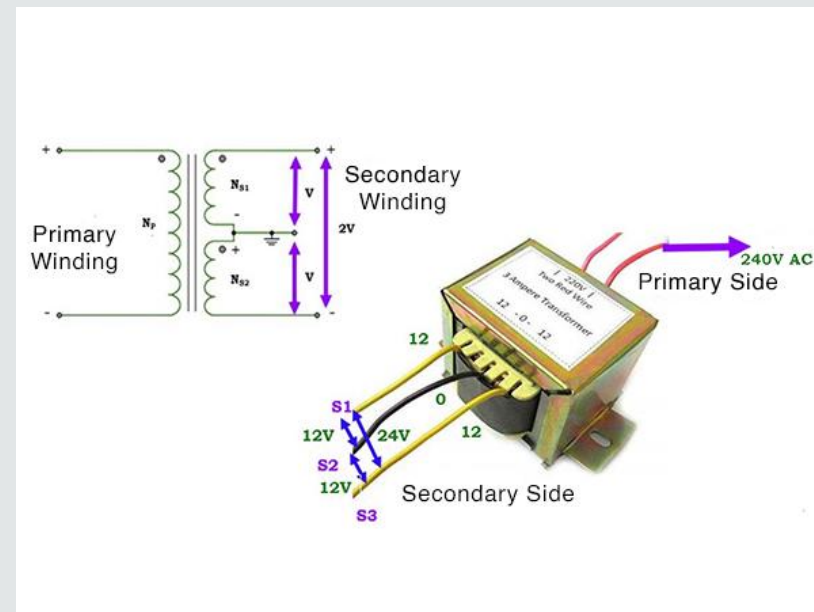
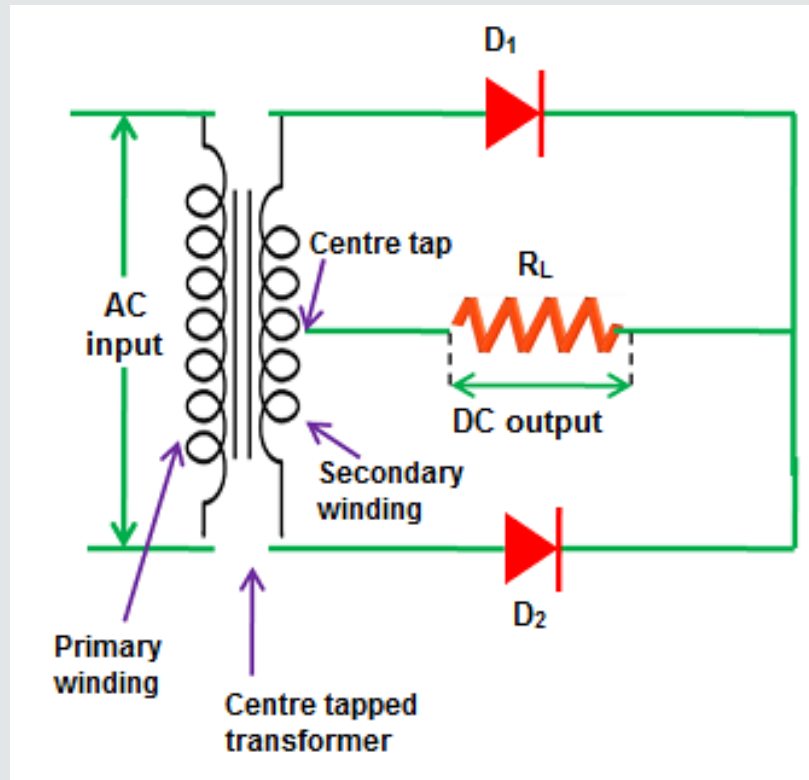
FULL WAVE RECTIFIER



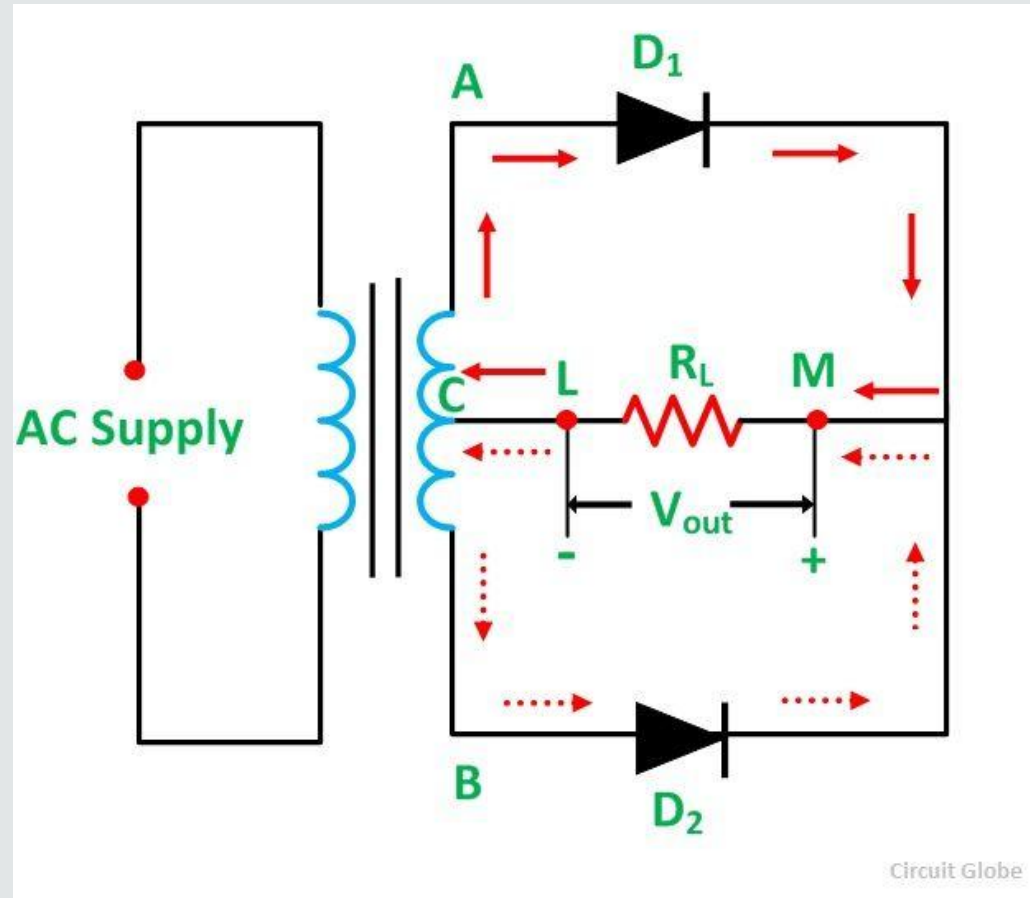
1 PH. (F.W.R) CENTER TAP

- It is consist of two half wave rectifier circuits.

- Each circuit will allow to part of the wave to pass through it.



THE **POSITIVE**
PART OF THE
WAVE WILL
PASS
THROUGH **D1**
TO THE LOAD
& THE
NEGATIVE
PART WILL
PASS
THROUGH **D2**
AS SHOWN IN
THE FIGURE
BELOW .



D.C & R.M.S VALUES CALCULATION

DC voltage can be calculated as following

$$V_o = \frac{1}{\pi} \int_0^{\pi} V_m \sin(\omega t) dt$$

$$V_o = \frac{V_m}{\pi} * [-\cos(\omega t)]_0^{\pi}$$

$$V_o = \frac{V_m}{\pi} * [-\cos(\pi) + \cos(0)]$$

$$V_o = \frac{V_m}{\pi} * 2 = \frac{2V_m}{\pi}$$

$$I_{dc} = \frac{V_{dc}}{R} = \frac{2V_m}{\pi R}$$

$$I_{r.m.s} = \frac{V_{r.m.s}}{R}$$

$$= \frac{V_m}{R\sqrt{2}}$$

WHERE
RMS
VALUE
CAN BE
CALCULA
TED AS
BELLOW

$$V_{or} = \left[\frac{1}{\pi} \int_0^{\pi} \{V_m \cdot \sin(\omega t)\}^2 \cdot dt \right]^{\frac{1}{2}}$$

$$V_{or} = \frac{V_m}{\sqrt{\pi}} \left[\int_0^{\pi} (\sin(\omega t))^2 \cdot dt + \right]^{\frac{1}{2}}$$

$$V_{or} = \frac{V_m}{\sqrt{\pi}} \left[\frac{1}{2} \left\{ \int_0^{\pi} 1 \cdot dt - \int_0^{\pi} \cos(2\omega t) \cdot dt \right\} \right]^{\frac{1}{2}} \quad \left(\sin^2(\omega t) = \frac{1 - \cos(2\omega t)}{2} \right)$$

$$V_{or} = \frac{V_m}{\sqrt{2\pi}} \left[[t]_0^{\pi} + \frac{1}{2} [\sin(2\omega t)]_0^{\pi} \right]^{\frac{1}{2}}$$

$$V_{or} = \frac{V_m}{\sqrt{2\pi}} \left[(\pi - 0) + \frac{1}{2} [\sin(2\pi) - \sin(0)] \right]^{\frac{1}{2}}$$

$$V_{or} = \frac{V_m}{\sqrt{2\pi}} \cdot [\pi]^{\frac{1}{2}} = \frac{V_m}{\sqrt{2}}$$

WAVE FORMS

Peak inverse voltage (PIV) value will be twice of the input value.

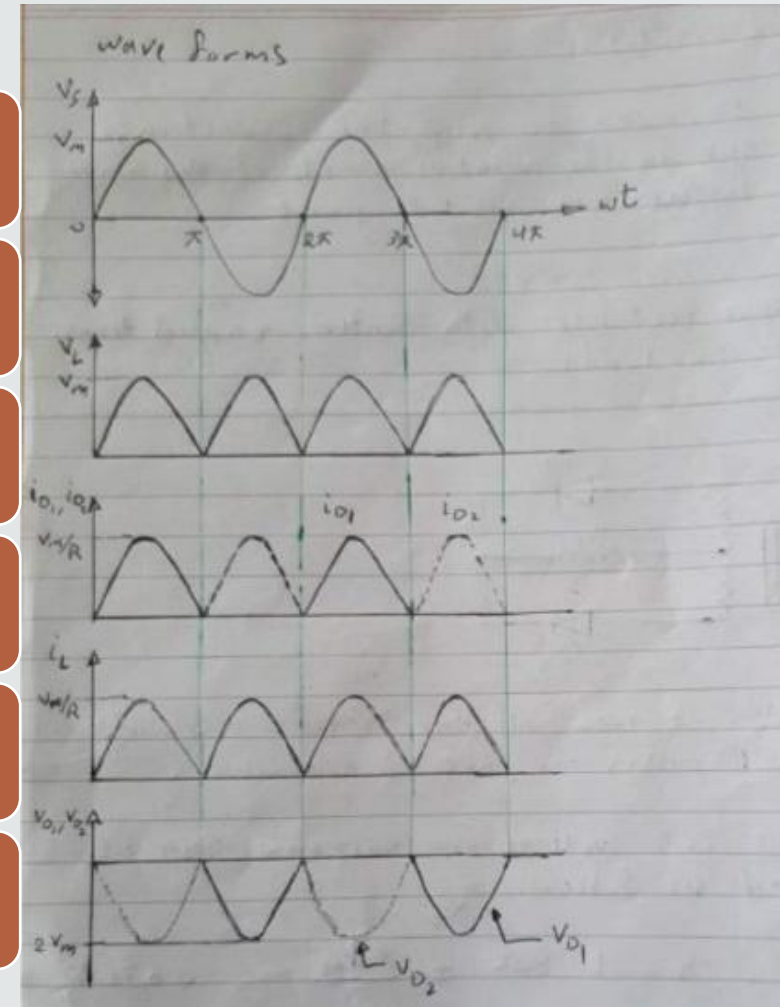
$$\text{PIV} = 2 V_m$$

$$\text{FF} = V_{\text{rms}} / V_{\text{dc}} = 1.11$$

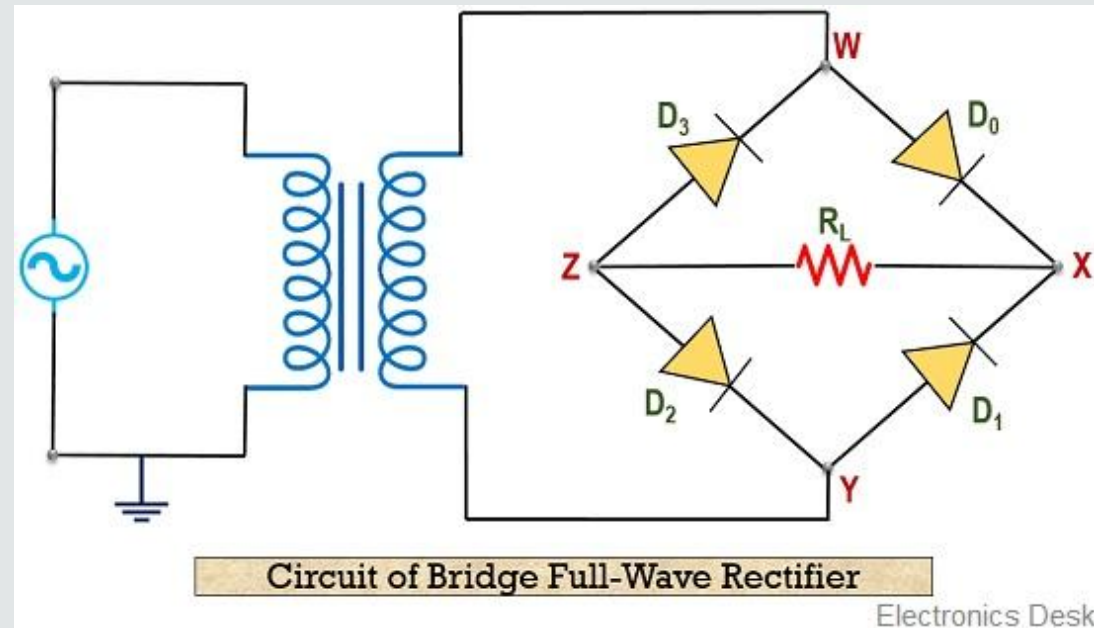
$$\text{RF} = V_{\text{ac}} / V_{\text{dc}} = 0.48$$

$$\text{TUF} = P_{\text{dc}} / 2 V_{\text{sls}} = 0.5732$$

$$\eta = P_{\text{dc}} / P_{\text{ac}} = 81.05\%$$



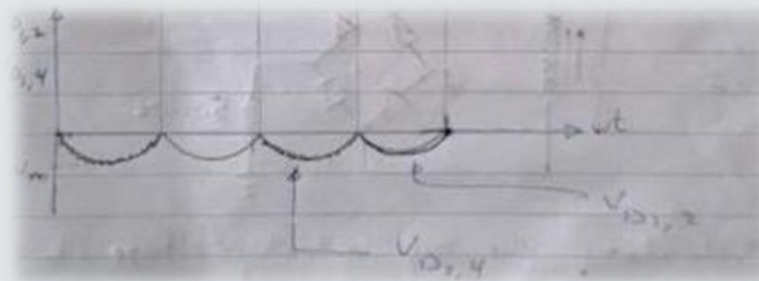
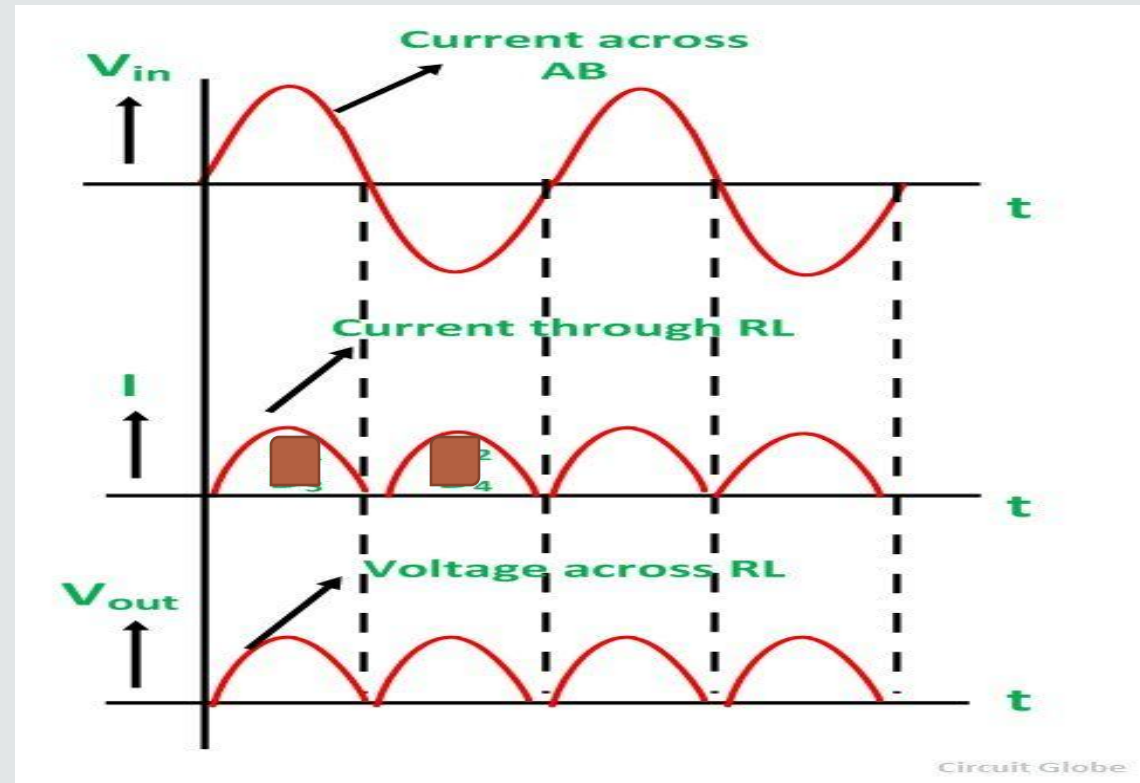
1 PH. (F.W.R) BRIDGE TYPE



- The positive part of the wave will pass through **D_0 & D_2** , where the negative part will pass through **D_1 & D_3** .

WAVE FORMS

$$\text{TUF} = 81\%$$



PIV is equal to the maximum value of the input wave

COMPARISON BETWEEN (F.W.R) BRIDGE & CENTER TAP FORMS

Bridge rectifier better than center tap rectifier? **Because** it does not require bulky tapped transformer which make its cheaper and its weight lighter.

The PIV ratings of the diodes in bridge rectifier is half than that of needed in a center tapped full wave rectifier, that is **why the diodes has capable to bearing high peak inverse voltage.**

Transformer utilization factor (TUF) more in bridge rectifier compared to the center tap rectifier.

COMPARE BETWEEN H.W.R & F.W.R

parameters	H.W.R	F.W.R (center tap)	F.W.R bridge
Rectified voltage V _{dc}	$V_m/\pi = 0.318 V_m$	$\frac{2V_m}{\pi} = 0.636 V_m$	$\frac{2V_m}{\pi} = 0.636 V_m$
Form factor FF	157%	111%	111%
Rectification ratio n	40.53%	81.05%	81.05%
Ripple factor RF	121%	48.2%	48.2%
Transformer utilization factor TUF	28.6%	57.32%	81%
Fundamental ripple frequency fr	F _s	2F _s	2F _s
PIV	V _m	2V _m	V _m

Q1 The applied input a.c. power to a half-wave rectifier is 100 watts. The d.c. output power obtained is 40 watts.

(i) What is the rectification efficiency ?

(ii) What happens to remaining 60 watts ?

Solution :

(i)

$$\text{Rectification efficiency} = \frac{\text{d.c. output power}}{\text{a.c. input power}} = \frac{40}{100} = 0.4 = 40\%$$

(ii) 40% efficiency of rectification does not mean that 60% of power is lost in the rectifier circuit. In fact, a crystal diode consumes little power due to its small internal resistance. The 100 W a.c. power is contained as 50 watts in positive half-cycles and 50 watts in negative half-cycles. The 50 watts in the negative half-cycles are not supplied at all. Only 50 watts in the positive half-cycles are converted into 40 watts.

$$\therefore \text{Power efficiency} = \frac{40}{50} \times 100 = 80\%$$

Although 100 watts of a.c. power was supplied, the half-wave rectifier accepted only 50 watts and converted it into 40 watts d.c. power. Therefore, it is appropriate to say that efficiency of rectification is 40% and not 80% which is power efficiency.

Q2. An a.c. supply of 230 V r.m.s is applied to a half-wave rectifier circuit through a transformer of turn ratio 10 : 1. Find (i) the output d.c. voltage and (ii) the peak inverse voltage. Assume the diode to be ideal.

Solution :

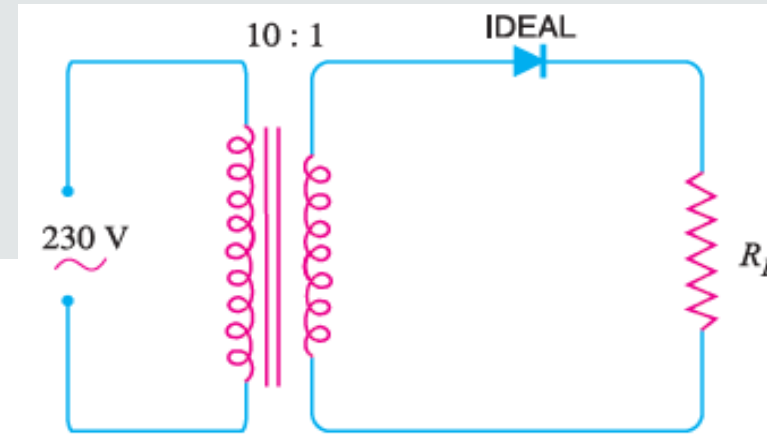
Primary to secondary turns is

$$\frac{N_1}{N_2} = 10$$

$$\begin{aligned}\text{R.M.S. primary voltage} \\ &= 230 \text{ V}\end{aligned}$$

∴ Max. primary voltage is

$$\begin{aligned}V_{pm} &= (\sqrt{2}) \times \text{r.m.s. primary voltage} \\ &= (\sqrt{2}) \times 230 = 325.3 \text{ V}\end{aligned}$$



Max. secondary voltage is

$$V_{sm} = V_{pm} \times \frac{N_2}{N_1} = 325.3 \times \frac{1}{10} = 32.53 \text{ V}$$

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

(ii) $V_{dc} = \frac{I_m}{\pi} \times R_L = \frac{V_{sm}}{\pi} = \frac{32.53}{\pi} = 10.36 \text{ V}$ pply, the diode is reverse biased and hence conducts no current. Therefore, the maximum secondary voltage appears across the diode.

$$\therefore \text{Peak inverse voltage} = 32.53 \text{ V}$$

~~Q3. A half wave rectifier is used to supply 50V d.c. to a resistive load of 800 Ω . The diode has a resistance of 25 Ω . Calculate a.c. voltage required.~~

Solution :

Output d.c. voltage, $V_{dc} = 50 \text{ V}$

Diode resistance, $r_f = 25 \text{ } \Omega$

Load resistance, $R_L = 800 \text{ } \Omega$

Let V_m be the maximum value of a.c. voltage required.

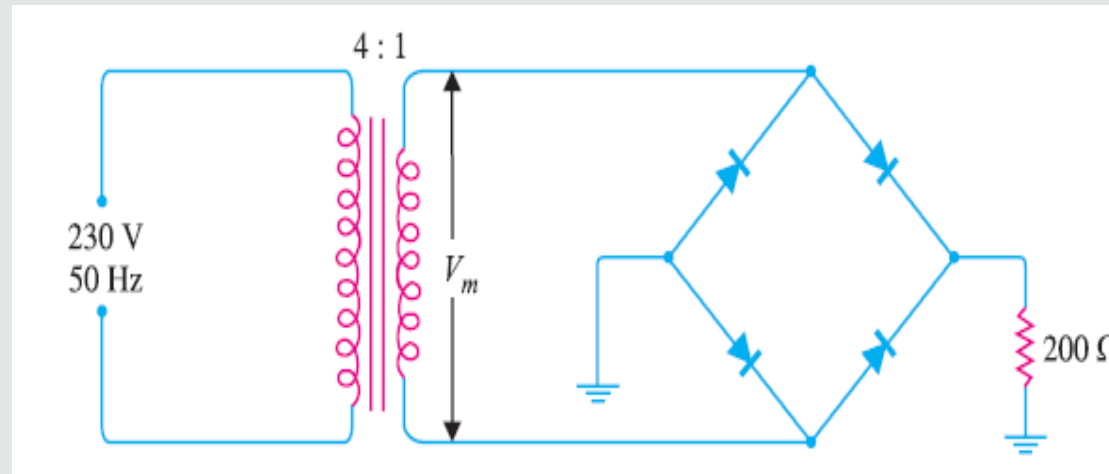
$$\begin{aligned} \therefore V_{dc} &= I_{dc} \times R_L \\ &= \frac{I_m}{\pi} \times R_L = \frac{V_m}{\pi(r_f + R_L)} \times R_L \end{aligned} \quad \left[\because I_m = \frac{V_m}{r_f + R_L} \right]$$

$$\text{or } 50 = \frac{V_m}{\pi(25 + 800)} \times 800$$

$$\therefore V_m = \frac{\pi \times 825 \times 50}{800} = \mathbf{162 \text{ V}}$$

Hence a.c. voltage of maximum value 162 V is required.

Q4. In the bridge type circuit shown in Fig. bellow, the diodes are assumed to be Ideal. Find : (i) d.c. output voltage (ii) peak inverse voltage (iii) output frequency. Assume primary to secondary turns to be 4.



Solution :

Primary/secondary turns, $N_1/N_2 = 4$

R.M.S. primary voltage = 230 V

$\therefore$ R.M.S. secondary voltage = $230 (N_2/N_1) = 230 \times (1/4) = 57.5 \text{ V}$

Maximum voltage across secondary is

$$V_m = 57.5 \times \sqrt{2} = 81.3 \text{ V}$$

$$(i) \quad \text{Average current, } I_{dc} = \frac{2V_m}{\pi R_L} = \frac{2 \times 81.3}{\pi \times 200} = 0.26 \text{ A}$$

$$\therefore \text{ d.c. output voltage, } V_{dc} = I_{dc} \times R_L = 0.26 \times 200 = \mathbf{52 \text{ V}}$$

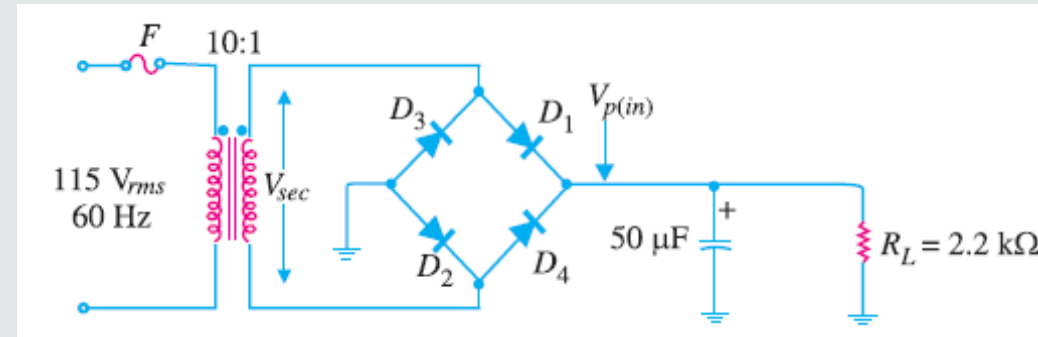
(ii) The peak inverse voltage is equal to the maximum secondary voltage *i.e.*

$$PIV = 81.3 \text{ V}$$

(iii) In full-wave rectification, there are two output pulses for each complete cycle of the input a.c. voltage. Therefore, the output frequency is twice that of the a.c. supply frequency *i.e.*

$$f_{out} = 2 \times f_{in} = 2 \times 50 = 100 \text{ Hz}$$

Q5. For the circuit shown in Fig. bellow, find the output d.c. voltage.



Solution :

It can be proved that output d.c. voltage is given by :

$$V_{dc} = V_{p(in)} \left(1 - \frac{1}{2f R_L C} \right)$$

Here $V_{p(in)}$ = Peak rectified full-wave voltage applied to the filter
 f = Output frequency

Peak primary voltage, $V_{p(prim)} = \sqrt{2} \times 115 = 163\text{V}$

Peak secondary voltage, $V_{p(sec)} = \left(\frac{1}{10} \right) \times 163 = 16.3\text{V}$

Peak full-wave rectified voltage at the filter input is

$$V_{p(in)} = V_{p(sec)} - 2 \times 0.7 = 16.3 - 1.4 = 14.9\text{V}$$

For full-wave rectification, $f = 2 f_{in} = 2 \times 60 = 120\text{ Hz}$

Now
$$\frac{1}{2f R_L C} = \frac{1}{2 \times 120 \times (2.2 \times 10^3) \times (50 \times 10^{-6})} = 0.038$$

Q6. A power supply A delivers 10 V dc with a ripple of 0.5 V r.m.s. while the power supply B delivers 25 V dc with a ripple of 1 mV r.m.s. Which is better power supply ?

Solution :

The lower the ripple factor of a power supply, the better it is.
For power supply A

$$\text{Ripple factor} = \frac{V_{ac(r.m.s.)}}{V_{dc}} = \frac{0.5}{10} \times 100 = 5\%$$

For power supply B

$$\text{Ripple factor} = \frac{V_{ac(r.m.s.)}}{V_{dc}} = \frac{0.001}{25} \times 100 = 0.004\%$$

Clearly, power supply B is better.

PRE-TEST

Q: what the main feature that we got by using a full-wave rectifier compare with half wave rectifier circuit?

THANK
YOU



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Lecture 3

Ass. lecturer Sadeq Abdullah

Electrical department

PRILIMINARY TEST

Q: what is the main difference between the single phase & three phase source?

3 PHASE HALF WAVE RECTIFIER

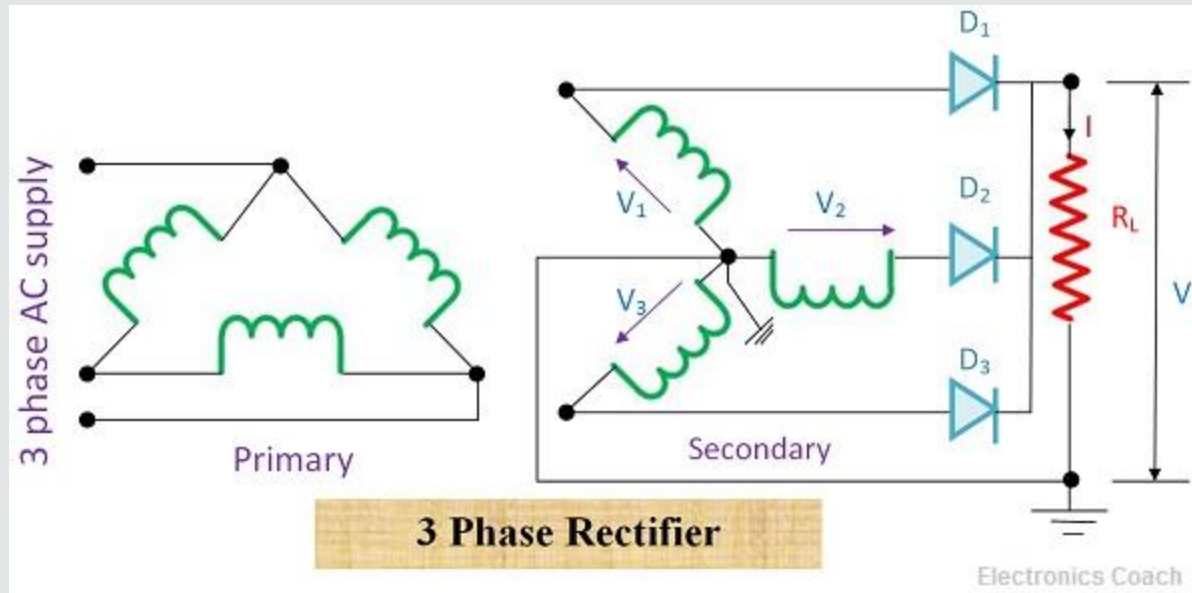
It consists of three half wave rectifier circuits each phase will be passed through specified diode.

The positive part of V_1 will pass through D_1 to the load, positive part of wave 2 & wave 3 will pass through D_2 D_3 respectively.

$$V_A = V_m \sin(\omega t - 0^\circ)$$

$$V_B = V_m \sin(\omega t - 120^\circ)$$

$$V_C = V_m \sin(\omega t - 240^\circ)$$

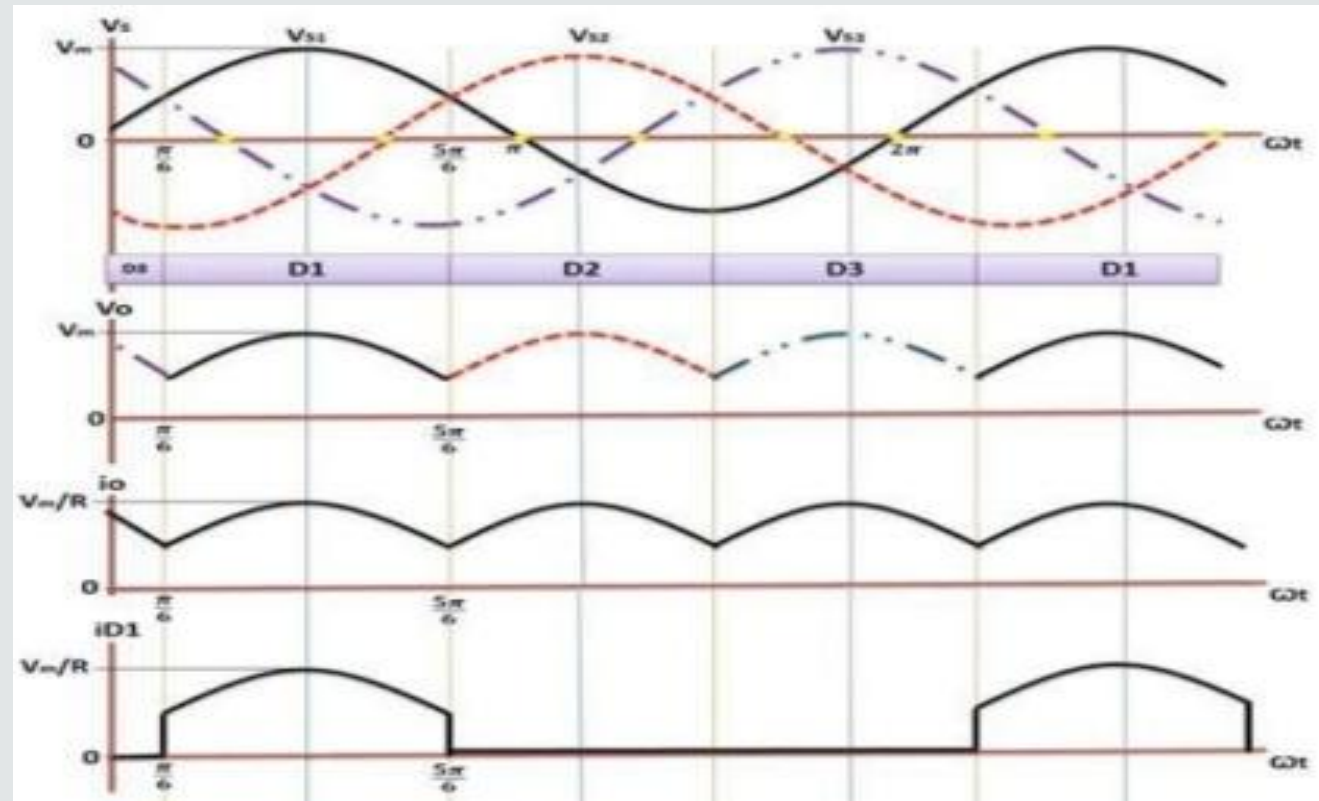


PRINCIPLE OF WORKING

- The anode of each diode is connected to one phase of the voltage supply with the cathodes of all three diodes connected together to the same positive point, effectively creating a diode OR type arrangement.
- This common point becomes the positive (+) terminal for the load while the negative (-) terminal of the load is connected to the neutral (N) of the supply.
- The three-phase rectification, whichever diode has a more positive voltage at its anode compared to the other two diodes it will automatically start to conduct, thereby giving a conduction pattern of: D_1 D_2 D_3 as shown in the figure bellow.

VOLTAGE AND CURRENT WAVE FORMS

It can be noticed that the output wave consists of three parts each part represent one third of the total wave .



OUTPUT WAVE CALCULATION

$$V_{line} = \sqrt{3}V_{phase}$$

The average value of the load voltage:

$$V_{DC(Load)} = \frac{3}{2\pi} \int_{\pi/6}^{5\pi/6} v_m \sin \omega t d\omega t$$

$$V_{DC(Load)} = \frac{3\sqrt{3}v_{m(phase)}}{2\pi}$$

The average value of the load current:

$$I_{DC(Load)} = \frac{V_{DC(Load)}}{R}$$

$$I_{DC(Load)} = \frac{3\sqrt{3}v_{m(phase)}}{2\pi R}$$

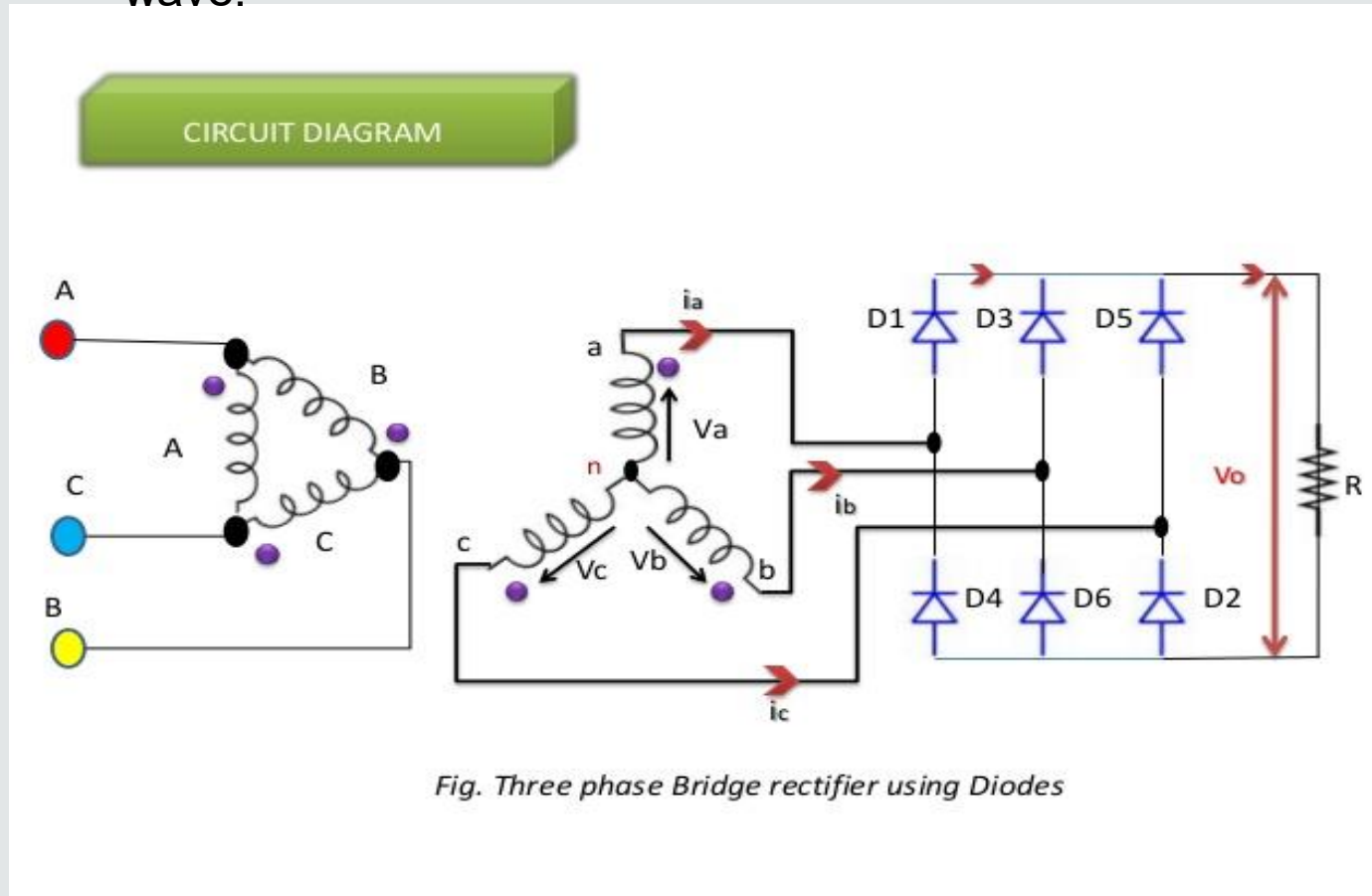
The rms value of the output voltage and current:

$$V_{RMS(Load)} = \sqrt{\frac{3}{2\pi} \int_{\pi/6}^{5\pi/6} [v_m \sin \omega t]^2 d\omega t} = 0.84v_{m(phase)}$$

$$I_{RMS(Load)} = \frac{V_{RMS(Load)}}{R}$$

3 PHASE FULL WAVE RECTIFIER

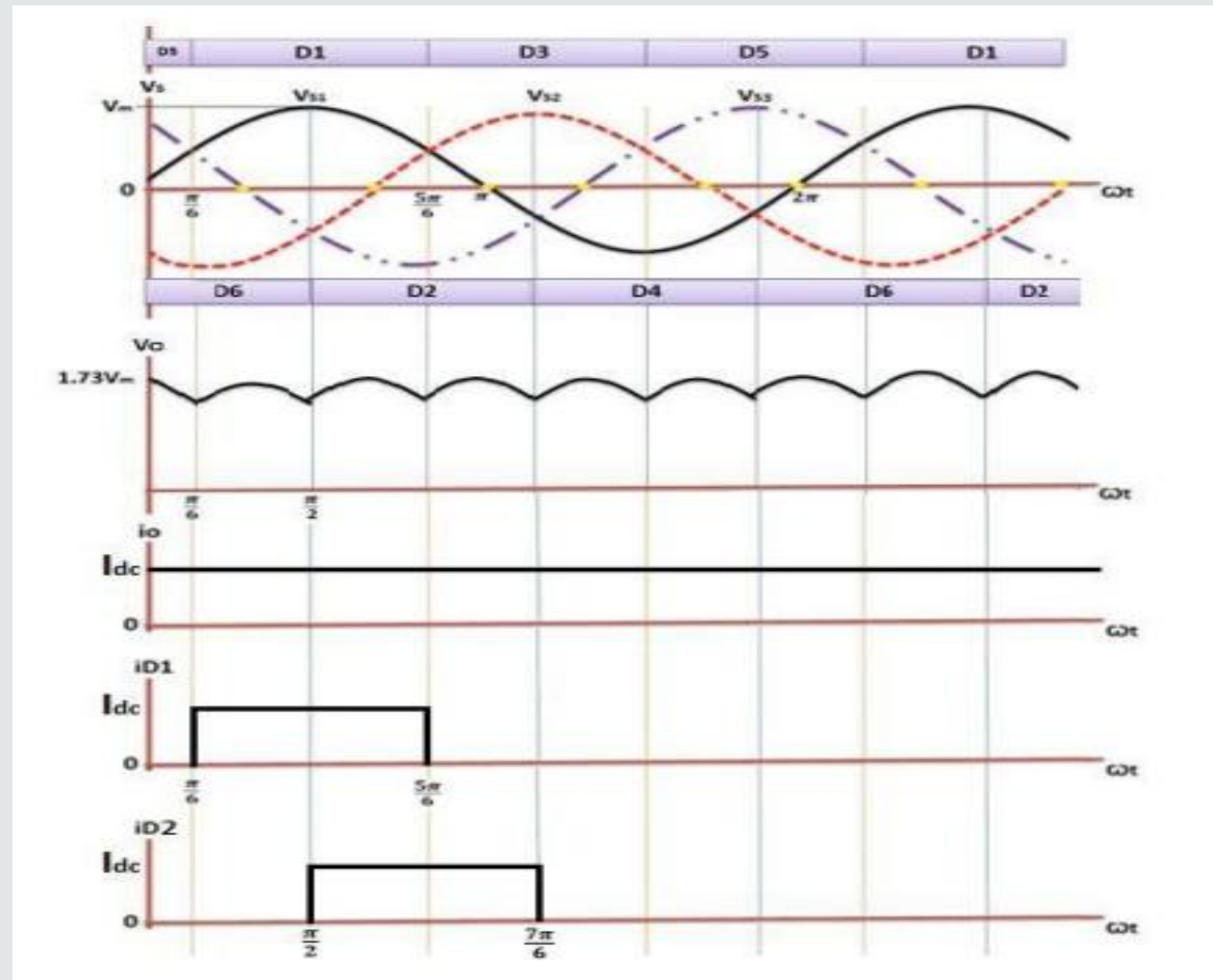
Each pair of the diodes will conduct one sixth of the total wave.



PRINCIPLE OF WORKING

- Each phase connects between a pair of diodes as shown. One diode of the conducting pair powers the positive (+) side of load, while the other diode powers the negative (-) side of load.
- Diodes D_1 D_3 D_2 and D_4 form a bridge rectifier network between phases A and B, similarly diodes D_3 D_5 D_4 and D_6 between phases B and C and D_5 D_1 D_6 and D_2 between phases C and A.
- Thus diodes D_1 D_3 and D_5 feed the positive rail and depending on which one has a more positive voltage at its anode terminal conducts. Likewise, diodes D_2 D_4 and D_6 feed the negative rail and whichever diode has a more negative voltage at its cathode terminal conducts.
- Then we can see that for three-phase rectification, the diodes conduct in matching pairs giving a conduction pattern for the load current of: D_{1-6} D_{1-2} D_{1-2} D_{3-2} D_{3-4} D_{5-4} D_{5-6} and D_{1-6} as shown.

OUTPUT VOLTAGE & CURRENT WAVE FORMS



VOLTAGE AND CURRENT CALCULATIONS

$$V_{DC(Load)} = \frac{3}{\pi} \int_{\pi/6}^{\pi/2} \sqrt{3}v_m \sin\left(\omega t + \frac{\pi}{6}\right) d\omega t = \frac{3}{\pi} \int_{\pi/3}^{2\pi/3} \sqrt{3}v_m \sin \omega t d\omega t$$

$$V_{DC(Load)} = \frac{3\sqrt{3}v_{m(phase)}}{\pi}$$

The average value of the load current:

$$I_{DC(Load)} = \frac{V_{DC(Load)}}{R}$$

$$I_{DC(Load)} = \frac{3\sqrt{3}v_{m(phase)}}{\pi R}$$

The rms value of the output voltage and current:

$$V_{RMS(Load)} = \sqrt{\frac{3}{2\pi} \int_{\pi/6}^{5\pi/6} \left[\sqrt{3}v_m \sin\left(\omega t + \frac{\pi}{6}\right) \right]^2 d\omega t} = 1.655v_{m(phase)}$$

$$I_{RMS(Load)} = I_{DC(Load)}$$

Example : Power is supplied to heavily inductive load from a three-phase supply, using a threephase bridge rectifier. If the supply phase voltage is 220 V and the resistance of the load is $10\ \Omega$, determine the DC load voltage and current. Then, sketch the output load voltage, the load current, and D4 current waveforms.

$$V_{s\ RMS(Phase)} = 220\ V, R = 10\ \Omega, L \gg R$$
$$V_{DC(Load)} = \frac{3\sqrt{3}v_{m(phase)}}{\pi}, \quad v_{m(phase)} = 220\sqrt{2}$$
$$V_{DC(Load)} = \frac{3\sqrt{3} \cdot (220\sqrt{2})}{\pi} = 514.9V$$

$$I_{DC(Load)} = \frac{V_{DC(Load)}}{R}$$
$$I_{DC(Load)} = \frac{514.9V}{10} = 51.49A$$

1. A heavily inductive load of $R = 5 \, \Omega$ is to be supplied with a DC voltage of 200 V, using three-phase bridge rectifier. Calculate:

- (a) The DC load current.
- (b) The RMS current of any diode.
- (c) The transformer secondary phase current.
- (d) The transformer secondary line voltage.

2. Repeat Q1 above if the rectifier is three-phase half-wave type.

PRE-TEST

Q: what is the difference between the single and three phase rectifier circuit?

شکرا جزیرا

LECTURE 4 SECOND LEVEL

ASS. LECTURER SADEQ ABDULLAH

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PRELIMINARY TEST

Q: give an example of practical circuit that have the transistors in its construction?

LECTURE'S GOALS

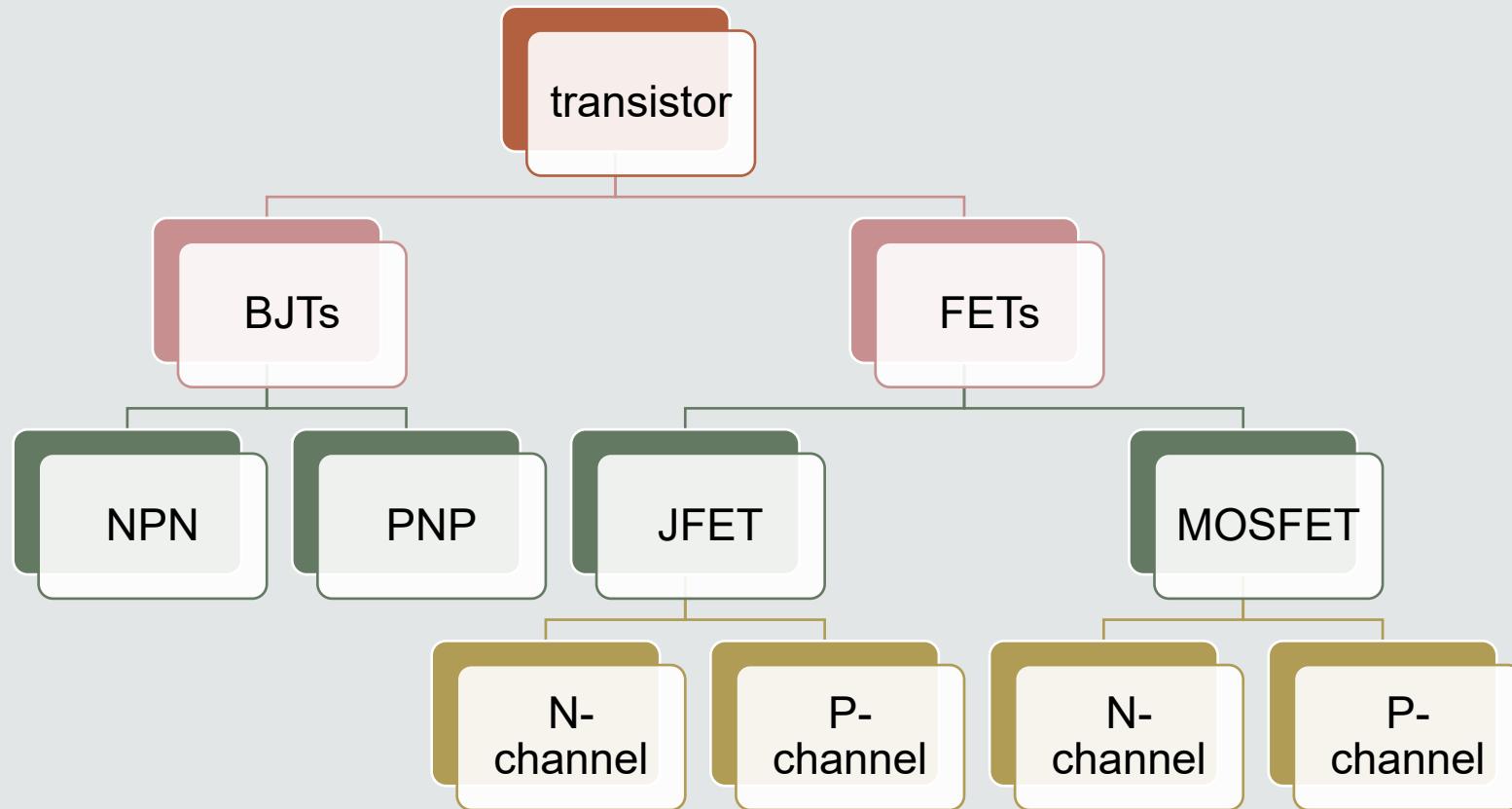
- The student after the lecture will be able to **define** the transistor , **describe** its constructions, **draw** its sample and **explain** it work characteristics.
- **Describe** the transistor's family
- **Do** the mathematical calculations of the circuits



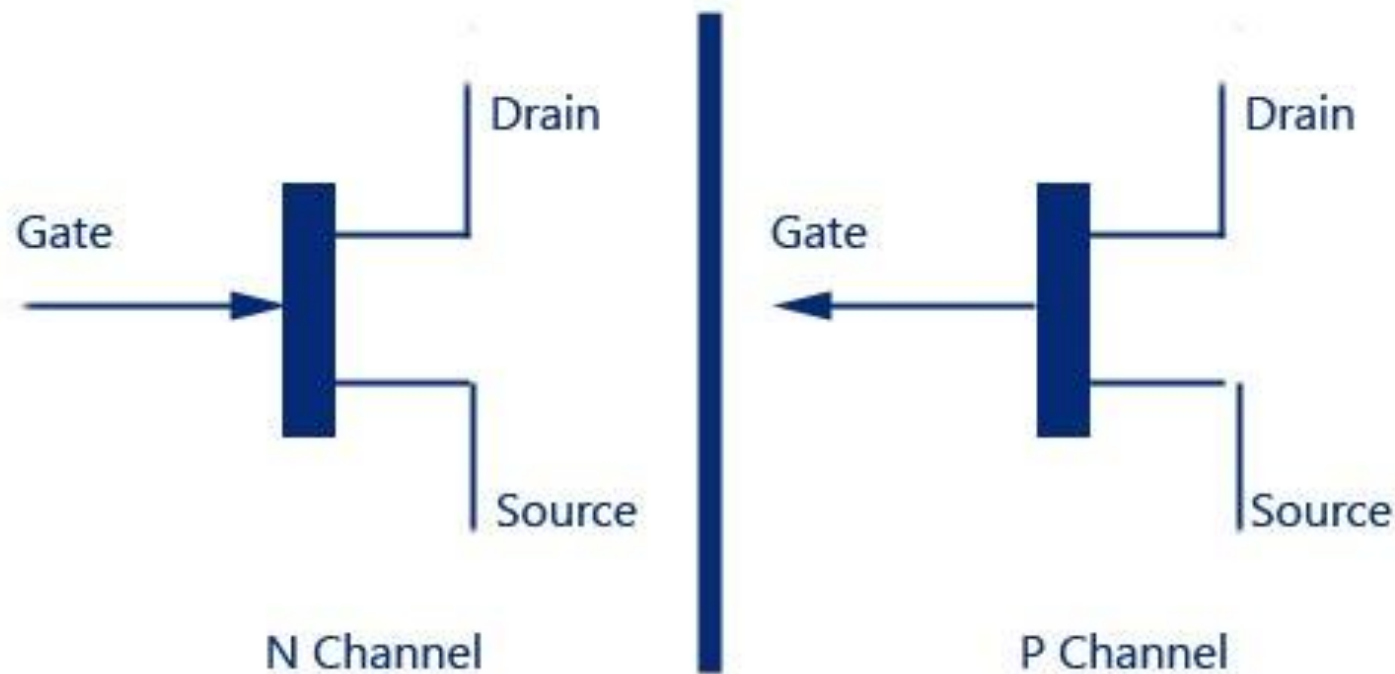
TRANSISTORS

- A **transistor** is a semiconductor device used to amplify or switch electronic signals and electrical power. It is composed of **semiconductor** material usually with at least three terminals for connection to an external circuit.
- **Trans-resistance** referred to as **mutual resistance**. It refers to the ratio between a change of the voltage at two output points and a related change of current through two input points.

TRANSISTOR FAMILY



(I) FET (FIELD EFFECT TRANSISTOR)

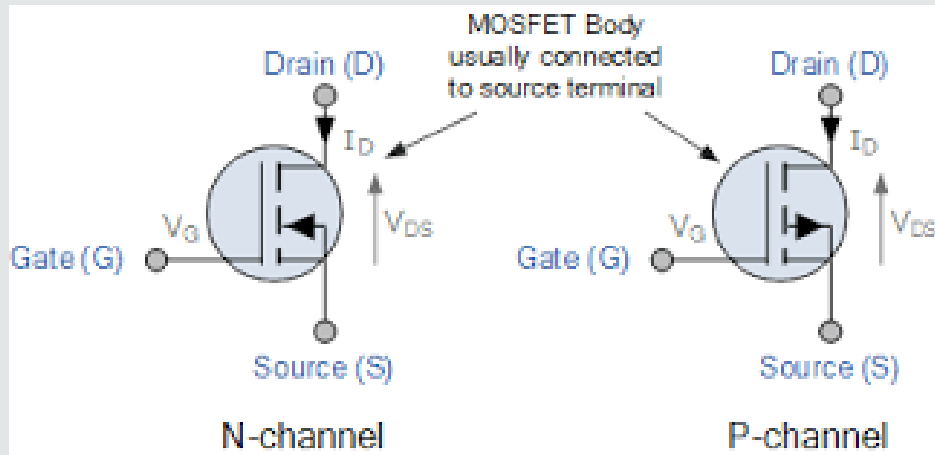


FET

Field Effect Transistor FET

_ It is a transistor which is made from three regions: **Gate, Source & drain.**

_ FETs are **voltage-controlled devices**. Which means that a voltage applied to the gate will control current flowing from the source to the drain.



- It is called **unipolar transistor** since it is using one type of charge carrier, holes or electrons not both as BJT.
- The most wide used is **MOSFETs** (metal oxide semiconductor field effect transistor)

(II) BIPOLAR JUNCTION TRANSISTOR BJTS

- Bipolar transistors are so named because they conduct by using both **majority** and **minority** carriers.
- This construction produces two p-n junctions a **Base-Emitter** junction and a **Base-Collector** junction, separated by a thin region of semiconductor known as the **Base** region.
- useful in **amplifiers** because the currents at the emitter and collector are controllable by a **relatively small base current**.

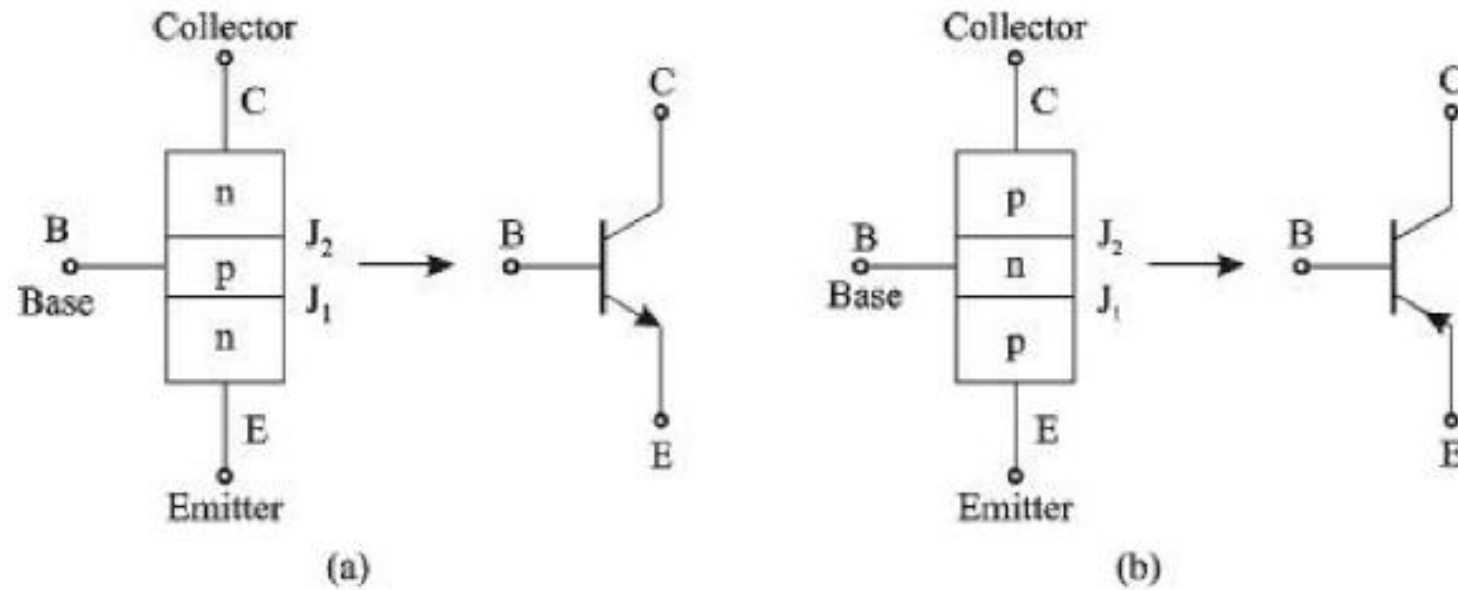


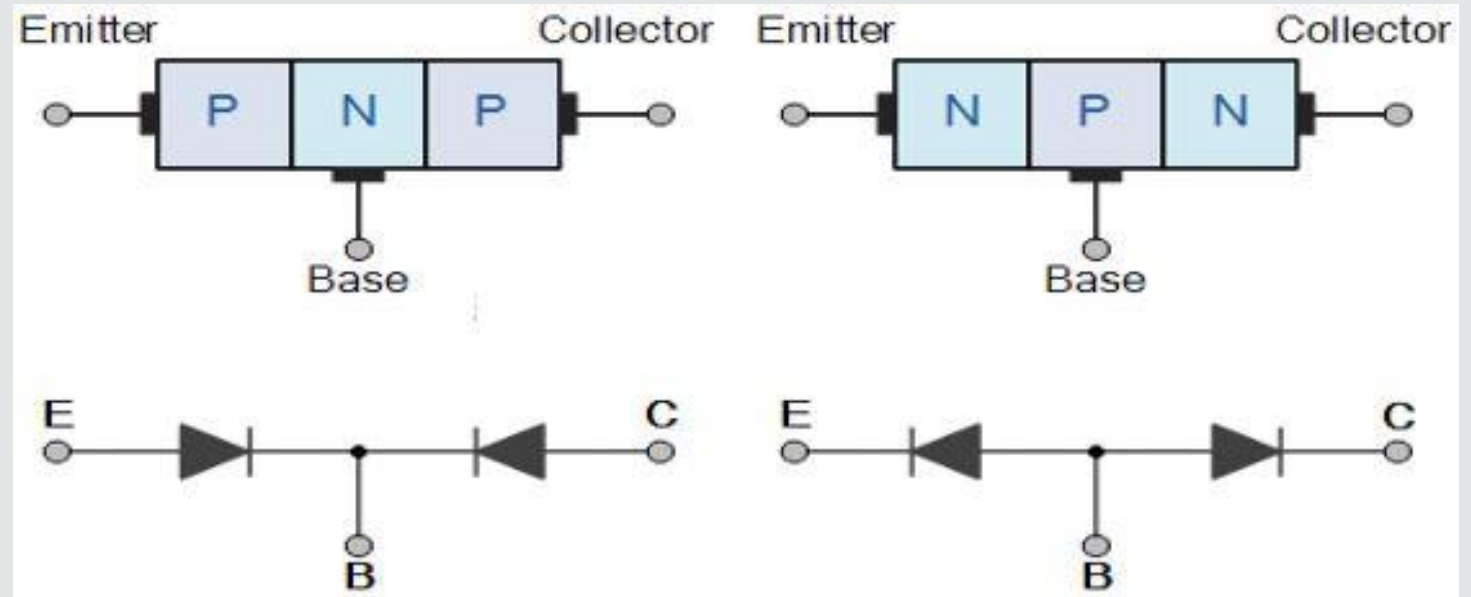
Fig.1 Bipolar power transistor and its symbol: (a) n-p-n; (b) p-n-p.

➤ the BJT has low-input-impedance device.

➤ If the base-emitter voltage (V_{BE}) is increased the base-emitter current and hence the collector-emitter current (I_{CE}) increase exponentially according to the Shockley diode model and the Ebers-Moll model.

➤ Because of this exponential relationship, the BJT has a higher trans-conductance than the FET.

➤ the BJT remained the transistor of choice for many analog circuits such as amplifiers because of their greater linearity



TRANSISTOR CURRENT GAIN

$$\alpha = \frac{I_c}{I_E}$$

$$\beta = \frac{I_c}{I_B}$$

$$I_c = \alpha \cdot I_E = \beta \cdot I_B$$

$$\alpha = \frac{\beta}{\beta + 1}$$

$$\beta = \frac{\alpha}{1 - \alpha}$$

$$I_E = I_c + I_B$$

- β : **common-emitter** current gain
- α : **common-base** current gain
- α is changing in a **small rate** due to β changing which will be **huge compare to** alpha.
- It represents the **forward active** therefore it will be written as α_f & β_f
- α is **constant and it is around one** in the transistor e.g. if $\beta = 100$, $\alpha = 0.99$

BJTs characteristics

A-(CUT- OFF & SATURATION REGIONS)

Cut-off region: it is the region where the **depletion layer is too large** because that I_B is equal to zero and **I_c is zero** and **V_{ce} is maximum.**
(FULLY OFF)

I/P & base are grounded

$V_{BE} < 0.7$

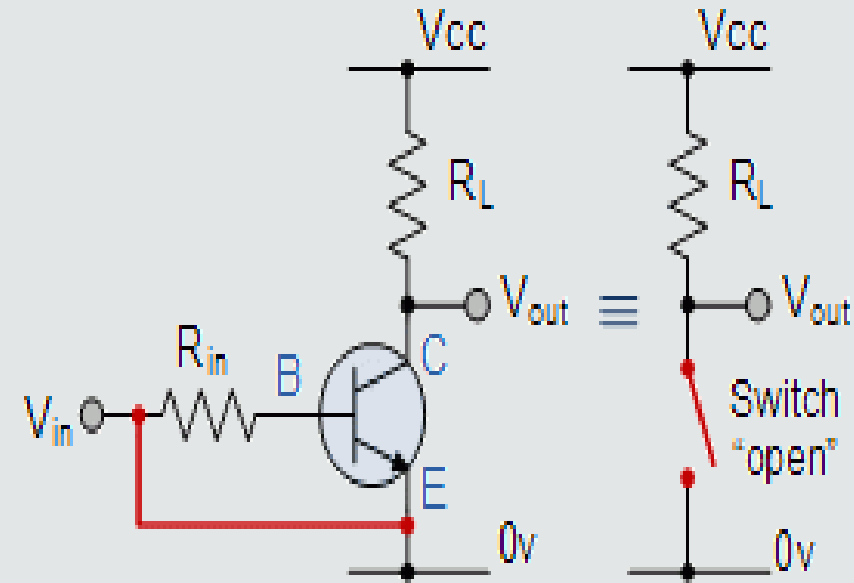
B-E junction in reverse bias

B-C junction in reverse bias

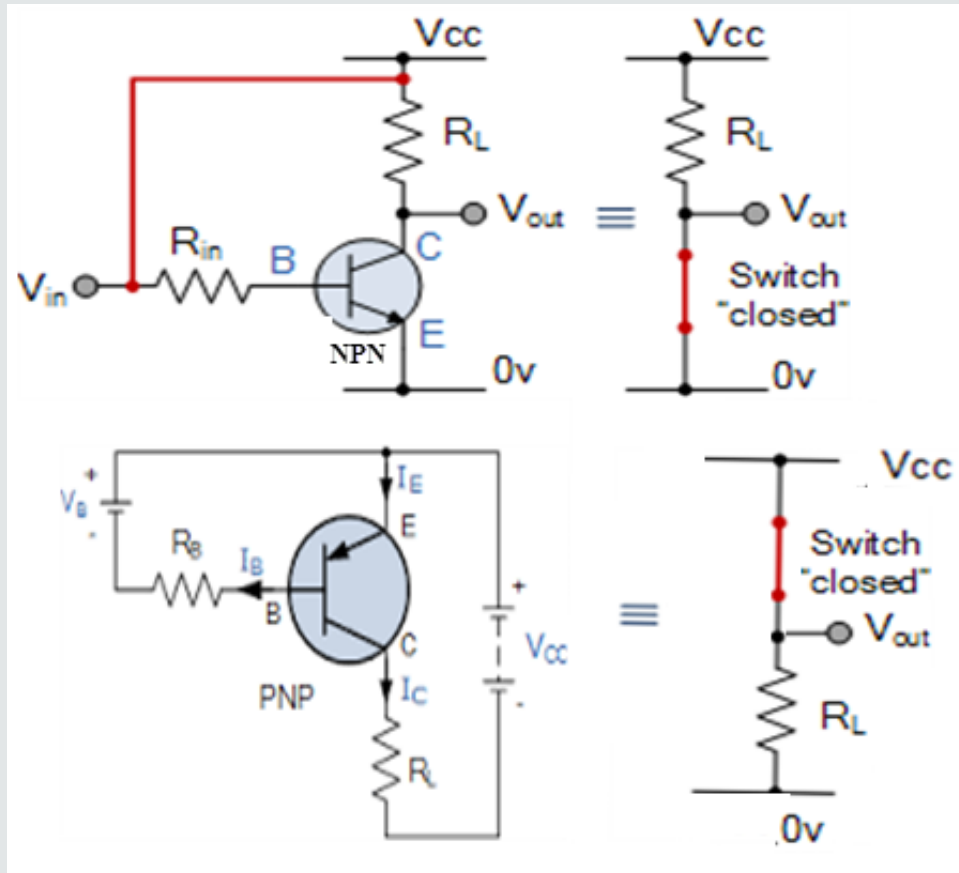
$I_c = 0$ no collector current

$V_{out} = V_{CE} = V_{CC}$

Open switch



B-SATURATION REGION



it will appear when a **maximum base current is applied** which will lead to **maximum collector current** will pass and **Vce** will be minimum, **depletion layer** will be as small as possible. (**FULLY-ON**)

I/P & Base are connected V_{cc}

B-E voltage $V_{BE} > 0.7$

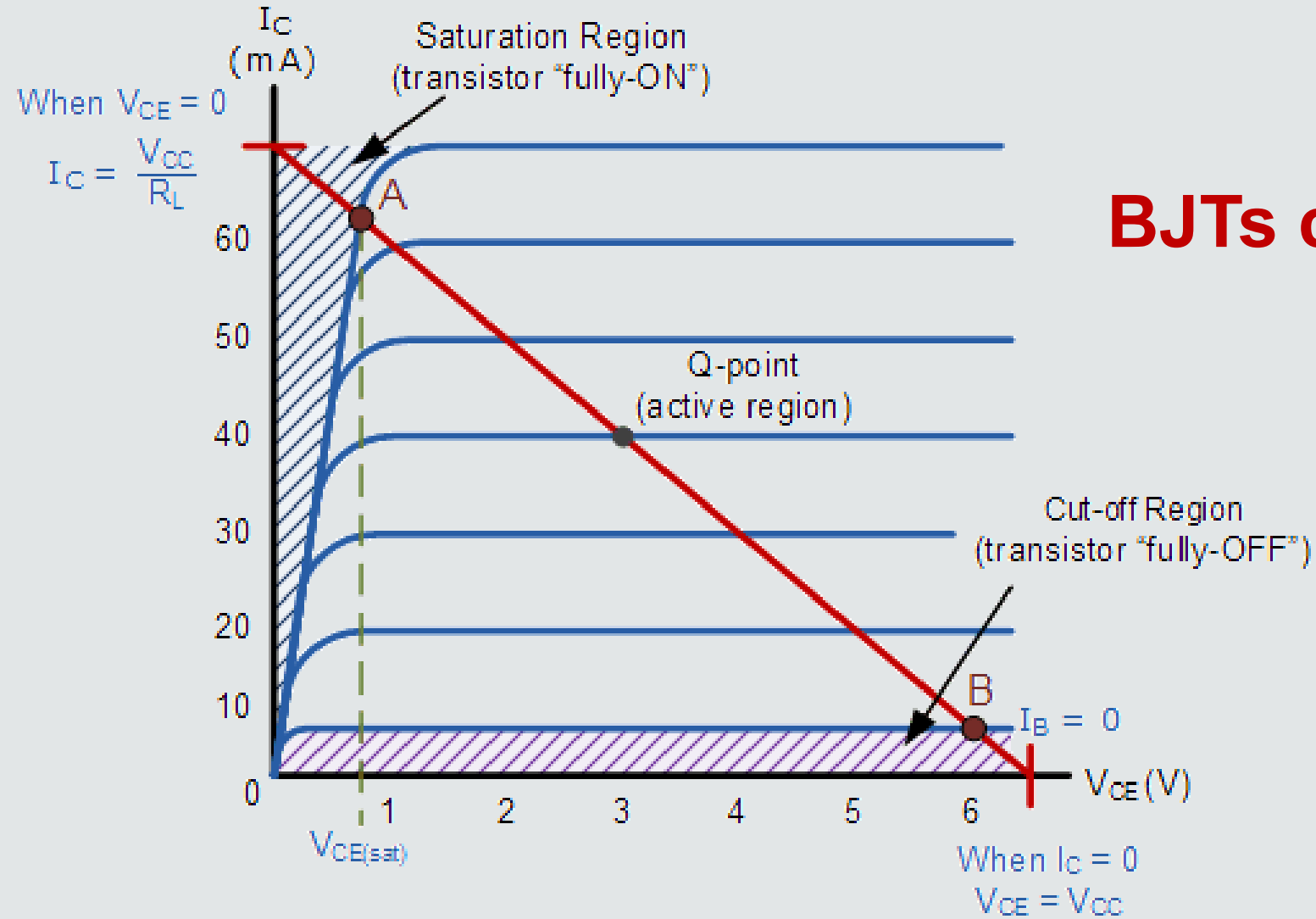
B-E junction is forward bias

B-C junction is forward bias

$$I_c = \max = \frac{V_{cc}}{R_L}$$

$V_{CE} = V_{out} = 0$ (ideal saturation)

BJTs characteristics



TRANSISTOR AS SWITCH

The transistor will be used as a switch therefore the operation point will be between cut-off and saturation points.

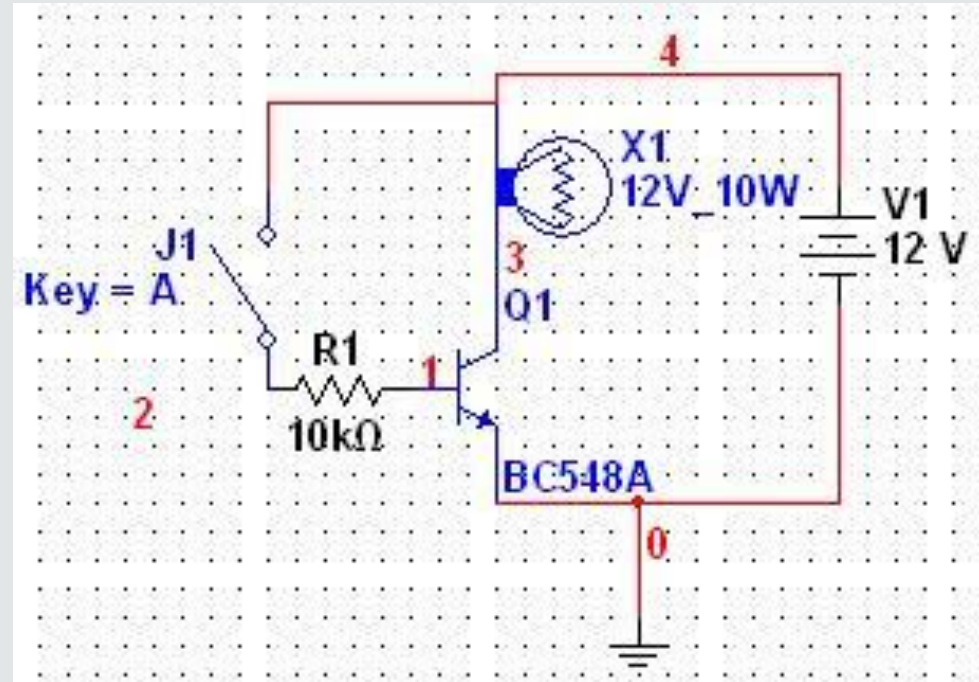
$$I_B = \frac{V_B - V_{BE}}{R_B}$$

$$V_C = V_{CE} = V_{CC} - I_C R_C$$

$$V_C = V_{CC} - \beta R_C \frac{V_B - V_{BE}}{R_B}$$

$$V_{CE} = V_{CB} + V_{BE}$$

$$V_{CB} = V_{CE} - V_{BE} \dots\dots\dots (1)$$



Max. Collector current can be obtained when $V_{CB} = 0$

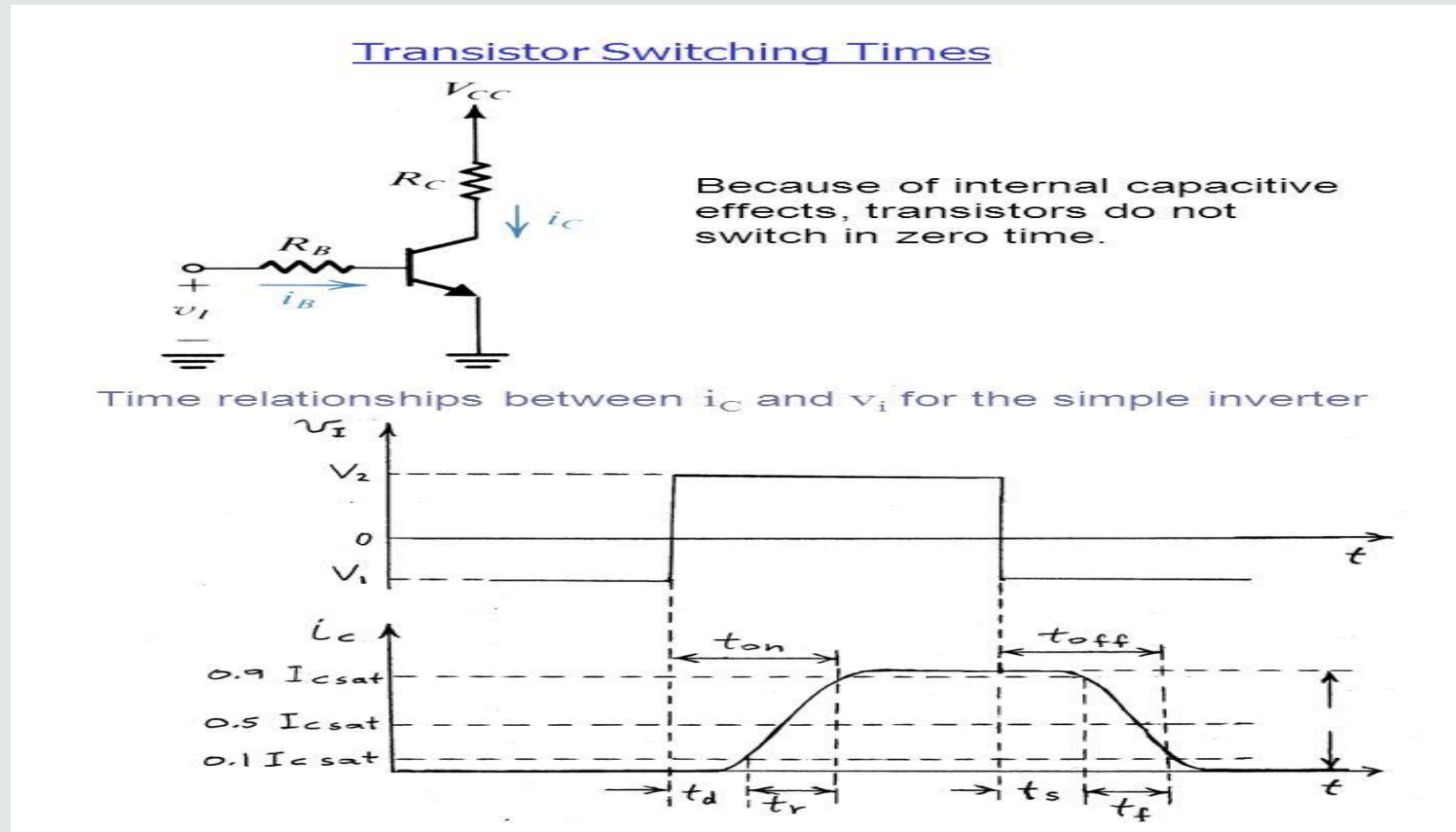
$$V_{CE} = V_{BE}$$

$$I_C = \frac{V_{CC} - V_{CE}}{R_C}, \quad I_B = \frac{I_C}{\beta}$$

$$I_C = \frac{V_{CC} - V_{CE\ sat}}{R_C}, \quad I_B\ sat = \frac{I_{Cs}}{\beta} \text{ at saturation}$$

$$\text{ODF (over drive factor)} = \frac{I_B}{I_{BS}}$$

SWITCHING TIME CHARACTERISTICS



t_d : delay time , **t_r** : rise time , **t_s** : storage time, **t_f** : fall time

Transistor response characteristic

NPN BJTS	PNP BJTs
In this the majority of n-types are present.	In this the majority of p-type materials are present
the carriers are electrons	the carriers in this type of transistors are holes
the terminal base is supplied with the increased amounts of current then the transistor gets switch to ON mode	for the low values of the currents the transistor is ON. Otherwise for high values of currents transistors it is OFF
the flow of current is evident from the collector to the emitter terminals.	the flow of current can be seen from the terminals of the emitter to the collector.
the arrow is pointing out	the indication of arrow is always pointing in
Sample as shown above	Sample as shown above

COMPARISON BETWEEN NPN & PNP

EX1: A transistor employs a 4 k Ω load and $V_{CC} = 13V$. What is the maximum input signal if $\beta = 100$? Given $V_{knee} = 1V$ and a change of 1V in V_B causes a change of 5mA in collector current.

- **Solution :**

- **Collector supply voltage, $V_{CC} = 13 V$**

- Knee voltage, $V_{knee} = 1 V$**

- Collector load, $R_C = 4 k\Omega$**

$\therefore$ Max. allowed voltage across $R_C = 13 - 1 = 12 V$

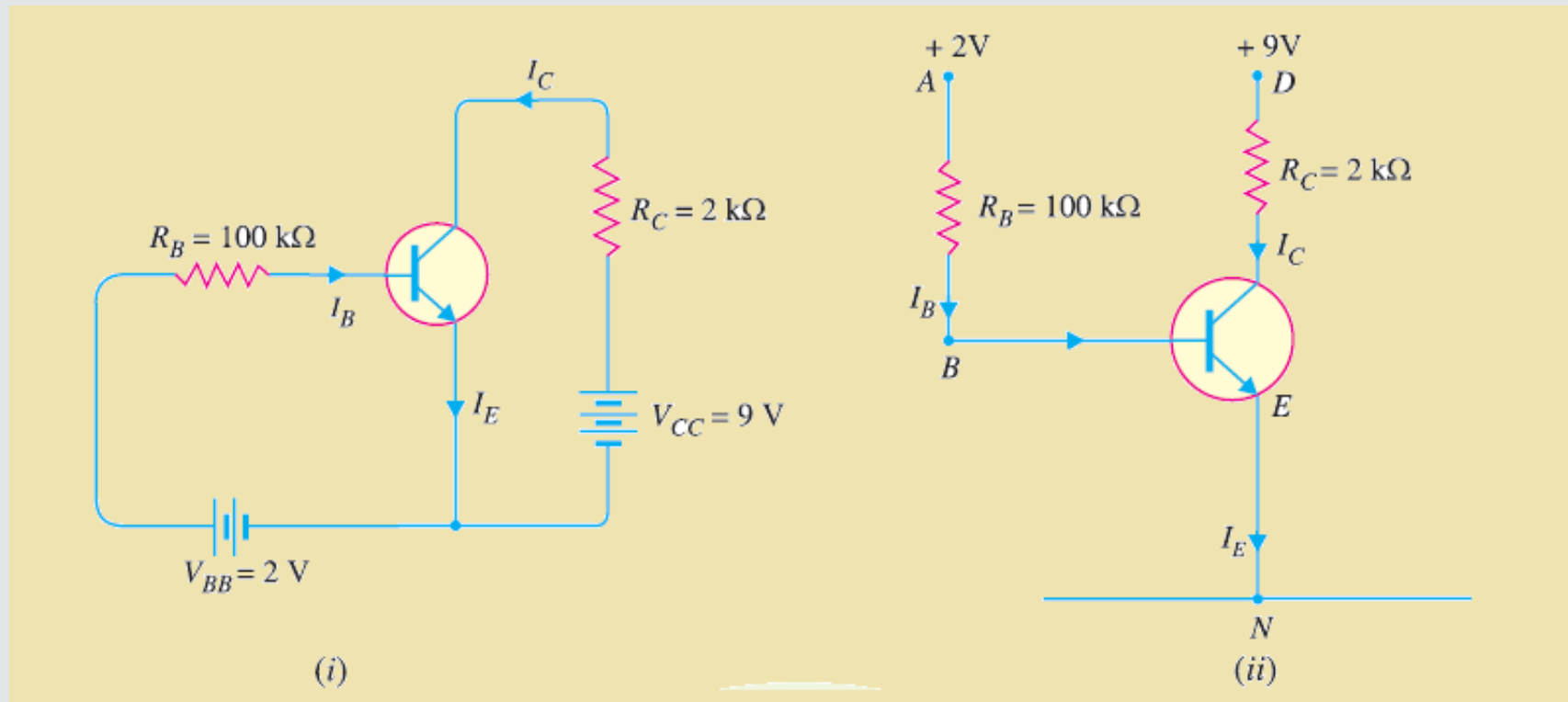
$\therefore$ Max. allowed collector current, $i_C = 12 V / R_C = 12 V / 4 K\Omega = 3 mA$

- Maximum base current, $i_B = i_C / \beta = 3 mA / 100 = 30 \mu A$

- Now Collector current / Base voltage (signal voltage) = 5 mA/V

- $\therefore$ Base voltage (signal voltage) = Collector current / (5 mA/V) = 3 mA / (5 mA/V) = 600 mV

EX2: in the Fig. bellow (i) shows biasing with base resistor method. (i) Determine the collector current I_C and collector-emitter voltage V_{CE} . Neglect small base-emitter voltage. Given that $\beta = 50$. (ii) If R_B in this circuit is changed to $50\text{ k}\Omega$, find the new operating point.



Solution :

- In the circuit shown in Fig. 2 (i), biasing is provided by a battery V_{BB} ($= 2V$) in the base circuit which is separate from the battery V_{CC} ($= 9V$) used in the output circuit.
- The same circuit is shown in a simplified way in Fig. 2 (ii). Here, we need show only the supply voltages, $+ 2V$ and $+9V$. It may be noted that negative terminals of the power supplies are grounded to get a complete path of current.
- (i) Referring to Fig.2 (ii) and applying Kirchhoff 's voltage law to the circuit ABEN, we get,

$$I_B R_B + V_{BE} = 2V$$

As V_{BE} is negligible,

$$\therefore I_B = \frac{2V}{R_B} = \frac{2V}{100 \text{ k}\Omega} = 20 \mu A$$

$$\text{Collector current, } I_C = \beta I_B = 50 \times 20 \mu A = 1000 \mu A = \mathbf{1 \text{ mA}}$$

Applying Kirchhoff's voltage law to the circuit DEN, we get,

$$I_C R_C + V_{CE} = 9$$

$$\text{or } 1 \text{ mA} \times 2 \text{ k}\Omega + V_{CE} = 9$$

$$\text{or } V_{CE} = 9 - 2 = \mathbf{7 \text{ V}}$$

(ii) When R_B is made equal to $50\text{ k}\Omega$, then it is easy to see that base current is doubled i.e. $I_B = 40\text{ }\mu\text{A}$.

$$\therefore \text{Collector current, } I_C = \beta I_B = 50 \times 40 = 2000\text{ }\mu\text{A} = 2\text{ mA}$$

$$\text{Collector-emitter voltage, } V_{CE} = V_{CC} - I_C R_C = 9 - 2\text{ mA} \times 2\text{ k}\Omega = 5\text{ V}$$

$\therefore$ New operating point is **5 V, 2 mA**.

- **EX3:** (i) A germanium transistor is to be operated at zero signal $I_C = 1\text{mA}$. If the collector supply $V_{CC} = 12\text{V}$, what is the value of R_B in the base resistor method ? Take $\beta = 100$.
(ii) If another transistor of the same batch with $\beta = 50$ is used, what will be the new value of zero signal I_C for the same R_B ?

- **Solution :**

- Given, $V_{CC} = 12\text{ V}$, $\beta = 100$
- As it is a Ge transistor, therefore, $V_{BE} = 0.3\text{ V}$
- (i) Zero signal $I_C = 1\text{ mA}$

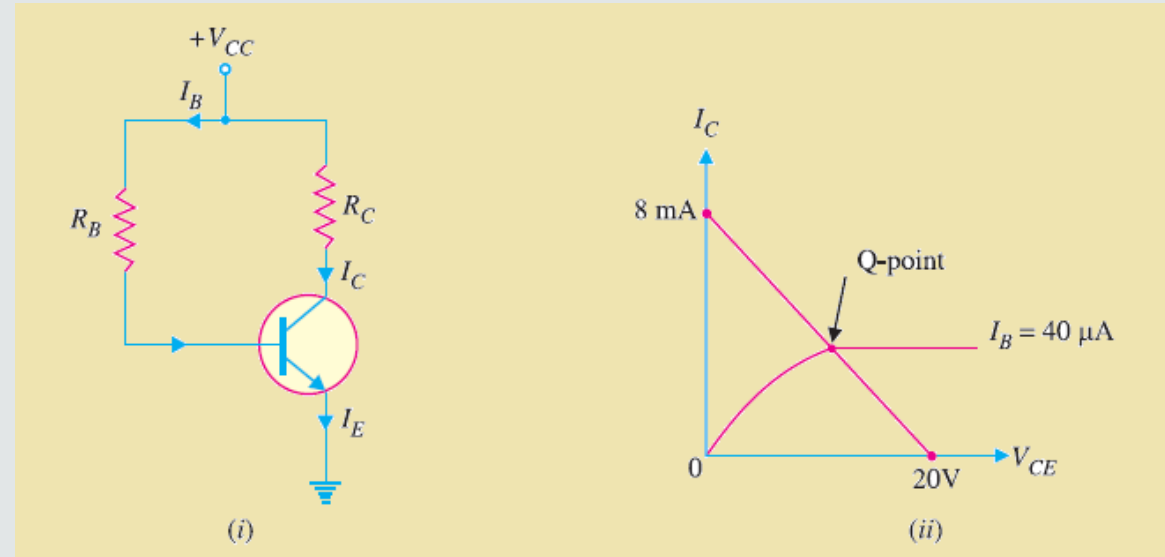
$$\begin{aligned}\therefore \quad \text{Zero signal } I_B &= I_C / \beta = 1\text{ mA} / 100 = 0.01\text{ mA} \\ \text{Using the relation, } V_{CC} &= I_B R_B + V_{BE} \\ \therefore \quad R_B &= \frac{V_{CC} - V_{BE}}{I_B} = \frac{12 - 0.3}{0.01\text{ mA}} \\ &= 11.7\text{ V} / 0.01\text{ mA} = \mathbf{1170\text{ k}\Omega}\end{aligned}$$

(ii) Now $\beta = 50$

Again using the relation, $V_{CC} = I_B R_B + V_{BE}$

$$\begin{aligned}\therefore I_B &= \frac{V_{CC} - V_{BE}}{R_B} = \frac{12 - 0.3}{1170 \text{ k}\Omega} \\ &= 11.7 \text{ V} / 1170 \text{ k}\Omega = 0.01 \text{ mA} \\ \therefore \text{Zero signal } I_C &= \beta I_B = 50 \times 0.01 = \mathbf{0.5 \text{ mA}}\end{aligned}$$

- **EX4: Fig. 8 (i) shows the base resistor silicon transistor circuit. The device (i.e. transistor) has the characteristics shown in Fig. 8 (ii). Determine V_{CC} , R_C and R_B .**



Solution :

From the d.c load line, $V_{CE} = V_{CC} - I_C R_C$, When $I_C = 0$, $V_{CE} = V_{CC}$
 $V_{CC} = 20\text{V}$.

$$\begin{aligned} \text{Max. } I_C &= \frac{V_{CC}}{R_C} \text{ (when } V_{CE} = 0\text{V)} \\ \therefore R_C &= \frac{V_{CC}}{\text{Max. } I_C} = \frac{20\text{V}}{8\text{mA}} = \mathbf{2.5 \text{ k}\Omega} \\ \text{Now } I_B &= \frac{V_{CC} - V_{BE}}{R_B} \\ \therefore R_B &= \frac{V_{CC} - V_{BE}}{I_B} = \frac{20\text{V} - 0.7\text{V}}{40 \mu\text{A}} = \frac{19.3\text{V}}{40 \mu\text{A}} = \mathbf{482.5 \text{ k}\Omega} \end{aligned}$$

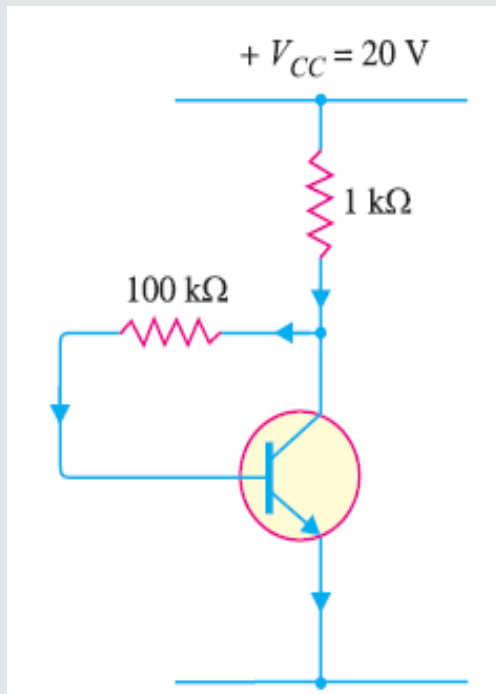
- EX5. Fig. below shows a silicon transistor biased by collector feedback resistor method. Determine the operating point. Given that $\beta = 100$.

Solution :

$V_{CC} = 20\text{V}$, $R_B = 100\text{ k}\Omega$, $R_C = 1\text{ k}\Omega$

Since it is a silicon transistor, $V_{BE} = 0.7\text{ V}$.

Assuming I_B to be in mA and using the relation



$$R_B = \frac{V_{CC} - V_{BE} - \beta I_B R_C}{I_B}$$

or $100 \times I_B = 20 - 0.7 - 100 \times I_B \times 1$

or $200 I_B = 19.3$

or $I_B = \frac{19.3}{200} = 0.096\text{ mA}$

$\therefore$ Collector current, $I_C = \beta I_B = 100 \times 0.096 = 9.6\text{ mA}$

Collector-emitter voltage is

$$\begin{aligned} V_{CE} &= V_{CC} - I_C R_C \\ &= 20 - 9.6\text{ mA} \times 1\text{ k}\Omega \\ &= 10.4\text{ V} \end{aligned}$$

$\therefore$ Operating point is **10.4 V, 9.6 mA.**

PRE-TEST

Q: define the transistor as electronic device and describe its work?

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