

Chapter-7

①

Special Purpose Diodes

Light-Emitting Diode (LED): An LED is a special type of diode that emits visible light when it is forward biased. LEDs are made from materials like gallium, phosphorus and arsenic. These materials determine the colour of light emitted.

* Gallium arsenide $\rightarrow$ Red Light

* Gallium phosphide $\rightarrow$ Green Light

Working Principle:

1. When forward-biased, electrons from the n-type region cross the junction and recombine with holes in the p-type region.
2. During recombination, energy is released as light and some heat.
3. ~~In silicon/germanium diodes,~~
3. In materials like gallium arsenide, the energy is released as visible light.

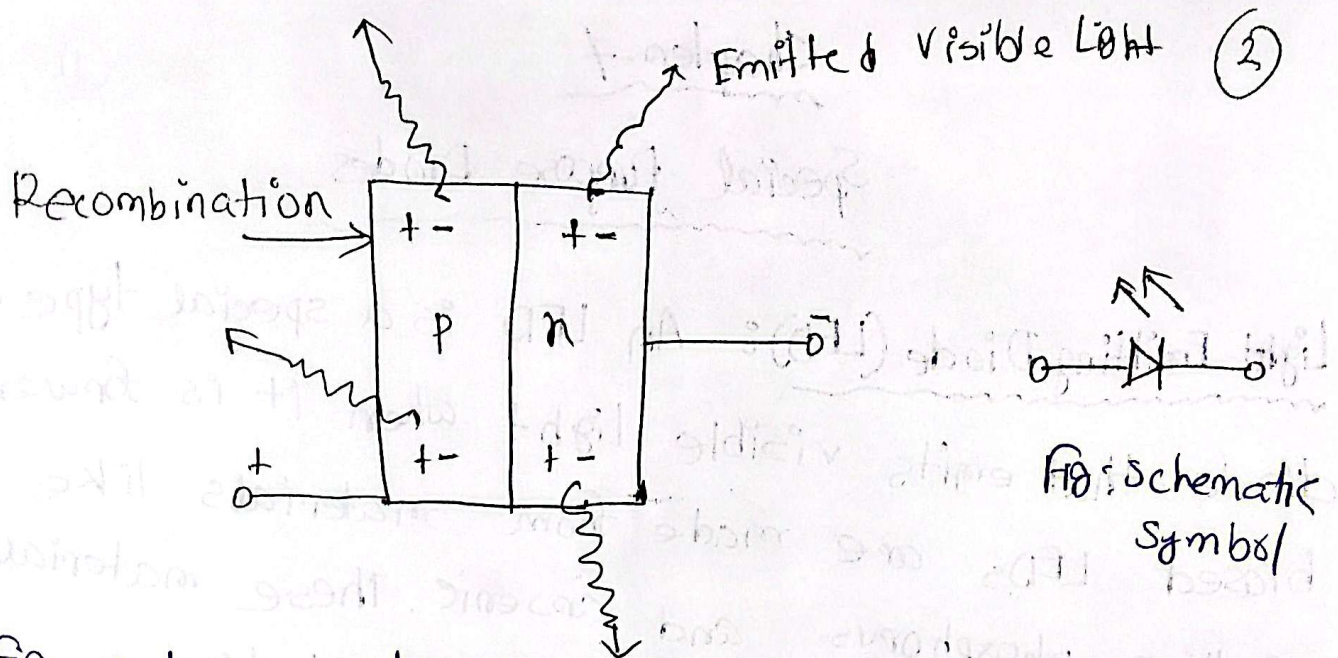
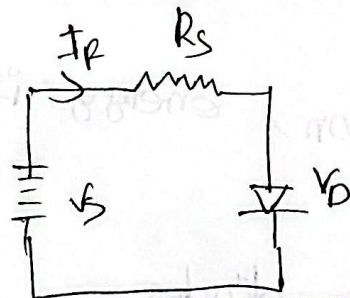
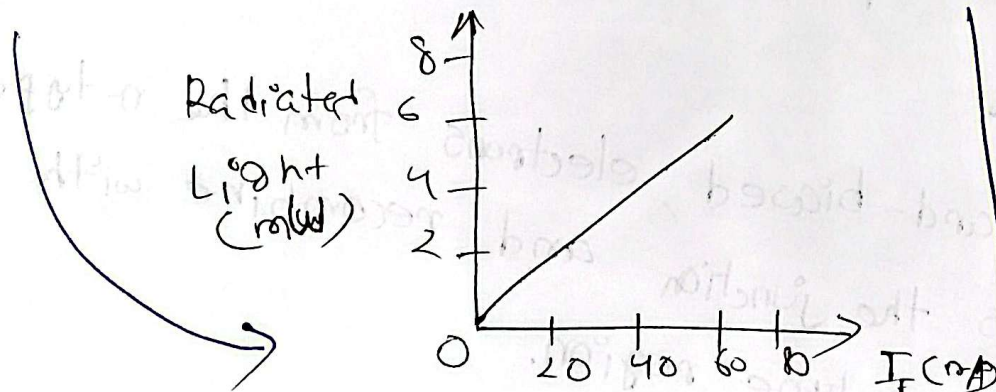


Fig: n type materials cross the pn junction.

Light intensity is directly proportional to the forward current.



voltage across current, I_F

$$R_S = \frac{V_S - V_D}{I_F}$$

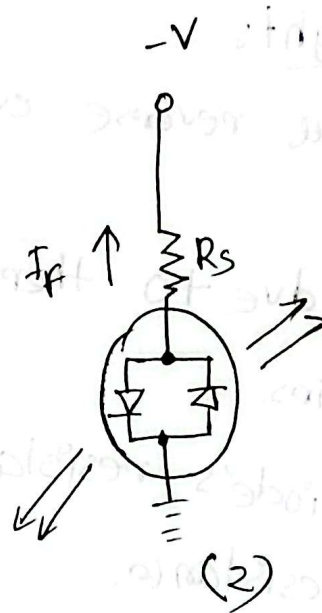
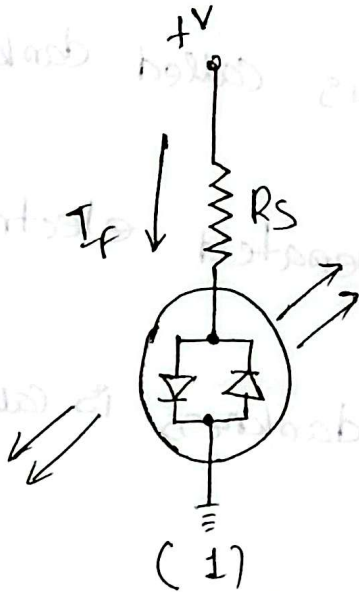
$$I_F = \frac{V_S - V_D}{R_S}$$

Advantages,

- ① Low voltage
- ② Longer life (more than 20 years)
- ③ Fast-on off switching

Multicolour LED: A LED that emits one colour when forward biased and another colour when reverse biased is called a multicolour LED. (3)

→ It actually contains two pn junctions that are connected in reverse-parallel (anode of one to cathode of the other).



Working Principles

→ Forward bias: current flows through junction 1
- emits colour (red).

→ Reverse bias: current flows ~~thru~~ through junction 2 → emits colour (green).

→ Fast switching: It will produce a yellow light when rapidly switched back and forth between biasing ~~pot~~ polarities.

Photo-diode:

(4)

→ A photo-diode is a reverse-biased pn junction diode made from silicon or germanium, where reverse current increases with light exposure.

Working Principle:

1. Without Light:

- Very small reverse current flows called dark current.
- This is due to thermally generated electron hole pairs.
- The diode's resistance in darkness is called dark resistance.

2. With Light:

- Photons hit the pn junction.
- They give energy to atoms, creating more free electrons and holes.
- This causes an increase in reverse current.

3. As Light intensity increases:

- More electrons are generated.

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→ Reverse current increases, up to a saturation point.

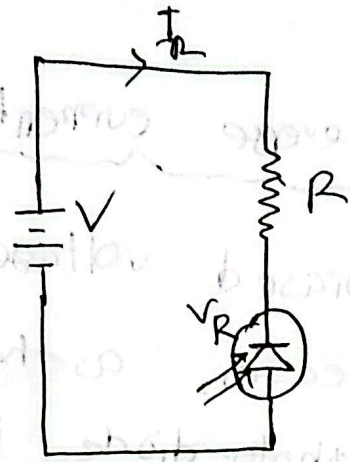


Fig: photo-diode circuit.

Characteristics:

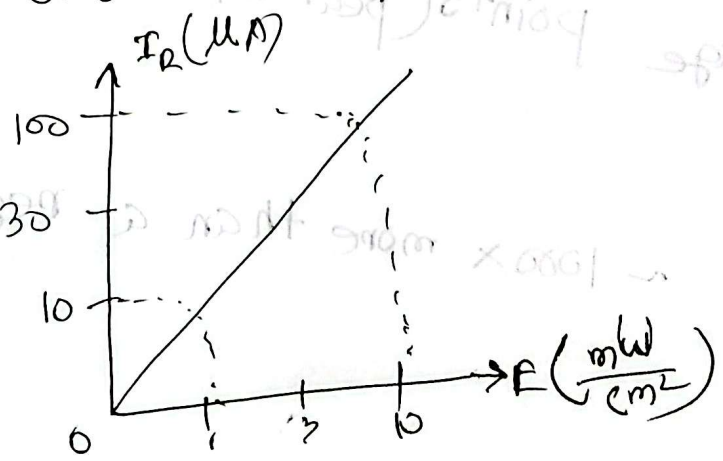
1. Reverse current vs Illumination curve:

→ Reverse current (I_R) is directly proportional to light intensity (E):

$$I_R = mE$$

m = slope of the straight line.

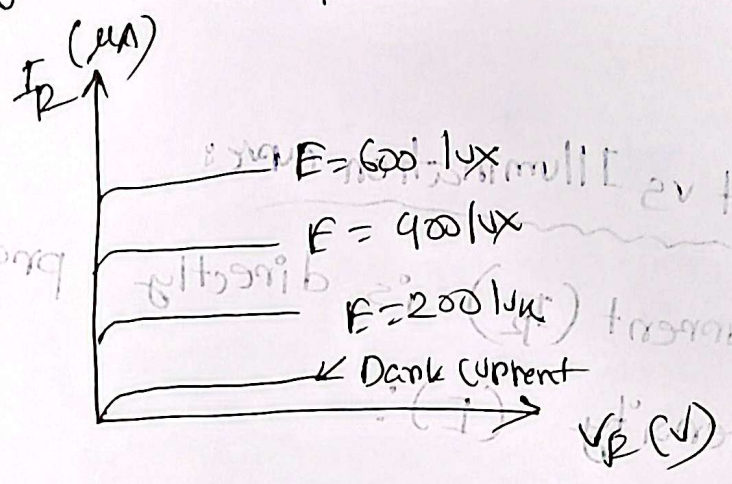
Note that the graph is a straight line passing through the origin.



The quantity m is called the sensitivity of the photo diode.

2. Reverse voltage vs Reverse current Curve

→ For a given reverse biased voltage V_R , the reverse current increases as the illumination (E) on the pn junction of photo-diode increased.

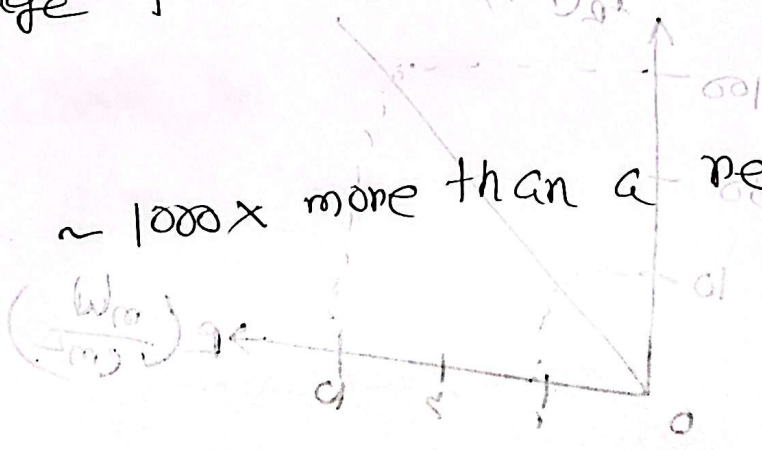


□ Tunnel Diode

→ A tunnel diode is a highly doped pn junction diode that shows negative resistance between two voltage points (peak and valley).

⑥ Doping

→ Doped $\sim 1000 \times$ more than a regular diode.

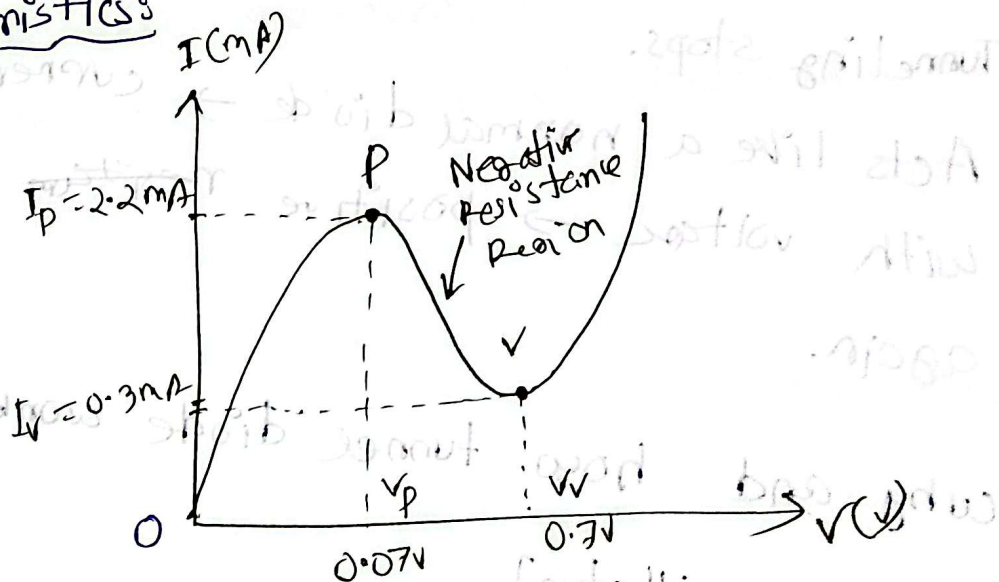


- (7)
- This makes the depletion layer extremely narrow
 - 100x narrower than normal diodes

→ Tunneling Effects

- Due to high doping, electrons can move directly from the valence band to the conduction band without gaining extra energy.
- The phenomenon is called tunneling.
- Enable conduction with very small forward voltage.

V-I characteristics



1. 0 to Peak Point (P)

- As forward voltage increases → tunneling starts →

(8)

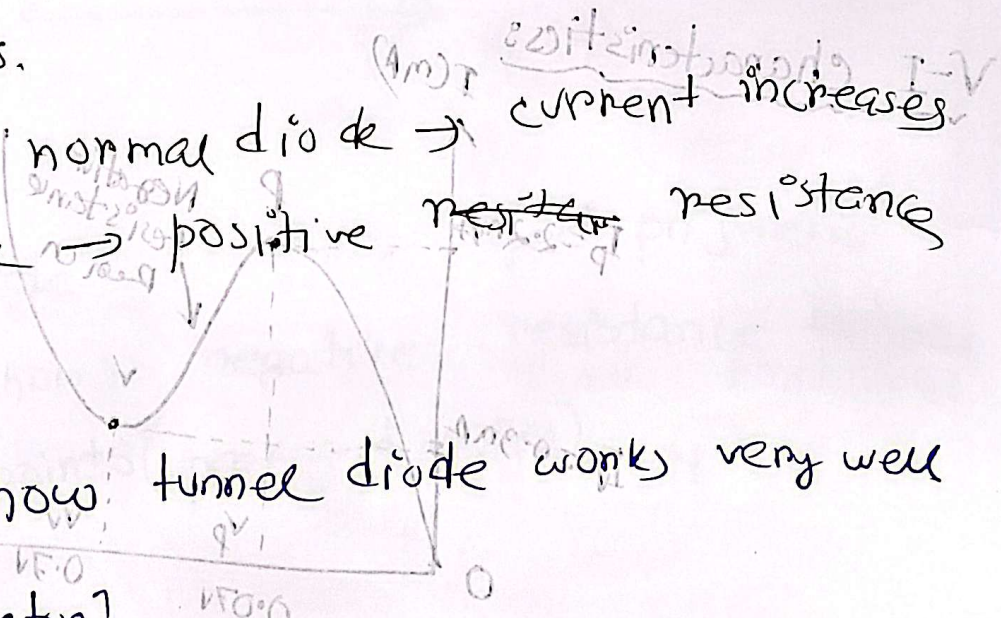
- current rises rapidly
- Reaches peak current (I_p) at peak voltage (V_p) — positive Resistance.

2. Peak to valley:

- Increase in voltage reducing tunneling → current decreases.
- Reaches valley current at valley voltage (V_v) — negative Resistance.

3. Beyond valley points

- Tunneling stops.
- Acts like a normal diode → current increases with voltage → positive resistance again.



□ why and how tunnel diode works very well in an oscillator?

A tunnel diode Oscillator is an electric circuit that generates high-frequency

Oscillations using the negative resistance property⁽²⁾ of a tunnel diode.

Why Tunnel diodes are ideal for Oscillators:

1. Negative Resistance Property:

→ Unlike normal resistors, a tunnel diode has a region where:

* Voltage $\uparrow \rightarrow$ Current $\downarrow$

* This 'negative resistance' cancel out losses in an LC Tank circuit.

2. Extremely Fast Switching:

→ Operates via quantum tunneling.

→ Works at GHz frequencies. (faster than transistor)

3. Simple Circuit Designs

→ NO need for complex biasing.

→ Just LC Tank + tunnel diode is sufficient.

4. Low Noise & High Stability:

→ Minimal thermal noise. (good for sensitive PF)

How it works as a Oscillator: (10)

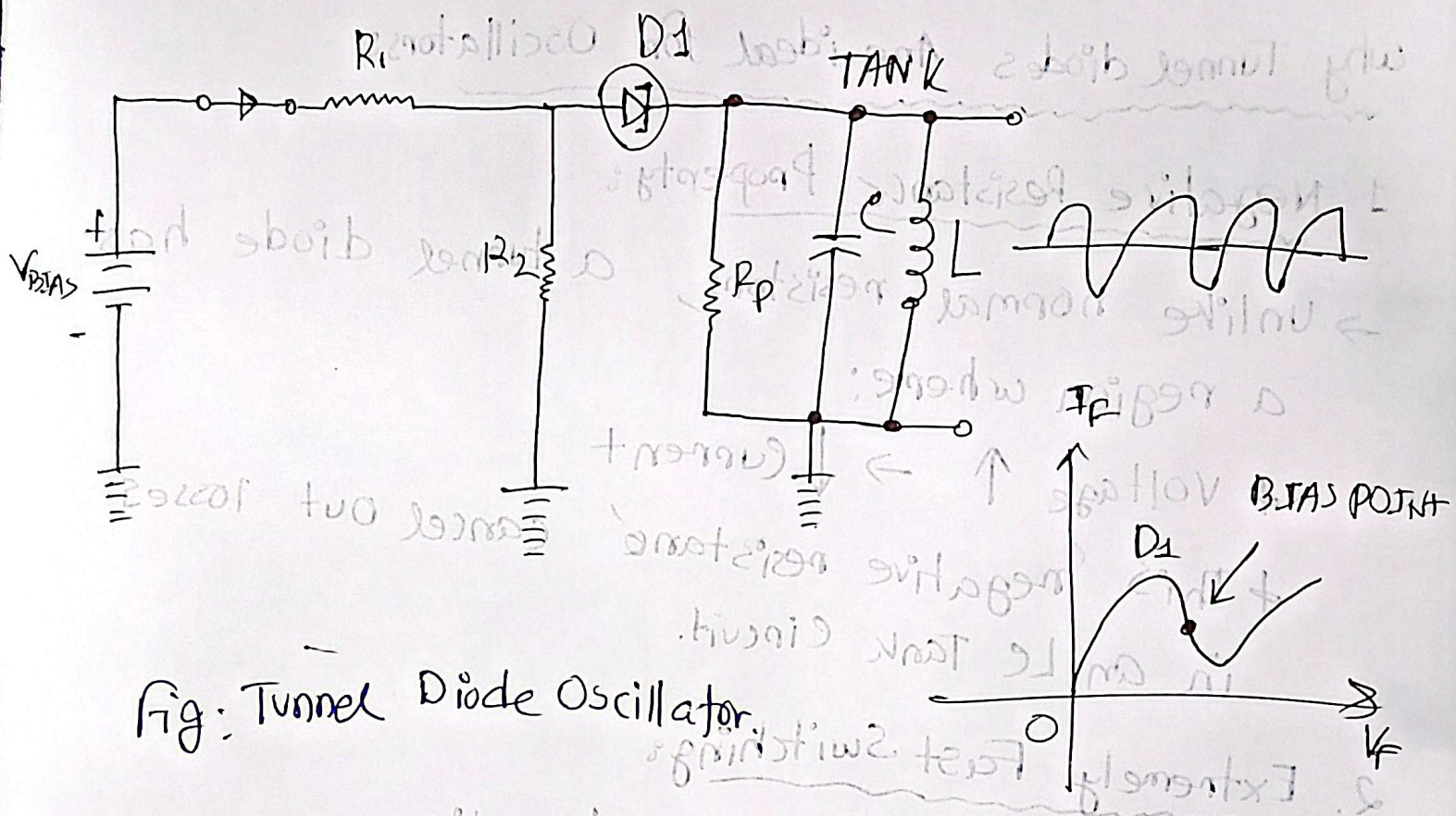


Fig: Tunnel Diode Oscillator.

1. LC Tank Circuit Generates Oscillations:

→ An inductor (L) + capacitor (C) naturally resonates

at:

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

→ But due to parasitic resistance (R_p), oscillations

die out (damped).

2. Tunnel Diode Biased in Negative Resistance Region (11)

- A small DC bias resistance
- When biased in the negative region, the tunnel diode reduces current as voltage increases.
- This behaviour counteracts energy loss in the circuit, maintaining continuous oscillations.

3. Sustained Oscillations:

- Negative resistance ($-R$) cancels positive resistance ($+R$) of the tank circuit.
- Net resistance $\approx 0 \rightarrow$ NO energy loss
- Undamped Oscillations.

4. Output signal:

- Continuous sine wave at resonant frequency f_r .

Chapter-8

Transistors

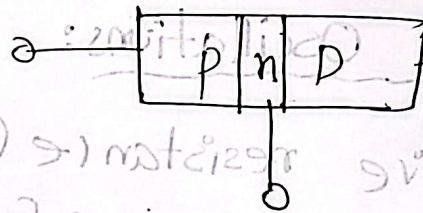
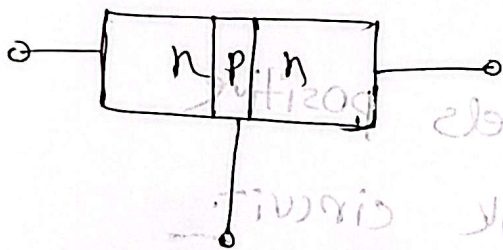
(12)

→ A transistor is a semiconductor device used to amplify or switch electric signals and power.

There are two types of transistors:

(i) n-p-n

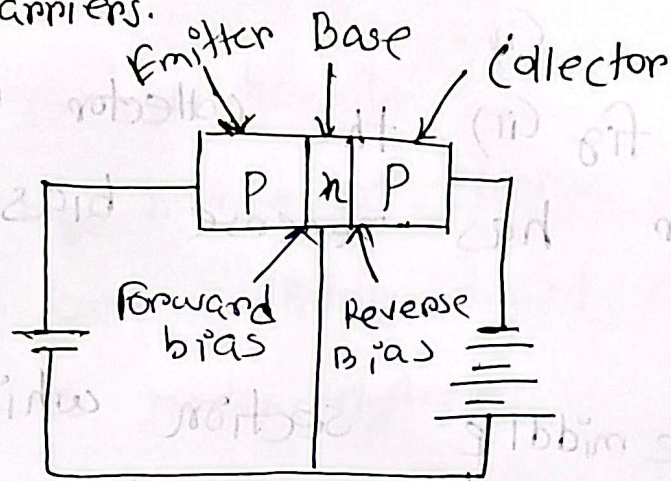
(ii) p-n-p



Naming the transistor Terminals:

A transistor (npn or pnp) has three sections of doped semiconductors. The section on one side is the emitter and the section on the opposite side is the collector. The middle section is called the base and forms two junction between the emitter & collector.

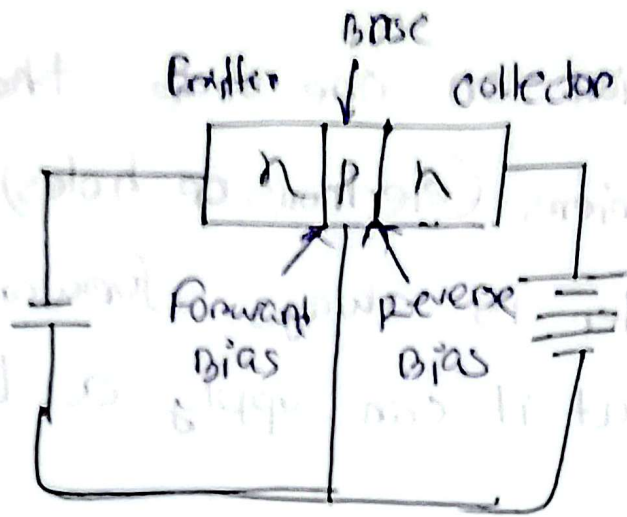
(i) Emitter: The section on one side ~~the~~ that (13) supplies charge carriers (electrons or holes) is called emitter. The emitter is always forward biased w.r.t. base so that it can supply a large number of majority carriers.



(i) In Fig (i), the emitter (p-type) of pnp transistor is forward biased and supplies hole charges to its junction with the base.

(ii) Collector: The section on the other side that collects the charges is called the collector. The collector is always reverse biased. Its function is to remove charges from its junction with the base.

(14)



Similarly in fig (ii) the collector (p-n-type) of an n-p-n transistor has reverse bias and receive electrons.

(iii) Base The middle section which forms two p-n junctions between the emitter and collector is called the base. The base-emitter junction is forward biased, allowing low resistance. The base-collector junction is reverse biased and provides high resistance.

Some facts / characteristics about Transistors (15)

- The transistor has three regions, namely: emitter, base and collector. The base is much thinner than the emitter while collector is wider than both.
- The emitter is ~~light~~ heavily doped so that it can 'inject' a large number of charge carriers into the base. The base is lightly doped, and very thin. The collector is moderately doped.
- The transistor has two pn junctions i.e. it is like two diodes. The junction between emitter and base may be called emitter-base diode. The junction between the base and collector may be called collector-base diode.
- The emitter diode is always forward biased whereas collector diode is always reverse biased.
- The resistance of emitter diode is very small as compared to collector diode.

Therefore, the forward bias applied to the emitter diode is generally very small whereas reverse bias on the collector diode is much higher.

Transistor Action:

nnp Transistor: An npn transistor is a type of Bipolar Junction Transistor (BJT) that amplifies current or acts as a switch. It consists of three semiconductor layers: two n-type (negative) regions and one p-type (positive) region in the middle.

Terminals of an npn Transistor:

1. Emitter (n-type): Heavily doped, emit electrons.
2. Base (p-type): Lightly doped, controls electron flow.
3. Collector (n-type): Moderately doped, collect electrons.

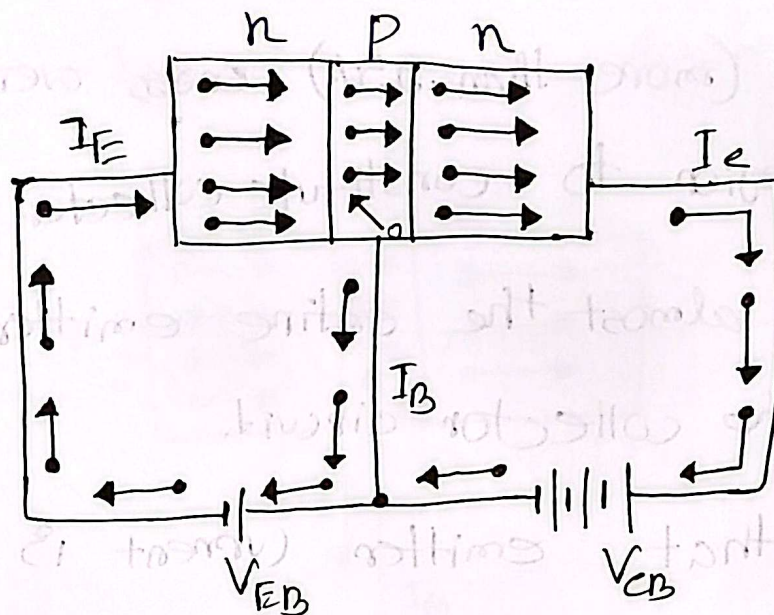


Fig: Basic Connection of npn transistor.

Working Principle:

- The figure shows the npn transistor with forward bias to emitter-base junction and reverse bias to collector-base junction.
- Due to forward bias, electrons from the n-type emitter move into the p-type base.
- This flow of electrons constitutes the Emitter current (I_E).
- As electrons enter the thin and lightly doped base, some (less than 5%) recombine with holes.
- This recombination produces a small Base current (I_B).

→ Most electrons (more than 95%) cross over into the collector region to constitute collector current (I_C)

→ In this way, almost the entire emitter current flows in the collector circuit.

→ It is clear that emitter current is the sum of collector and base current.

$$I_E = I_B + I_C$$

Pnp transistor: A Pnp transistor is a type of Bipolar Junction Transistor (BJT) that amplifies current or acts as a switch. It consists of three region semiconductor layers: two p-type (positive) regions and one n-type (negative) region in the middle.

Terminals of an pnp Transistor:

1. Emitter (p-type): Heavily doped
2. Base (n-type): very thin, and lightly doped.

3. Collector (p-type) : Moderately doped.

(19)

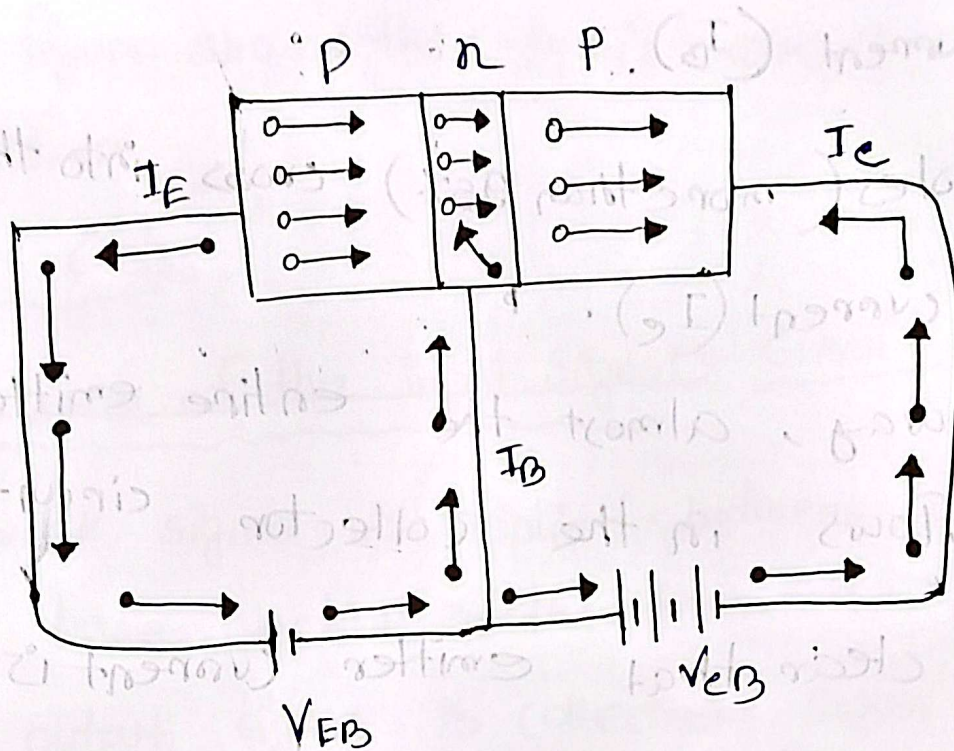


Fig: Basic Connection of pnp transistor.

Working Principles

- The figure shows the basic connection of a pnp transistor.
- Forward bias on the EBJ pushes holes from the p-type emitter into the n-type base.
- This hole flow constitutes the emitter current (I_E).
- Some holes (less than 5%) recombine with electrons in the n-type base.

→ This small recombination current forms the base current (I_B).

→ Most holes (more than 95%) cross into the collector current (I_C).

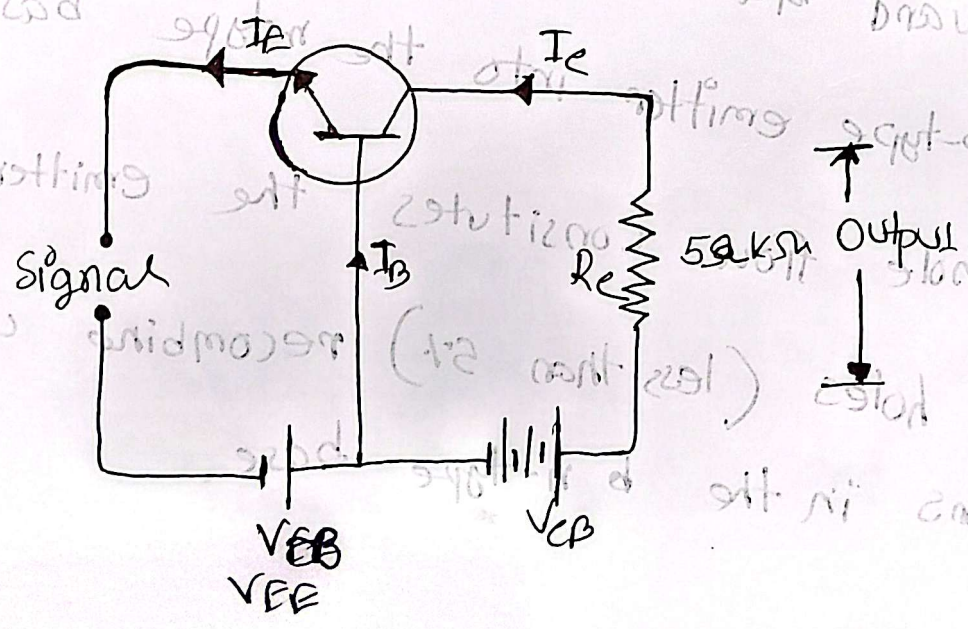
→ In this way, almost the entire emitter current flows in the collector circuit.

→ It is clear that emitter current is the sum of collector and base current.

$$I_E = I_B + I_C$$

Transistor circuit as an Amplifier:

A transistor raises the strength of a weak signal and thus acts as an amplifier.



How it works: acts:

(21)

→ The figure shows the basic circuit of a transistor amplifier.

How it acts:

1. Application of the input signal's circuit setup:

→ A weak signal is applied between the emitter and base junction of the transistor.

→ The output signal is collected across the load resistor (R_L) in the collector circuit.

→ A DC bias voltage V_{EE} is applied to the input to keep the emitter-base junction forward biased at all times.

2. Importance of Biasing:

→ The bias voltage V_{EE} ensures the transistor stays in the active region, regardless of signal polarity.

→ This condition is necessary for faithful amplification.

3. Low Resistance in Input Circuits

→ The input circuit (base-emitter) has low resistance.

→ Even a small variation in signal voltage causes a noticeable change in emitter current I_E .

4. Transistor Action - Current Control

→ Due to transistor action, a change in emitter current results in an almost equal change in collector current I_C .

→ This is because $I_C \approx I_E$

5. Voltage Gain at the Output

→ The collector current I_C flows through the high load resistor R_L .

→ A small increase in collector current cause a large voltage drop across R_L , producing a large output voltage.

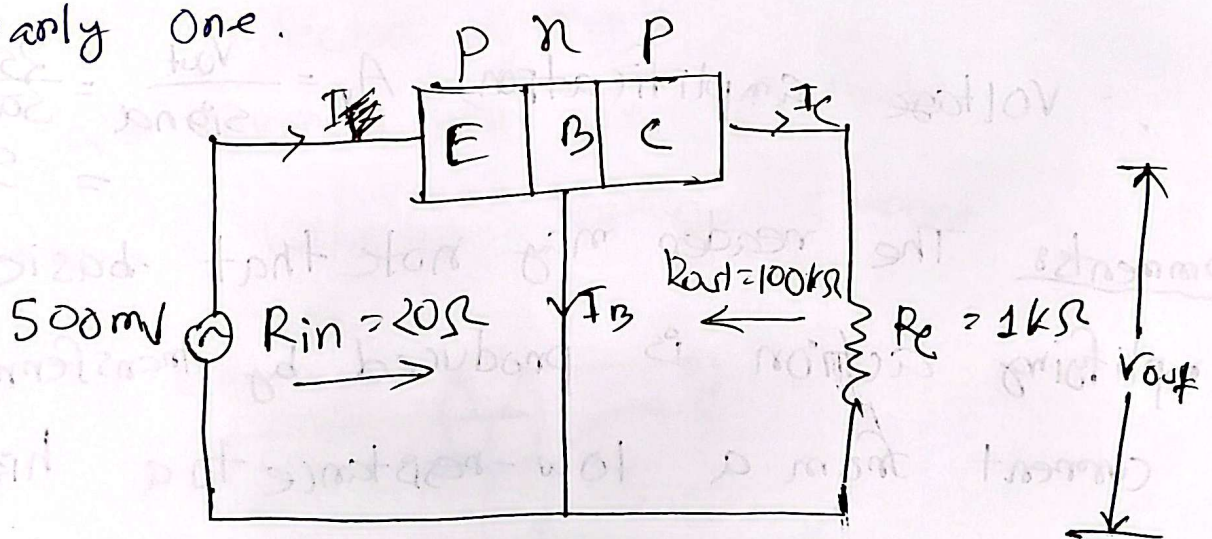
→ This voltage is the amplified output signal.

6. Final Result - Amplified Signal ::

→ A weak signal applied in the input circuit appears in the amplified form in the collector circuit.

→ It is in this way that a transistor acts as an amplifier.

Example 8.1: A common base transistor amplifier has an input resistance of 20Ω and output resistance is $1k\Omega$. If a signal of $100k\Omega$. The collector load is $1k\Omega$. If a signal of $500mV$ is applied between emitter and base, find the voltage amplification. Assume α_{ac} to be nearly one.



⇒ The figure shows the conditions of the problem. Note that output resistance is very high as compared to input resistance. This is not surprising because input junction (base to emitter) of the transistor is forward biased while the output junction is reverse biased.

$$\text{Input current, } I_E = \frac{\text{Signal}}{R_{in}} = \frac{500 \text{ mV}}{20 \Omega} = 25 \text{ mA}$$

Since α_{ac} is nearly 1, output current $I_C = I_E = 25 \text{ mA}$

$$\text{Output voltage, } V_{out} = I_C R_C = 25 \text{ mA} \times 1 \text{ k}\Omega = 25 \text{ V}$$

$$\therefore \text{voltage amplification, } A_v = \frac{V_{out}}{\text{Signal}} = \frac{25 \text{ V}}{500 \text{ mV}} = 50$$

Comments: The reader may note that basic amplifying action is produced by transferring a current from a low-resistance to a high-resistance circuit. The name Transistor is come

from combining the two terms given in below (25)

Transfer + Resistor $\rightarrow$ Transistor

Common Base Connections

* Expression for collector current

The whole emitter current does not reach the collector. As the collector-base junction is reverse biased, therefore some leakage current flows due to minority carriers.

$$\rightarrow \text{Total collector current, } I_C = \alpha I_E + I_{\text{Leakage}}$$

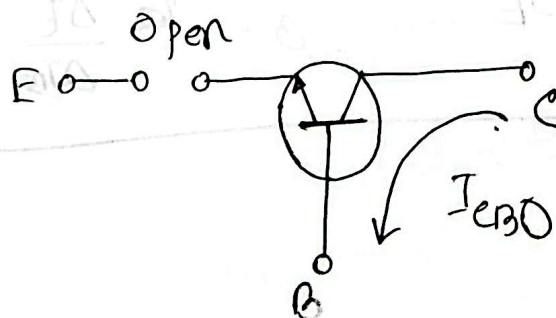
Here,

I_E = emitter current

I_C = collector current

α = current gain in CB mode.

I_{Leakage} = collector leakage current



Now,

$$I_E = I_C + I_B$$

$$I_C = \alpha (I_C + I_B) + I_{leakage}$$

If $I_E = 0$ a small leakage current still flows in the collector circuit. This $I_{leakage}$ is abbreviated as I_{CBO} meaning collector-base current with emitter open.

$$I_C = \alpha I_E + I_{CBO}$$

$$I_E = \beta I_B + I_{CEO}$$

Now,

$$I_E = I_C + I_B$$

$$\therefore I_C = \alpha (I_C + I_B) + I_{CBO}$$

$$\therefore I_C(1-\alpha) = \alpha I_B + I_{CBO}$$

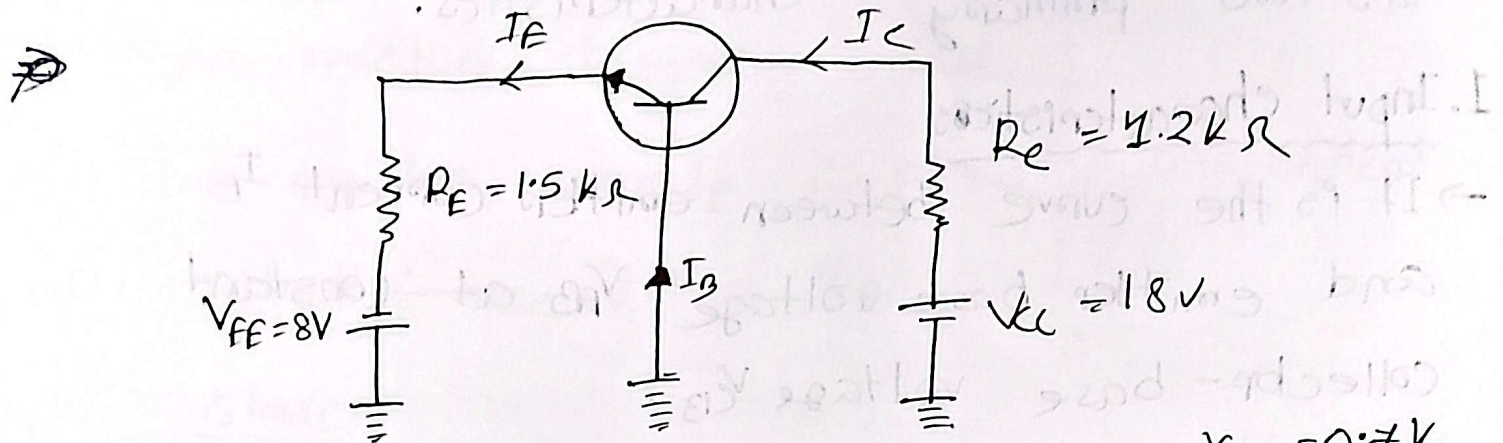
$$\therefore I_C = \frac{\alpha}{1-\alpha} I_B + \frac{I_{CBO}}{1-\alpha}$$

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

$$I_C = \alpha I_E$$

$$\beta = \frac{\Delta I_C}{\Delta I_B}$$

Example: 8.7 For the common base circuit, (27)
 shown in Fig. Determine I_E , V_{CB} . Assume the
 transistor to be of silicon.



Since the transistor is of silicon, $V_{BE} = 0.7V$.
 Applying KVL to the emitter side loop,
 we get,

$$V_{EE} = I_E R_E + V_{BE}$$

$$\Rightarrow I_E = \frac{V_{EE} - V_{BE}}{R_E}$$

$$= \frac{8 - 0.7}{1.5 k\Omega} = 4.87 mA \quad (Ans.)$$

$$\therefore I_C \approx I_E = 4.87 mA$$

Applying KVL to the collector side loop, we get
 $V_{CC} = I_C R_C + V_{CB} \Rightarrow V_{CB} = 18V - (4.87 \times 1.2 k\Omega)$
 $= 12.16V \quad Ans.$

Characteristics of Common Base Connection:

A common-base (CB) transistor configuration has two primary characteristics.

1. Input characteristics:

→ It is the curve between emitter current I_E and emitter base voltage V_{EB} at constant collector-base voltage V_{CB} .

→ The emitter current is generally taken along y-axis and emitter base voltage along x-axis.

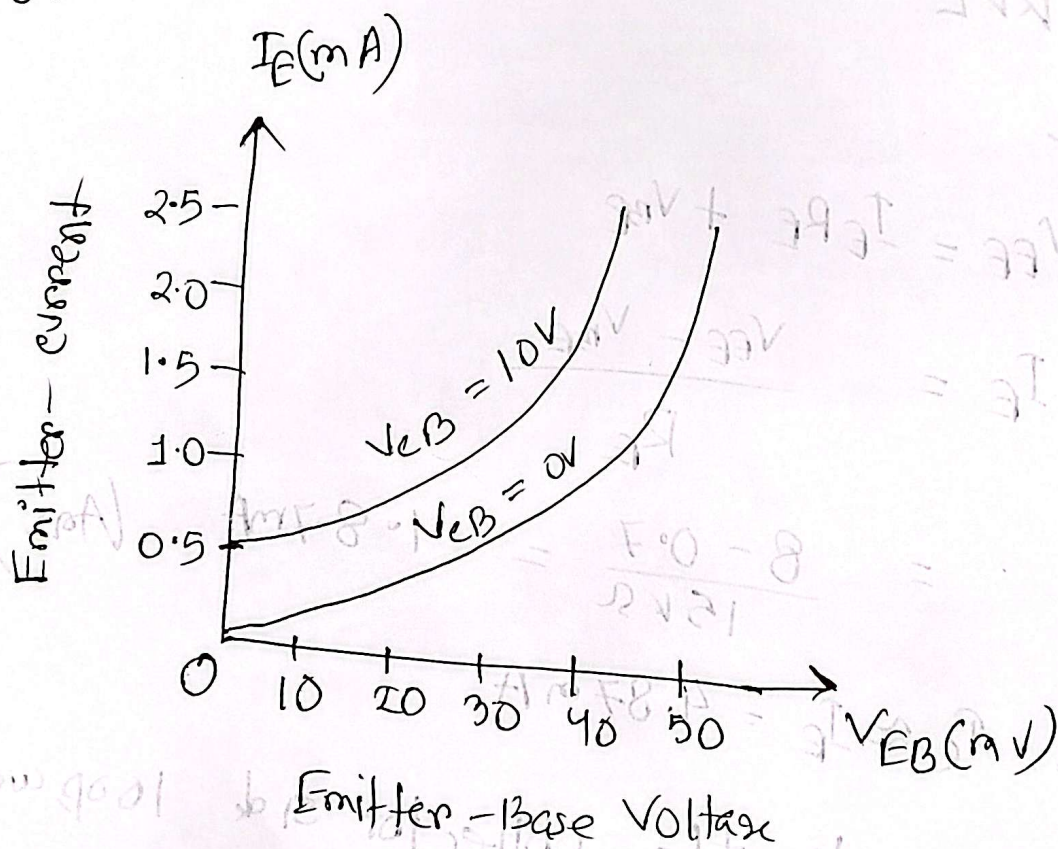


Fig. 2: Input characteristics in CB arrangement.

➤ Following characteristics

- The emitter current I_E increases rapidly with small increase in emitter-base voltage V_{EB} .
- Input resistance is very small.
- The emitter current I_E is almost independent of collector-base voltage V_{CB} .

Input resistance

- It is the ratio of change in emitter-base voltage (ΔV_{EB}) to the resulting change in emitter current (ΔI_E) at constant collector-base voltage (V_{CB}) (i.e.)

Input resistance, $r_i = \frac{\Delta V_{EB}}{\Delta I_E}$ at constant V_{CB} .

2. Output Characteristics:

- It is the curve between collector current I_C and collector-base voltage V_{CB} at constant emitter current I_E .
- Generally, collector current I_C is taken along y-axis and collector base voltage along x-axis.

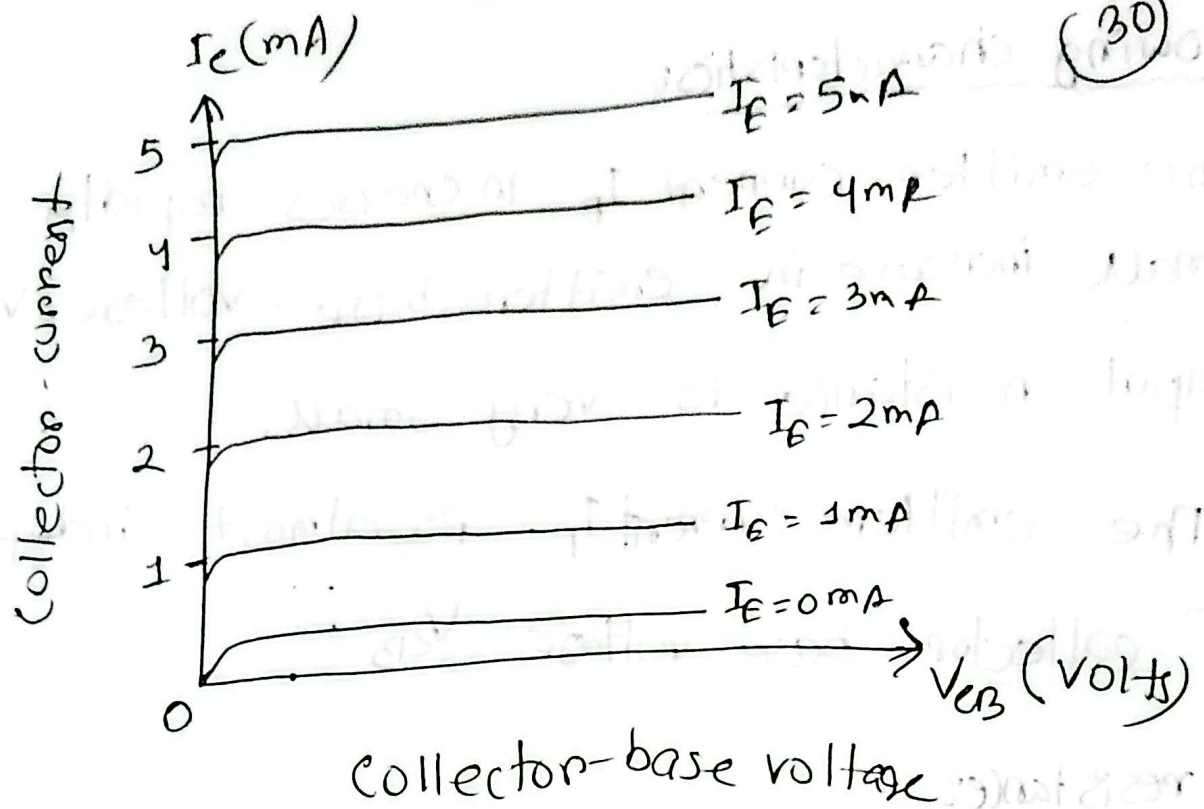


Fig: Output characteristics in CB arrangement.

Following characteristics:

- The collector current I_C varies $\propto$ with V_{CB} only at very low voltages ($< 1 \text{ V}$).
- When the value of V_{CB} is raised above $1-2 \text{ V}$, the collector current I_C becomes constant, indicated as straight horizontal curves.
- I_C is independent of V_{CB} and depends only on I_E , confirming $I_C \approx I_E$.

→ Output Resistance is very high.

Output Resistance:

(31)

→ It is the ratio of change in collector-base voltage (ΔV_{CB}) to the resulting change in collector current (ΔI_C) at constant emitter current (I_E) i.e.

$$\text{Output resistance, } r_o = \frac{\Delta V_{CB}}{\Delta I_C} \text{ at constant } I_E$$

→ The output resistance of CB circuit is very high.

Relation between β and α :

The current gain of a transistor is represented by two parameters:

1. α (alpha): Common-base current gain, which is the ratio of collector current to emitter current.

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

2. β (beta): Common-emitter current gain, which is the ratio of collector current to base current.

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

Relation between α & β :

A simple relation exists between α & β . This can be derived as follows:

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \quad \text{--- (i)}$$

$$\beta = \frac{\Delta I_C}{\Delta I_B} \quad \text{--- (ii)}$$

Now,

$$I_E = I_C + I_B$$

$$\text{or, } \Delta I_E = \Delta I_C + \Delta I_B$$

$$\text{or, } \Delta I_B = \Delta I_E - \Delta I_C$$

Substituting the value of ΔI_B in exp. (ii) we get,

$$\beta = \frac{\Delta I_C}{\Delta I_E - \Delta I_C} \quad \text{--- (iii)}$$

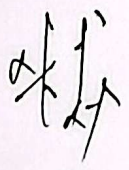
Dividing the numerator and denominator of

R.H.S. of exp. (iii) by I_E , we get,

$$\beta = \frac{\Delta I_C / \Delta I_E}{\frac{\Delta I_C}{\Delta I_E} - \frac{\Delta I_E}{\Delta I_E}} = \frac{\alpha}{1 - \alpha}$$

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

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



Characteristics of Common-emitter Connections

The important characteristics of this circuit arrangement are the input characteristics and output characteristics.

1. Input Characteristics

- It is the curve between base current I_B and base-emitter voltage V_{BE} at constant collector-emitter voltage V_{CE} .
- The base current I_B is taken along y-axis, and base-emitter voltage V_{BE} along x-axis.

fig. 22.2(a)

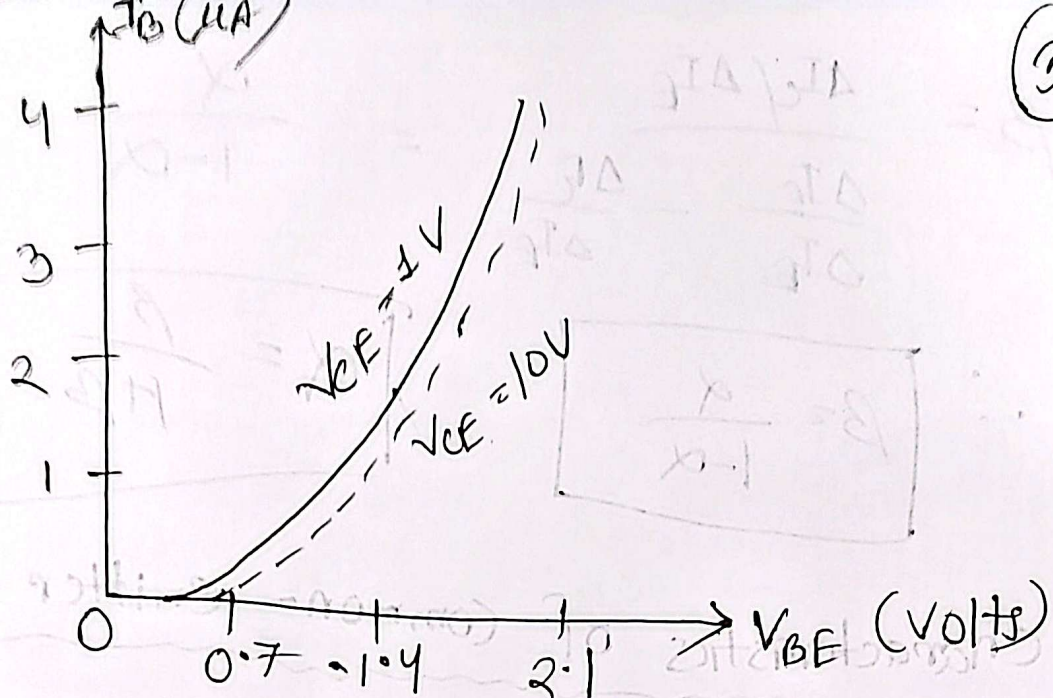


Fig: Input characteristics in CE Arrangement.

Following characteristics:

- The curve resembles a forward-biased diode, as the base-emitter junction is a diode.
- I_B increases less rapidly with V_{BE} , so input resistance is higher than in EB circuit.

Input resistance:

- It is the ratio of change in base-emitter voltage (ΔV_{BE}) to the resulting change in base current (ΔI_B) at constant V_{CE} i.e.

Input resistance, $r_i = \frac{\Delta V_{BE}}{\Delta I_B}$ at constant V_{CE}

2. Output characteristics:

→ It is the curve between collector current I_C and collector-emitter voltage V_{CE} at constant base current I_B .

→ The collector current (I_C) is taken along y axis and the collector-emitter voltage (V_{CE}) taken along x axis.

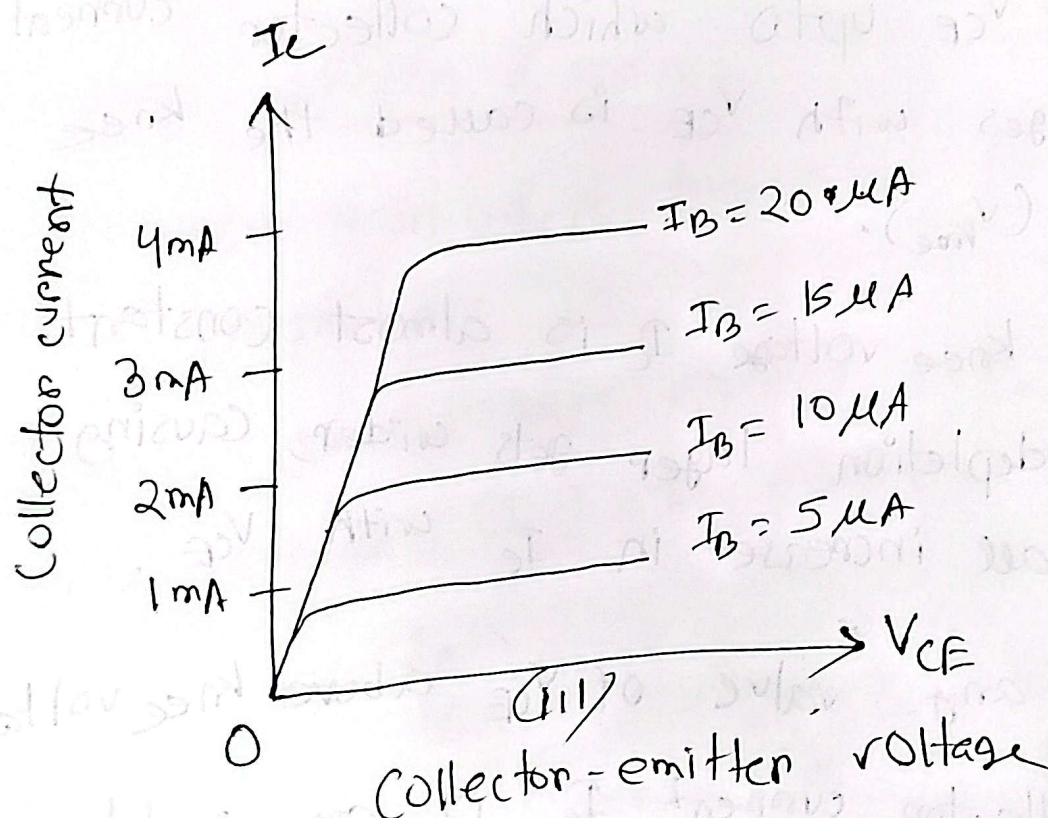
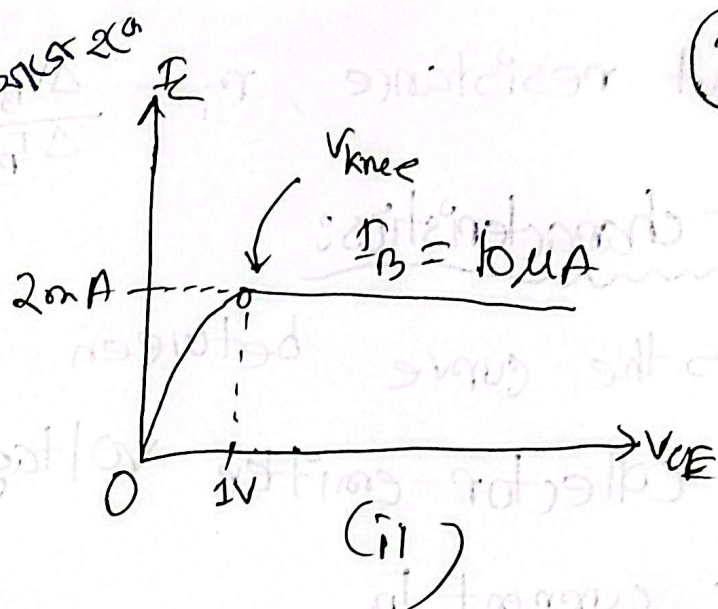
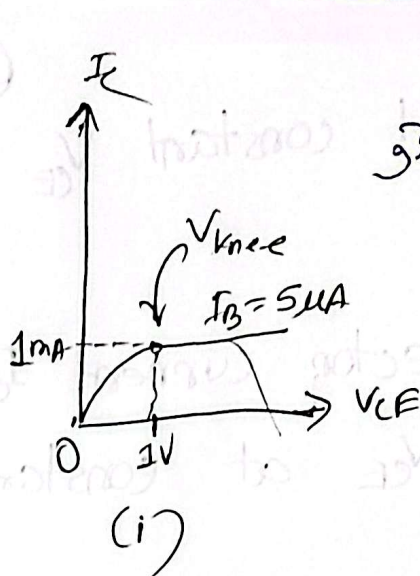


Fig: Output characteristics in CE arrangement



Following characteristics:

- The collector current I_C varies with V_{CE} for V_{CE} between 0 and 1V only. This value of V_{CE} upto which collector current I_C changes with V_{CE} is called the knee voltage (V_{knee}).
- Above knee voltage, I_C is almost constant. The depletion layer gets wider, causing a small increase in I_C with V_{CE} .
- For any value of V_{CE} above knee voltage, the collector current I_C is approximately equal to $\beta \times I_B$.

Output Resistance:

(37)

→ It is the ratio of change in collector-emitter voltage (ΔV_{CE}) to the resulting change in collector current (ΔI_C) at constant I_B i.e.

$$\text{Output resistance, } r_o = \frac{\Delta V_{CE}}{\Delta I_C} \text{ at constant } I_B$$

→ The Output resistance of a CE circuit is less than ~~that~~ CB circuit. Its value is of the order of $50\text{ k}\Omega$.

Relation between γ and α :

The current gain of a transistor is represented by two parameters:

1. α (alpha): common-base current gain, ratio of collector current (I_C) to emitter current (I_E).

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

2. γ (Gamma): common-collector current gain, ratio of emitter current (I_E) to base current (I_B)

$$\therefore \gamma = \frac{I_E}{I_B}$$

Relations

A simple relation exists between α and γ .

This can be derived as follows:

$$\gamma = \frac{\Delta I_E}{\Delta I_B} \quad \text{--- (i)}$$

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \quad \text{--- (ii)}$$

Now,

$$I_E = I_B + I_C$$

$$\text{Or, } \Delta I_E = \Delta I_B + \Delta I_C$$

$$\text{Or, } \Delta I_B = \Delta I_E - \Delta I_C$$

Substituting the value of ΔI_B in exp. (i), we get

$$\gamma = \frac{\Delta I_E}{\Delta I_E - \Delta I_C} \quad \text{--- (iii)}$$

Dividing the numerator and dominator of R.H.S. by ΔI_E , we get -

$$\gamma = \frac{\Delta I_E / \Delta I_E}{\Delta I_E / \Delta I_E - \Delta I_C / \Delta I_E}$$

$\therefore \gamma = \frac{1}{1 - \alpha}$

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



Comparison of Transistor Connections

(39)

SL. No	Characteristic	Common base	Common emitter	Common collector
1.	Input resistance	Low (about 10Ω)	Low (about 750Ω)	Very high (about $750k\Omega$)
2.	Output resistance	Very high (about $450k\Omega$)	High (about $45k\Omega$)	Low (about 50Ω)
3.	Voltage gain	about 150	about 500	less than 1
4.	Applications	For high frequency applications	For audio frequency applications	For impedance matching
5.	Current gain	No (less than 1)	High (β)	Appreciable

Commonly used Transistor Connections:

(40)

The common emitter (CE) configuration is the most widely used transistor connection (used in 90-95% of applications) due to its superior performance.

1. High Current Gains

* Output Current: $I_C = \beta I_B + I_{CE0}$

* Since β is large (20-500), CE mode provides very high current amplification.

2. High Voltage & Power Gains:

* High current gain leads to high voltage & power gain.

* Ideal for amplification purposes.

3. Moderate output to input impedance Ratio

* Output impedance $\approx$ Input impedance ≈ 50 .

- This makes it suitable for stage coupling. (11)
- Efficient signal transfer between transistor stages.

□ How would you determine load line & operating point of a transistor.

⇒ 1. Determining the D.C. Load Line:

The load line is a graphical representation of all possible combinations of collector current (I_C) and collector-emitter voltage (V_{CE}) for a given transistor circuit under d.c. conditions (no input signal).

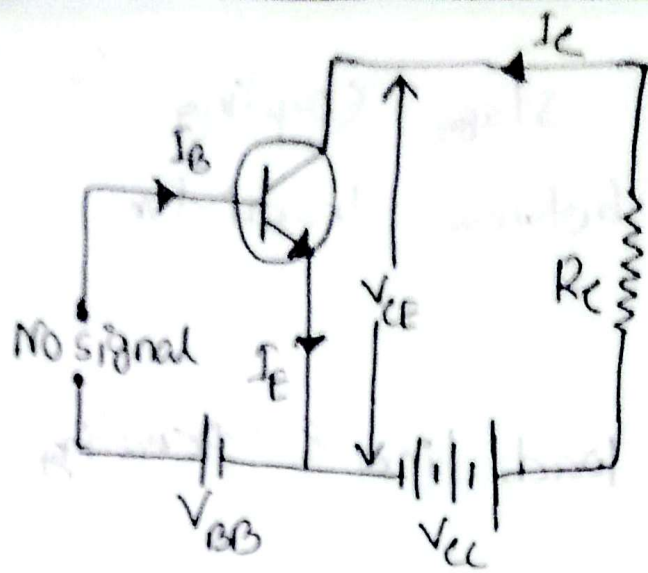
a. Write the Load Line Equation:

For a common-emitter npn transistor (as in Fig-1)

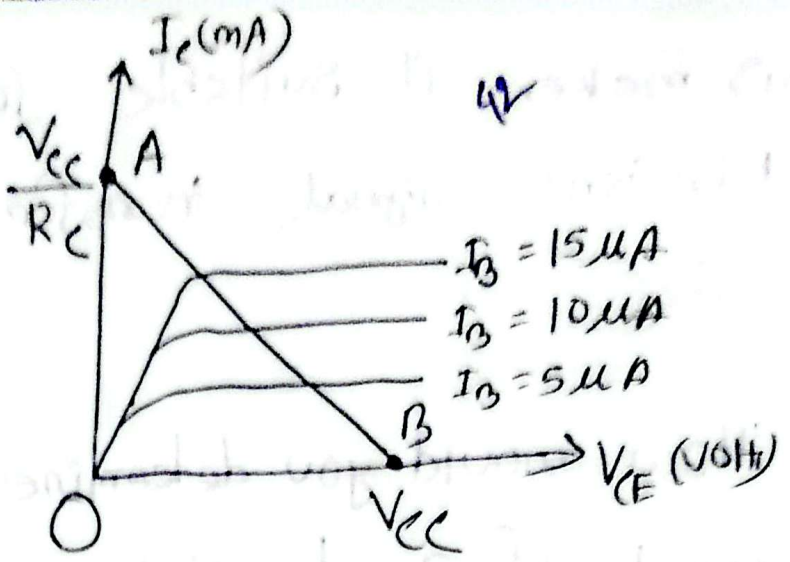
the relationship is derived from the collector-emitter loop: The output characteristics of this circuit are shown in Fig (2).

The value of collector-emitter voltage V_{CE} at any time is given by:

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



(i)



(ii)

b. Find Two Extreme Points to Plot the Load Lines

* Point A (Saturation Point) : When $V_{CE} = 0$:

$$I_C = \frac{V_{CC}}{R_C} \text{ (Maximum possible collector current)}$$

→ This point lies on the current axis (y-axis).

* Point B (Cutoff Point) : When $I_C = 0$:

$$V_{CE} = V_{CC} \text{ (Maximum possible collector-emitter voltage)}$$

→ This point lies on the voltage axis (x-axis).

c. Plot the Load Lines

→ Draw a straight line connecting Point A

($I_C = V_{CC}/R_C$, $V_{CE} = 0$) and Point B ($I_C = 0$,

$V_{CE} = V_{CC}$) .

→ This line is the d.c. load line (labeled AB in Fig 11)

2. Determining the Operating Point (Q-Point):

→ The zero signal values of I_C and V_{CE} are known as Operating point.

→ The Q-point is the zero signal operating condition of the transistor, defined by the intersection of the load line and the transistor's characteristic curve for a given base current (I_B).

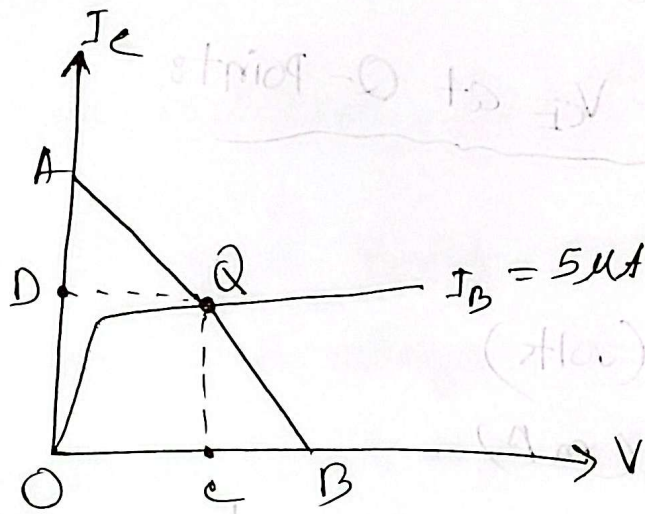


Fig: (i)

a. Determine base current

→ For fixed bias calculate I_B using

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

+ Example: If $I_B = 5 \mu A$, use this value to locate the Q point.

b. Locate the Q Point:

→ On the transistor's output characteristics graph (fig 1), identify the curve corresponding to $I_B = 5 \mu A$.

→ The intersection of this curve with the d.c. load line (AB) is the Q-point.

c. Extract I_C and V_{CE} at Q-Point

→ From fig (1),

$$V_{CE} = OQ \text{ (volts)}$$

$$I_C = OD \text{ (mA)}$$



These are zero signal values.

Therefore, the zero signal values of I_C and V_{CE} (i.e., operating point) are determined by the point where d.c. load line intersects the proper base current curve.

Performance of Transistor Amplifiers

45

The performance of a transistor amplifier depends upon input resistance, output resistance, effective collector load, current gain, voltage gain and power gain. Let's break them down clearly:

1. Input resistance: It is the ratio of small change in base-emitter voltage (ΔV_{BE}) to the resulting change in base-current (ΔI_B) at constant collector-emitter voltage i.e.

$$\text{Input resistance, } R_i = \frac{\Delta V_{BE}}{\Delta I_B}$$

The value of input resistance is quite small because the input circuit is always forward biased.

2. Output Resistance: It is the ratio of change in collector-emitter voltage (ΔV_{CE}) to the resulting change in collector current (ΔI_C) at constant base current i.e.

$$\text{Output resistance, } R_o = \frac{\Delta V_{CE}}{\Delta I_C}$$

3. Effective collector load: It is the total load.

as seen by the a.c collector current.
In case of single stage amplifiers, the effective collector load is parallel combination of R_c and R_o .

Effective collector load, $R_{Ac} = R_c \parallel R_o$

$$= \frac{R_c \times R_o}{R_c + R_o}$$
$$\approx R_c$$

For Multi stage Amplifier

Effective collector load, $R_{Ac} = R_c \parallel R_o \parallel R_i$

$$\approx R_c \parallel R_i$$

$$= \frac{R_c R_i}{R_c + R_i}$$

4. Current gain: It is the ratio of change in collector current (ΔI_c) to the change in base current (ΔI_b) i.e.

$$\text{Current gain, } \beta = \frac{\Delta I_c}{\Delta I_b}$$

5. Voltage gain: It is the ratio of change in output voltage (ΔV_{CE}) to the change in input voltage (ΔV_{BE}) i.e.

$$\begin{aligned} \text{Voltage gain, } A_V &= \frac{\Delta V_{CE}}{\Delta V_{BE}} \\ &= \frac{\Delta I_C \times R_{AC}}{\Delta I_B \times R_i} \\ &= \beta \times \frac{R_{AC}}{R_i} \end{aligned}$$

For single stage, $R_{AC} = R_C$

For multi stage, $R_{AC} = \frac{R_C \times R_i}{R_C + R_i} \rightarrow R_i$ is the input resistance of the next stage.

6. Power gain: It is the ratio of output signal power to the input signal power i.e.

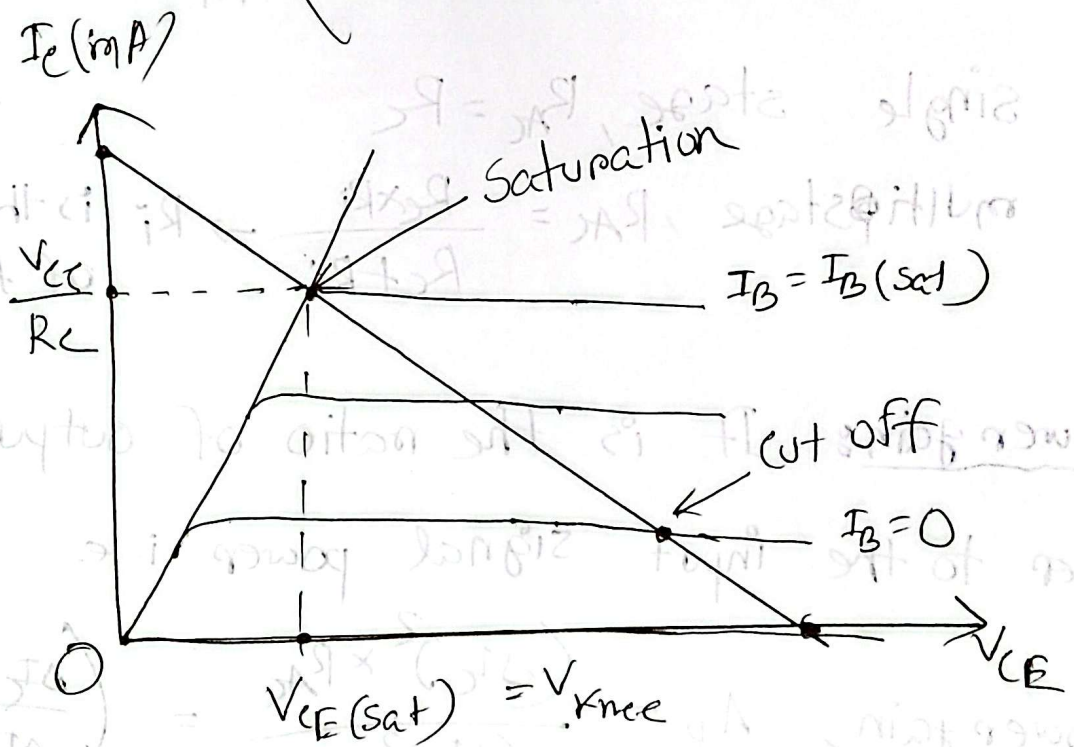
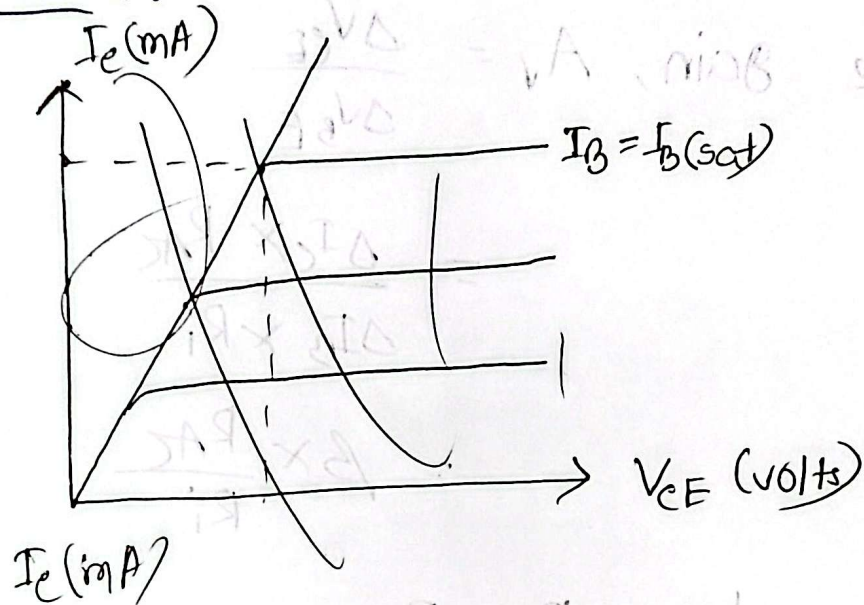
$$\text{power gain, } A_P = \frac{(\Delta I_C)^2 \times R_{AC}}{(\Delta I_B)^2 \times R_i} = \left(\frac{\Delta I_C}{\Delta I_B} \right) \times \frac{\Delta I_C \times R_{AC}}{\Delta I_B \times R_i}$$

= (current gain $\times$ voltage gain)

$$= \beta \times A_V$$

II Cutoff & Saturation Points

1. Cutoff State



→ Base current $I_B = 0$ (emitter diode off).

→ Collector-base current junction reverse-biased.

→ Only a tiny leakage current flows.

→ $V_{ce} = V_{cc}$

- Intersection of the load line and the $I_B = 0$ curve.
- Transistor acts as an open switch.

2. Saturation State:

- Base current $I_B \geq I_{B(sat)}$ (emitter and collector diodes are ON)
- Collector-base junction forward-biased.
- Collector current reaches maximum:

$$I_{C(sat)} = \frac{V_{CC}}{R_C} ; V_{CE} = V_{CE(sat)} = V_{Knee}$$
- Intersection of the load line and the $I_B = I_{B(sat)}$ curve
- Transistor acts as a closed switch.

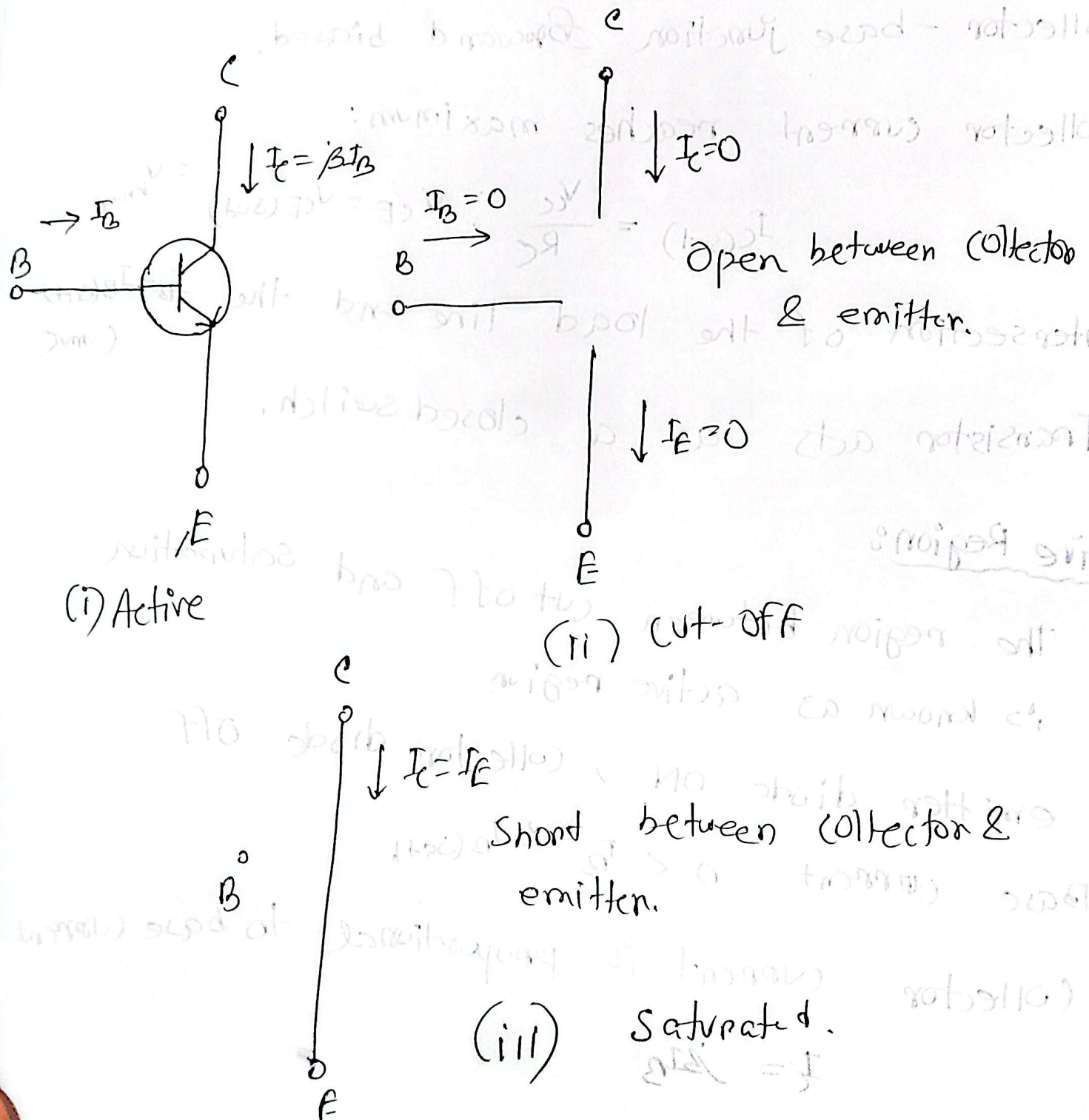
3. Active Region:

- The region between cut off and saturation is known as active region.
- emitter diode ON, collector diode OFF
- Base current $0 < I_B < I_{B(sat)}$
- Collector current is proportional to base current

$$I_C = \beta I_B$$

→ The graphical representation will be the region between cut-off and saturation on the load line.

→ Transistor acts as an amplifier.



Transistor VS Vacuum Tubes

511

Advantages of transistors

A transistor is a solid state device that performs the same functions as the grid-controlled vacuum tube.

(i) High voltage gain

- we can get much more voltage gain with a transistor than with a vacuum tube.
- Transistor can provide a voltage gain of 300 or more.
- Tube usually provide less than 75.

(ii) Lower supply voltage

- Vacuum tubes require much higher d.c. voltages than transistors.
- Transistors operate at low voltages (9V-12V).
- Tubes need high voltages (200V-400V).

(iii) NO heating Required 52

→ Transistors don't need heaters

→ Tubes require ~~heater~~ heating, waste power and have limited life.

(iv) @ Miscellaneous

→ Transistors are smaller than tubes

→ Stronger & Lightweight.

→ Easily integrated into ICs.

Disadvantages of Transistors

(i) Lower power dissipation

→ Most power transistors have power dissipation below 300W.

→ vacuum tubes can handle kilowatts - better for transmitters, microwaves.

(ii) Lower input impedance

→ A transistor has low input impedance.

→ Tubes have high input impedance because the control grid draws negligible current.

→ FETs solve this for transistors.

(iii) Temperature dependence:

→ Performance changes with temperature.

→ Tubes are more stable in varying temperature.

(iv) Inherent variation of parameters:

→ Transistor parameters (e.g., β) vary even in the same batch.

→ Tubes more consistent within a type.

Control

Chapter-19

5*

Field Effect Transistors

FET: Field Effect Transistor:

A FET is a type of transistor that uses voltage to control the flow of electricity. It is widely used in amplifiers and digital circuits due to its high impedance and low power consumption.

Key terms in FET:

- * Source(S): The terminal through which carriers enter the channel.
- * Drain(D): The terminal through which carriers leave the channel.
- * Gate(G): The control terminal that regulates the current flow between source & drain by creating an electric field.
- * Channel: The path between source & drain where current flows. It can be n-type or p-type semiconductor material.

Types of FET:

551

1. JFET (Junction FET): Uses a reverse biased PN junction to control current.
2. MOSFET (Metal-Oxide-Semiconductor FET): Uses an insulated gate and is widely used in digital circuits.

Advantages:

- High input impedance
- Low power consumption
- Good thermal stability.

Basic working Principles

- A voltage applied at the gate controls the current flowing from source to drain.
- The gate controls an electric field that "opens" or "closes" the current path — like a valve.

JFET (Junction Field Effect Transistor) 56

Difference

JFET (Junction Field Effect Transistor)

A JFET is a three terminal semiconductor device in which current conduction is by one type of carrier i.e., electrons or holes.

Constructional details

→ A JFET consists of a p-type or n-type silicon bar containing two pn junctions at the sides.

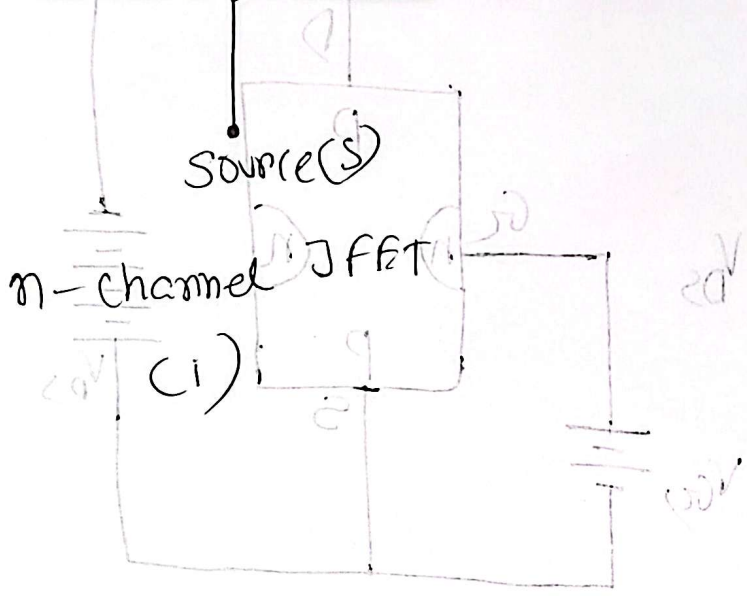
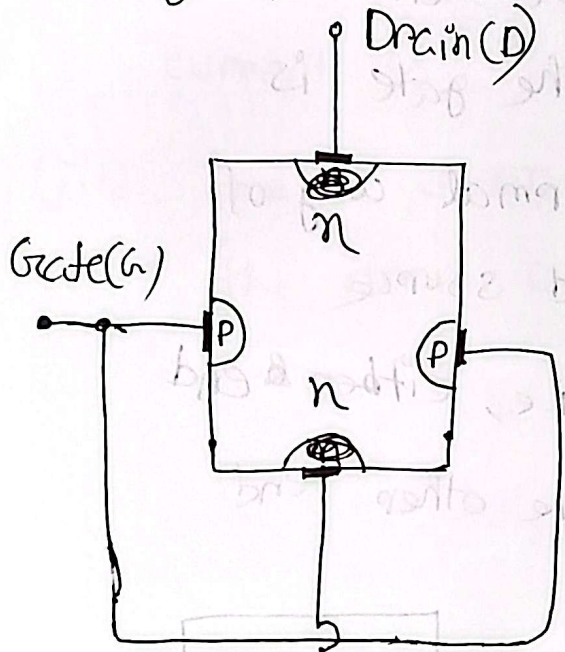
→ the bar forms the conducting channel for the charge carriers.

→ If the bar is of n-type it is called n-channel JFET

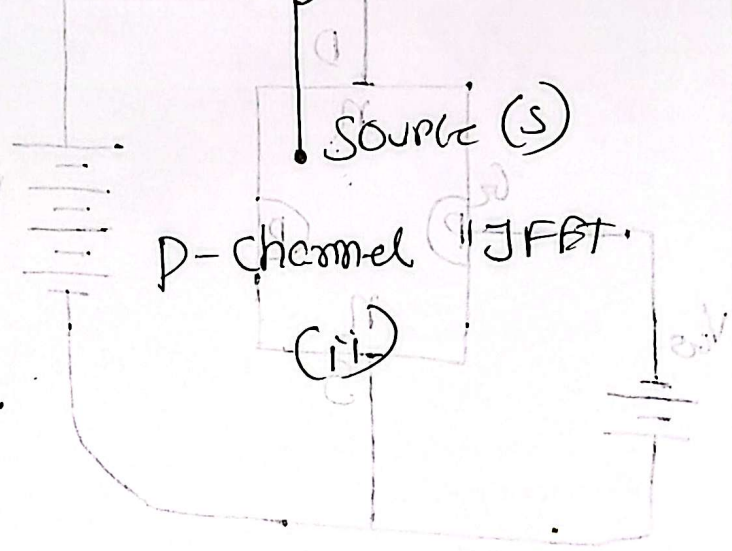
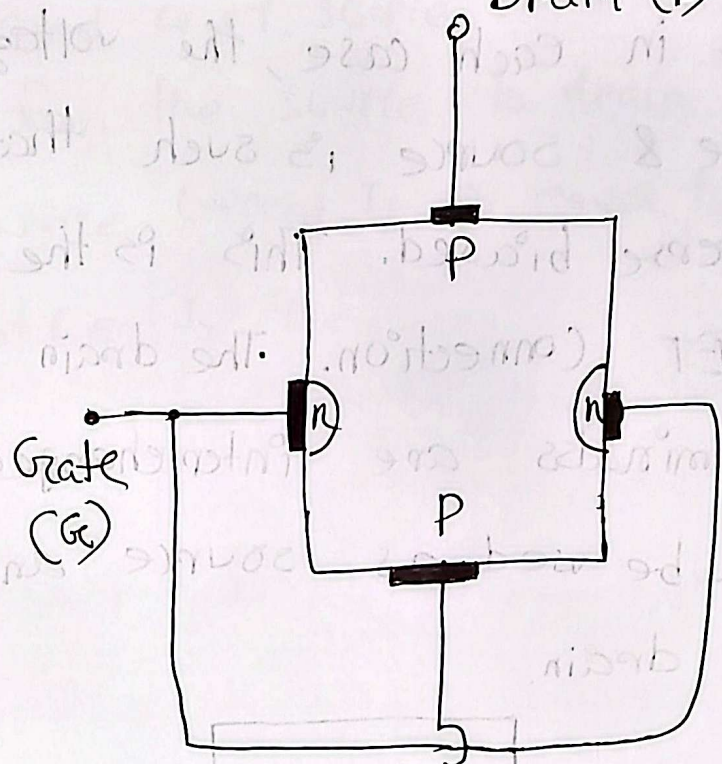
→ If the bar is of p-type it is called p-channel JFET

→ The two pn junctions forming diodes are connected by gate.

→ JFET has essentially three terminal source, gate, drain.



(ii)

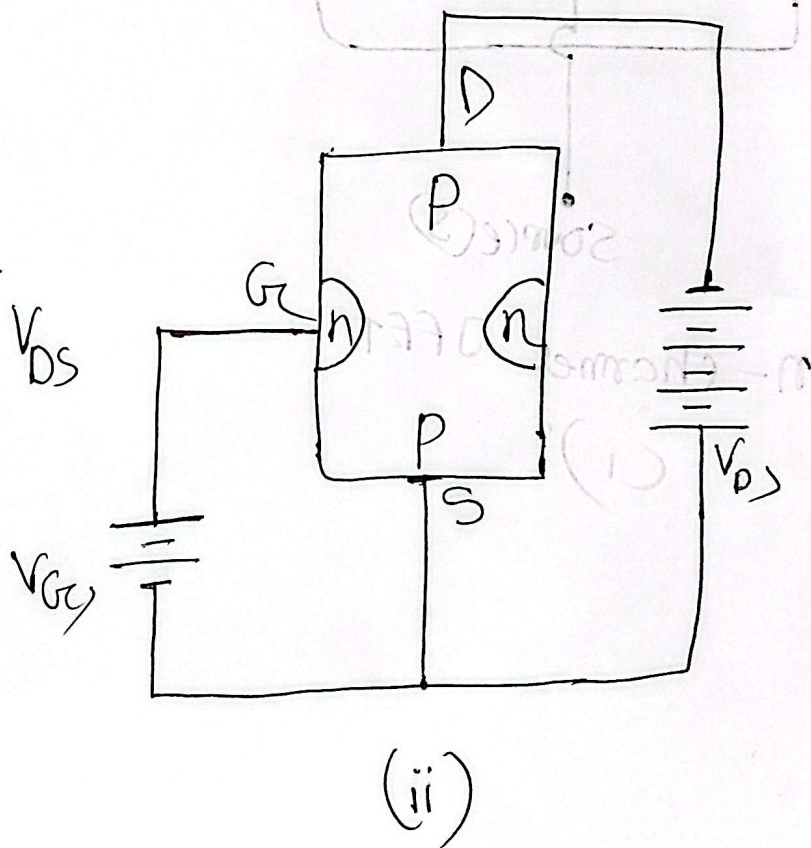
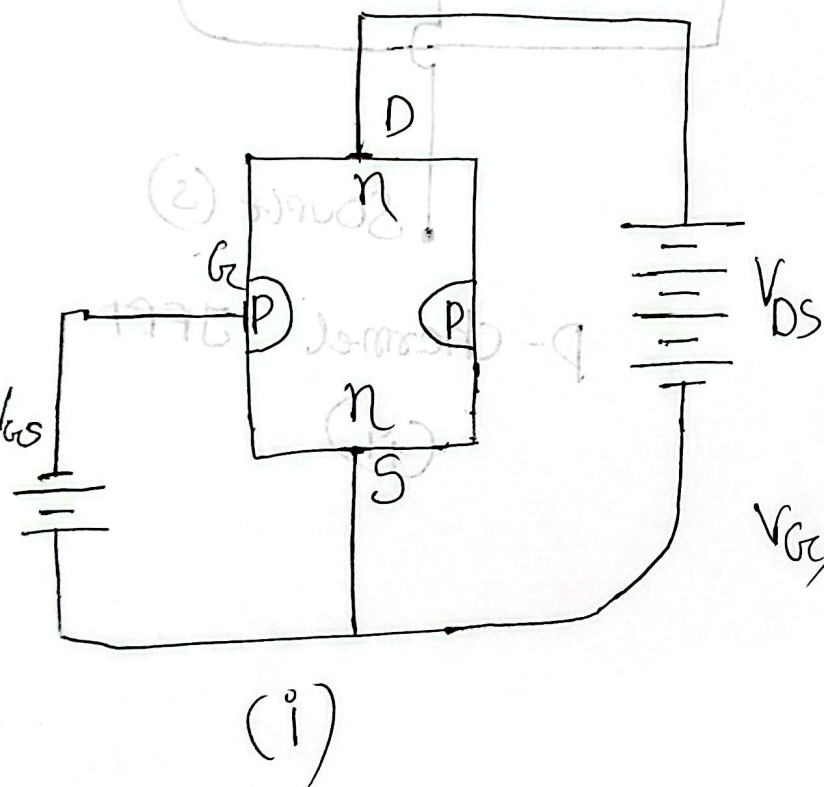


(i)

JFET Polarities

58

Fig (i) shows n-channel JFET polarities whereas Fig (ii) shows p-channel JFET polarities. Note that in each case, the voltage between the gate & source is such that the gate is reverse biased. This is the normal way of JFET connection. The drain and source terminals are interchangeable i.e., either end can be used as source and the other end as drain.



The following points may be noted: 59

- (i) The input circuit of a JFET is reverse biased. This means that the device has high input impedance.
- (ii) The drain is so biased w.r.t. source that drain current I_D flows from the source to drain.
- (iii) In all JFETs - source current I_S is equal to the drain current i.e. $I_S = I_D$.

Principle & Working of JFET:

60

1. Principle of JFET:

- The two pn junction at the sides form two depletion layers.
- The current flows from Source to Drain through channel between these depletion layers.
- the width of depletion layer & resistance controlled by input voltage V_{gs} .
- When apply ^{the} a reverse voltage, become greater,
 - the width of depletion layer increased
 - the narrower will be conducting channel.
 - narrower channel means greater resistance.
 - So, less current ^{can} pass from Source to Drain.

process
→ This will happen reverse when V_{GS} decreased. 61

2. Working of JFET (N-channel JFET)

a) When Gate voltage $V_{GS} = 0$ (No Reverse Bias)

→ when a voltage V_{DS} is applied between Drain and Source:

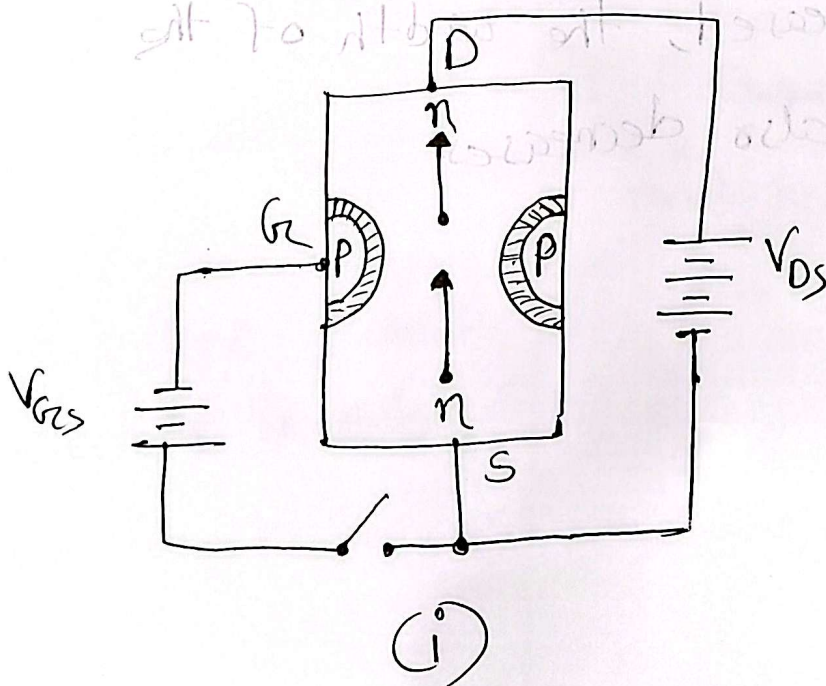
→ Gate is not connected to any voltage ($V_{GS} = 0$).

→ Natural depletion layers form at the junctions

but they are narrow.

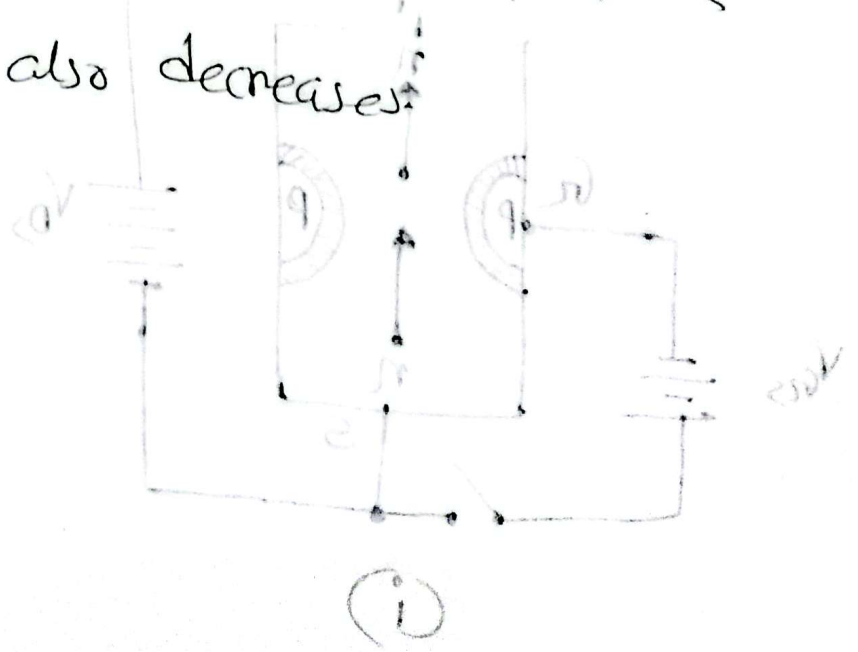
→ A wide channels exist between the depletion layers.

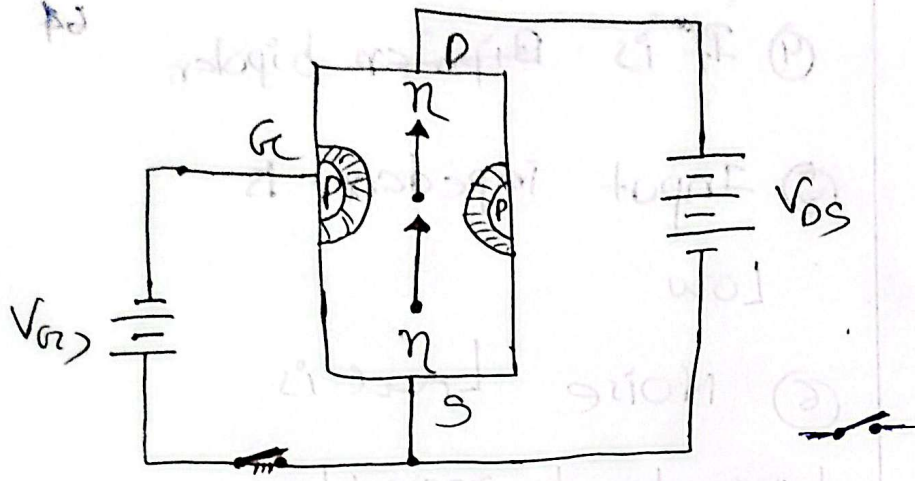
→ so electrons flow easily from Source to Drain.



b) When a Reverse Gate Voltage is Applied ($V_{GS} < 0$)

- Now, a negative voltage is applied to the gate.
- This reverse biases the PN junctions more.
- The ^{width of the} depletion layers is increased.
- This makes the channel narrower, so:
 - * Resistance increases.
 - * Current decreases.
- The more negative the V_{GS} , the narrower the channel and less current flows.
- On the other hand, if the reverse voltage on the gate is decreased, the width of the depletion layer also decreases.





(ii)

Difference between JFET & BJT

JFET

- ① JFET stands for Junction field effect transistor.
- ② voltage controlled device
- ③ There is only one type of carrier, holes in p-type channel and electrons in n-type channel.

BJT

- ① BJT stands for Bipolar Junction Transistor.
- ② Current controlled device
- ③ There is both electrons and holes are used.

④ It is Unipolar

⑤ Input impedance is very high.

⑥ Noise level is Low.

⑦ Power consumption is Low.

⑧ ~~Slow~~ Switching speed is slower than BJT

⑨ Thermal stability is better.

⑩ Lower voltage gain.

⑪ Applications: High impedance amplifiers, buffers, analog switches.

⑫ Reverse biased

④ It is ~~Bipolar~~ bipolar

⑤ Input impedance is Low.

⑥ Noise Level is high due to ~~majority~~ minority carrier.

⑦ Higher

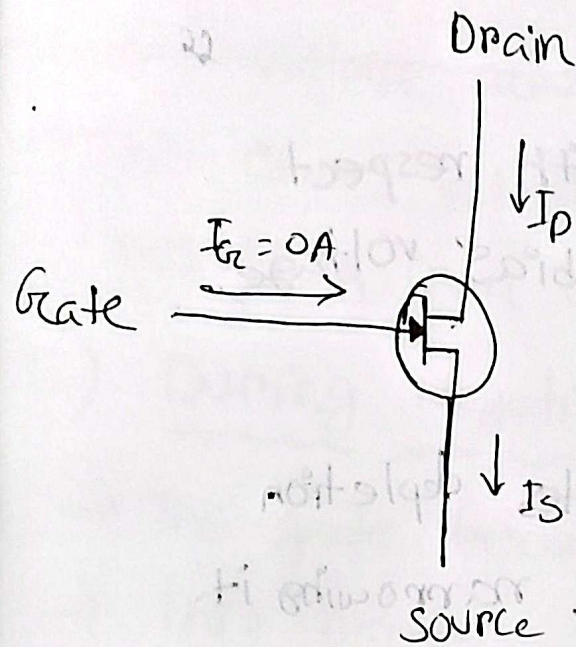
⑧ Faster

⑨ Less stable

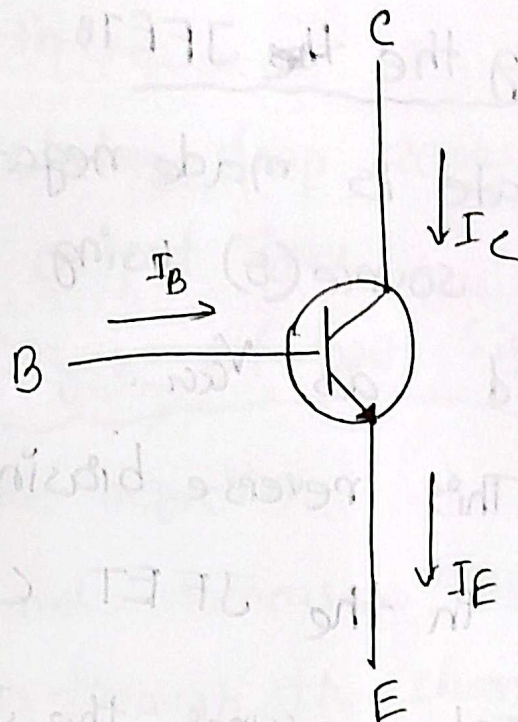
⑩ Higher voltage gain.

⑪ Applications: Power amplifiers, digital switching.

⑫ Forward biased.

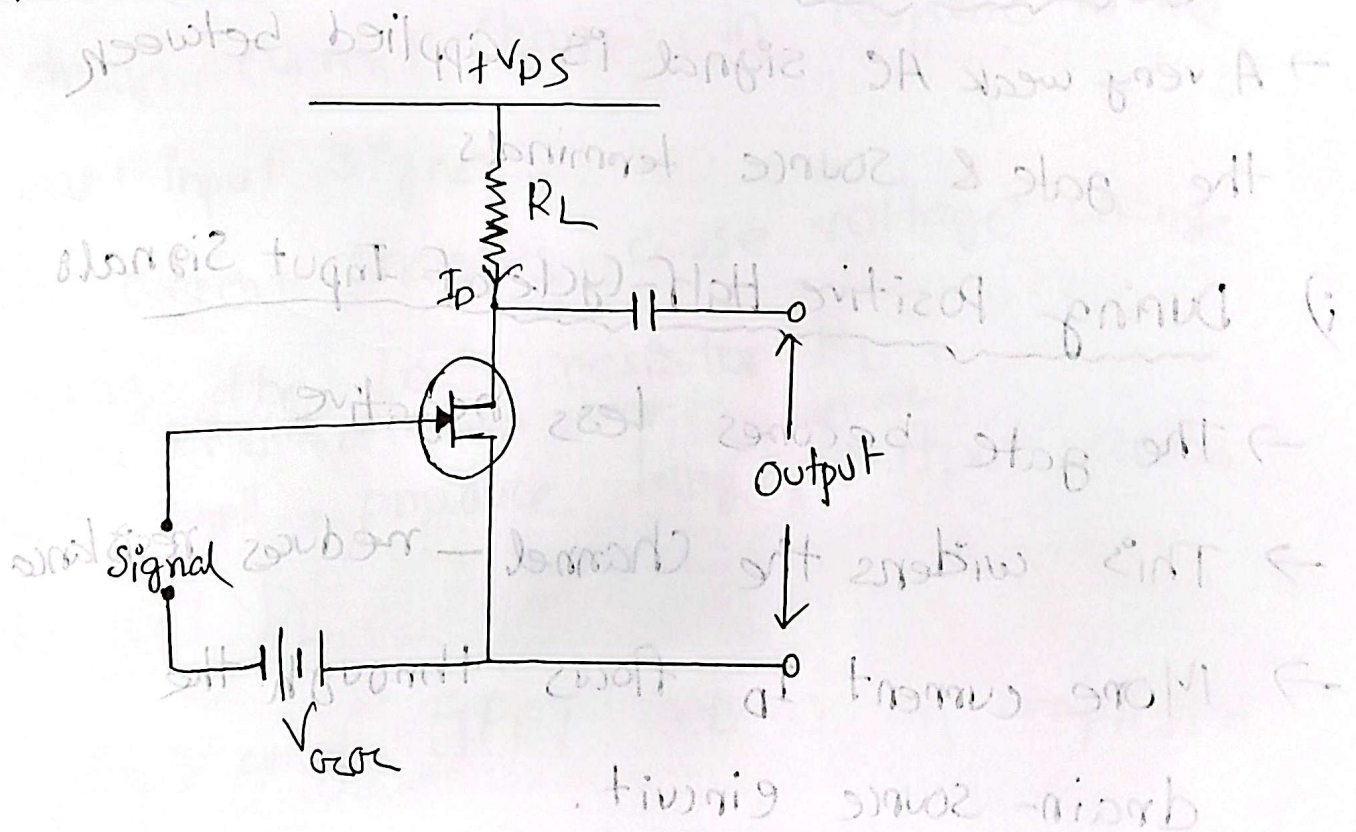


FET



BJT

JFET as an Amplifiers / How JFET Amplifier Works:



1. Biasing the JFET

- The gate is made negative with respect to the source(s) using a DC bias voltage, denoted as V_{GS} .
- This reverse biasing creates depletion regions in the JFET channel, narrowing it.
- This setup ensures the JFET operates in the active region.

2. When Input Signal is Applied

- A very weak AC signal is applied between the gate & source terminals.
- i) During Positive Half-Cycle of Input Signal
 - The gate becomes less negative
 - This widens the channel — reduces resistance
 - More current I_D flows through the drain-source circuit.

→ So, voltage across R_L increases. 67
→ This causes a larger voltage drop across R_L , resulting in a stronger output signal.

ii) During Negative Half-cycle of Input Signal

→ The gate becomes more negative.
→ This narrows the channel — increases resistance.
→ Less current I_D flows through the channel.
→ So, voltage across R_L decreases.

3. Output Signal

→ The drain current changes in response to the small input signal.
→ This current changes cause voltage change across the load resistor R_L .
→ These large variations of in drain current voltage will produce large output across the load R_L .

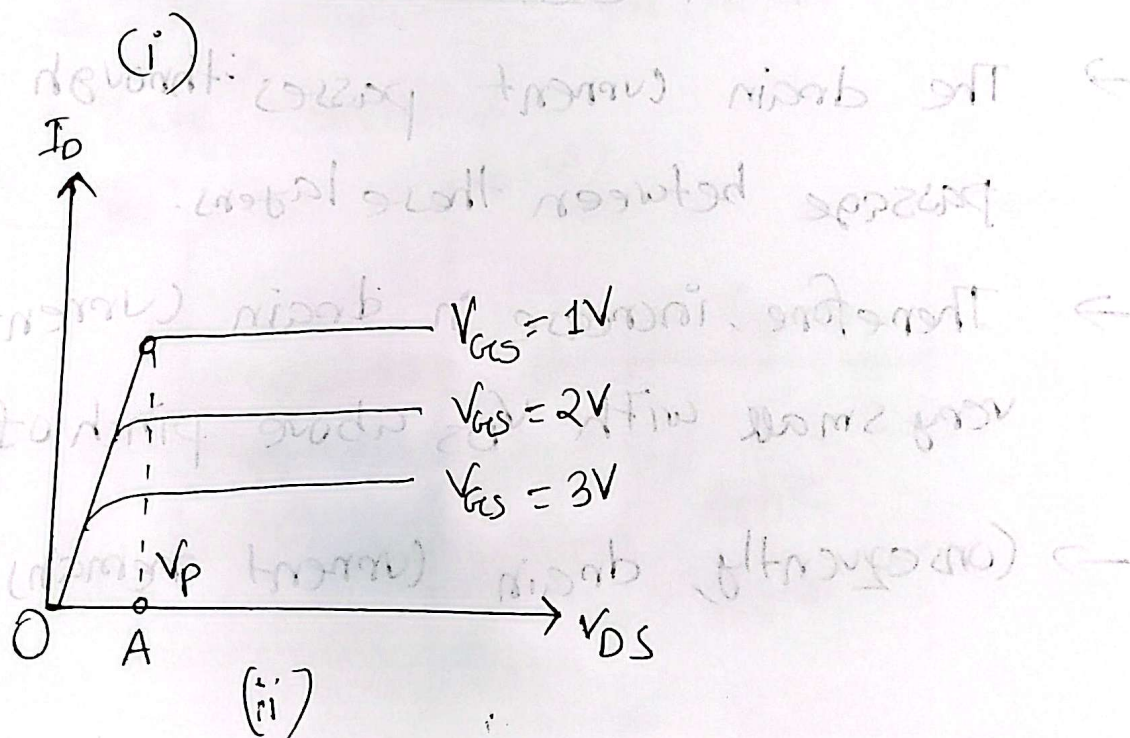
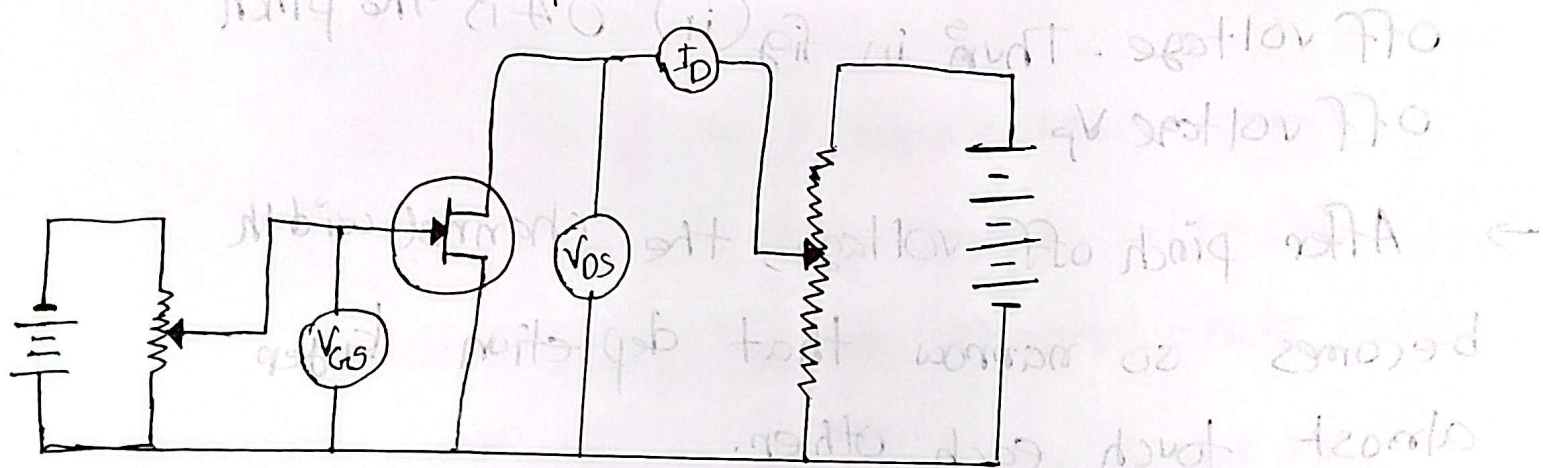
→ In this way, JFET acts as an amplifier.

Salient features of JFET:

- A JFET is a three terminal voltage-controlled semiconductor.
- input voltage controls the output characteristics of JFET.
- Operated in reverse biased $\beta = 0$
- ~~there is no~~ The gate current, $I_g = 0A$.
- Since there is no gate current, $I_D = I_S$
- The JFET must operated between $V_{GS} = 0V$ and $V_{GS} (off)$.
- Since JFET has no gate current, there is no β rating of the device.
- The drain current I_D is controlled by changing the channel width.

Output Characteristics of JFETs

The curve between drain current (I_D) and drain-source voltage (V_{DS}) of a JFET at constant gate-source voltage (V_{GS}) is known as output characteristics of JFET. Fig (i) shows the circuit for determining the output characteristics of JFET. Fig (2) shows a family of output characteristics.



The following points may be noted from the characteristics: 76

- At first, the drain current, I_D rises rapidly with drain source voltage V_{DS} but then becomes constant.
- The drain source voltage above which drain current becomes constant is known as pinch off voltage. Thus in fig(ii) OA is the pinch off voltage V_P .
- After pinch off voltage, the channel width becomes so narrow that depletion layer almost touch each other.
- The drain current passes through the small passage between these layers.
- Therefore, increase in drain current is very small with V_{DS} above pinch off voltage.
- Consequently, drain current remains constant.

→ The characteristics resemble that of a pentode valve.

Important terms:

* Shorted-gate drain current (I_{DSS}):

→ It is the ~~max~~ I_{DSS} is the maximum drain current of a JFET when the gate is shorted to the source (i.e. $V_{GS} = 0$) and drain voltage (V_{DS}) equal to pinch off voltage.

→ This is also called the zero-bias current.

→ Fig (i) shows the JFET circuit with $V_{GS} = 0$.

This is normally called shorted-gate condition.

→ Fig (ii) shows the graph between I_D and V_{DS} for the shorted gate condition.

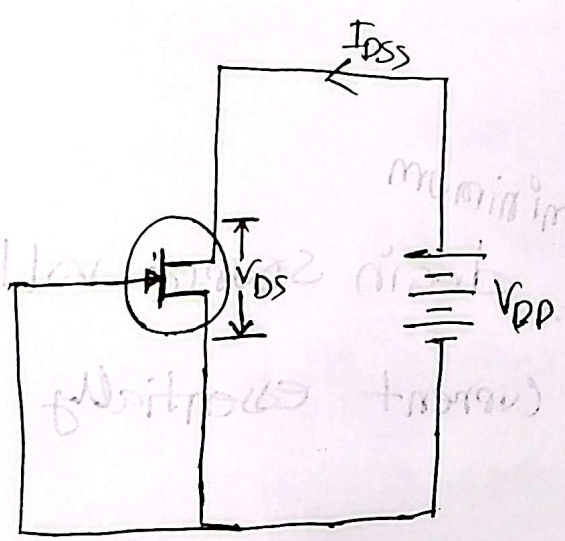


Fig (i)

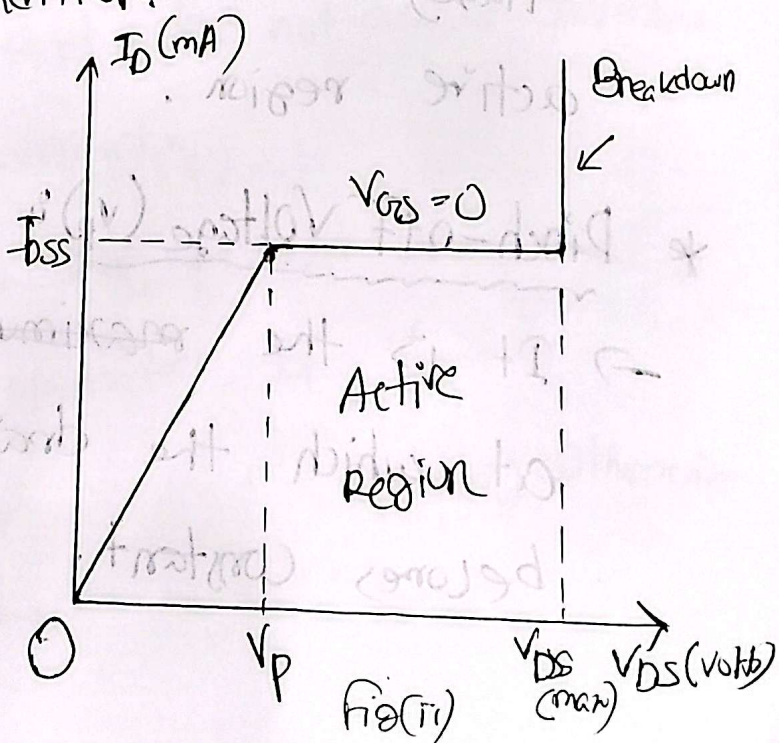


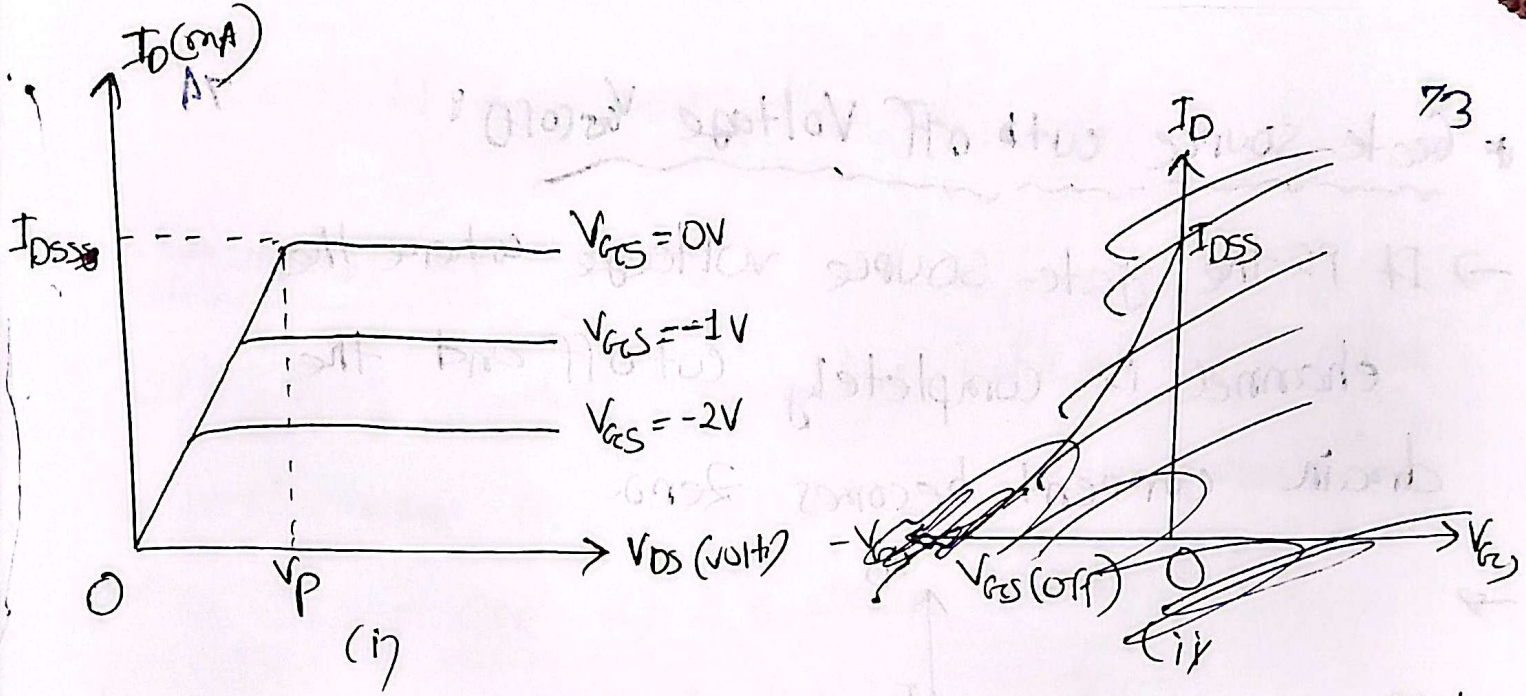
Fig (ii)

The following points may be noted:

- The drain current rises quickly at first then levels off ~~one~~ at pinch-off voltage V_p .
reached.
- Even if V_{DS} increased beyond V_p , the drain current stays constant at I_{DSS} - the JFET behaves like a current limiter.
- There is a maximum drain voltage $[V_{DS(max)}]$ (breakdown) that can be applied to a JFET. If the drain voltage exceeds $V_{DS(max)}$, JFET would breakdown as shown in fig(2).
- The region between V_p and $V_{DS(max)}$ (breakdown voltage) is called constant-current region or active region.

* Pinch-off Voltage (V_p): minimum

- It is the ~~maximum~~ drain source voltage at which the drain current essentially becomes constant.

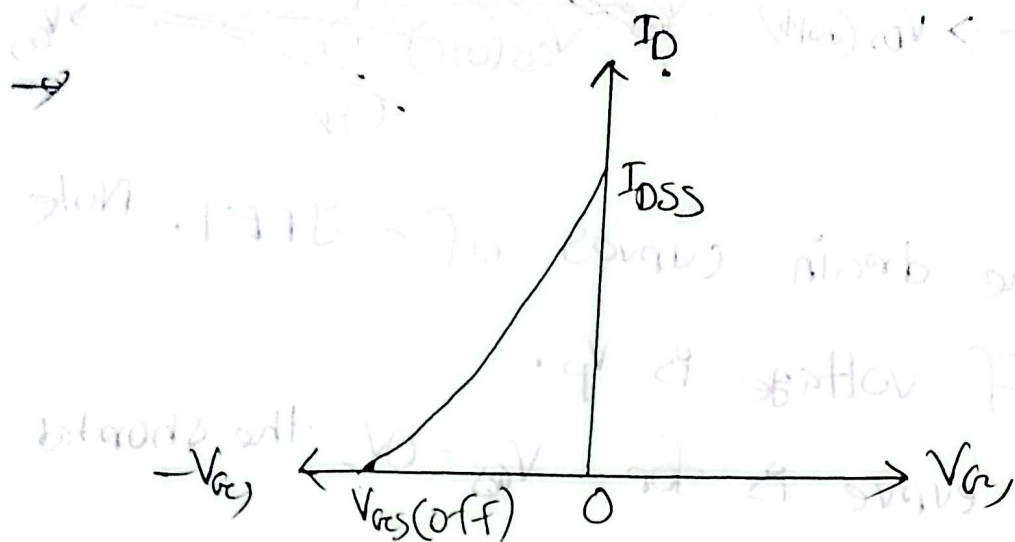


- fig (i) shows the drain curves of a JFET. Note that pinch off voltage is V_p .
- The highest curve is for $V_{GS} = 0V$, the shorted gate condition.
- for values of V_{DS} greater than V_p , the drain current is almost constant.
- It is because when V_{DS} equals V_p , the channel is effectively closed and does not allow further increase in drain current.
- It may be noted that, for proper function of JFET, it is always operated for $V_{DS} > V_p$.
- However, V_{DS} should not exceed $V_{DS(max)}$ otherwise JFET may breakdown.

* Gate-source cut off Voltage $V_{GS(off)}$

74

→ It is the gate-source voltage where the channel is completely cut off and the drain current becomes zero.



→ As V_{GS} becomes more negative, the channel narrows, reducing I_D .

→ At a certain negative voltage, the depletion layers fully block the channel — this voltage is called $V_{GS(off)}$ (gate-source cut off voltage).

→ At $V_{GS(off)}$ the JFET stops conducting ($I_D \approx 0$).

→ Magnitude of $V_{GS(off)}$ is equal to pinch-off voltage but opposite in sign:

* Example: If $V_{DD} = +6V$, then $V_{GS}(\text{off}) = -6V$. ..75

Parameters of JFETs

A JFET has certain parameters which determine its performance in a circuit. The main parameters of a JFET are (i) a.c. drain resistance (ii) transconductance (iii) amplification factor.

(i) a.c. drain resistance (r_d): It is the ratio of change in drain-source voltage (ΔV_{DS}) to the change in drain current (ΔI_D) at constant gate source voltage i.e.

$$\text{a.c. drain resistance, } r_d = \frac{\Delta V_{DS}}{\Delta I_D} \text{ at constant } V_{GS}$$

(ii) Transconductance (g_{fs}): It is the ratio of change in drain current (ΔI_D) to the change in gate source voltage (ΔV_{GS}) at constant drain-source voltage i.e.

$$\text{Transconductance, } g_{fs} = \frac{\Delta I_D}{\Delta V_{GS}} \text{ at constant } V_{DS}$$

→ measured in mA/volt , μmho .

(iii) Amplification factor ^(μ) It is the ratio of change in drain source voltage (ΔV_{DS}) to the change in gate-source voltage (ΔV_{GS}) at constant drain current. i.e.

$$\text{Amplification factor, } \mu = \frac{\Delta V_{DS}}{\Delta V_{GS}} \text{ at constant } I_D$$

→ Indicates how much more effective gate voltage is than drain voltage ⁱⁿ controlling I_D .

⊞ Relation among JFET parameters:

The relation ~~between~~ among JFET parameters can be established as under:

$$\text{we know, } \mu = \frac{\Delta V_{DS}}{\Delta V_{GS}}$$

Multiplying the numerator and denominator on R.H.S by ΔI_D , we get,

$$\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}} \times \frac{\Delta I_D}{\Delta I_D} = \frac{\Delta V_{DS}}{\Delta I_D} \times \frac{\Delta I_D}{\Delta V_{GS}} \quad 78$$

$$\therefore \mu = r_d \times g_{fs}$$

i.e. amplification factor = a.c. drain resistance $\times$ transconductance.

Amplification factor of a JFET is 50, it means that gate voltage is 50 times as effective as the drain voltage in controlling the drain current (I_D).

the depletion layer between them acts as the dielectric of the capacitor.

$$\frac{A}{4\pi\epsilon_0} = C \quad \therefore \text{A parallel plate capacitor}$$

with depletion layer

Chapter-7

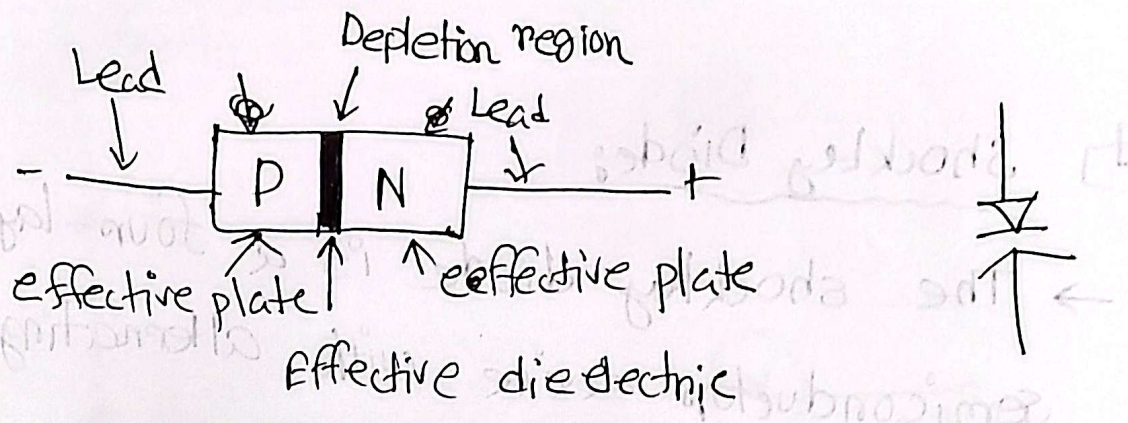
Varactor Diode: A varactor diode is a special type of junction diode that acts as a variable capacitor when operated under reverse bias.

Working Principles

- When a pn junction is formed:
- A depletion layer is created at the junction
- This layer has no free carriers, so it behaves like an insulator.
- The p-region and n-region act like the plates of a capacitor.
- The depletion layer between them acts as the dielectric of the capacitor.

Capacitance formula: $C_T = \epsilon \frac{A}{W_d}$

Here $C_T \propto \frac{1}{W_d}$ width of depletion layer



Applications:

- Used in tuning circuit
- Acts as a voltage controlled capacitor in filters and phase-locked loop.

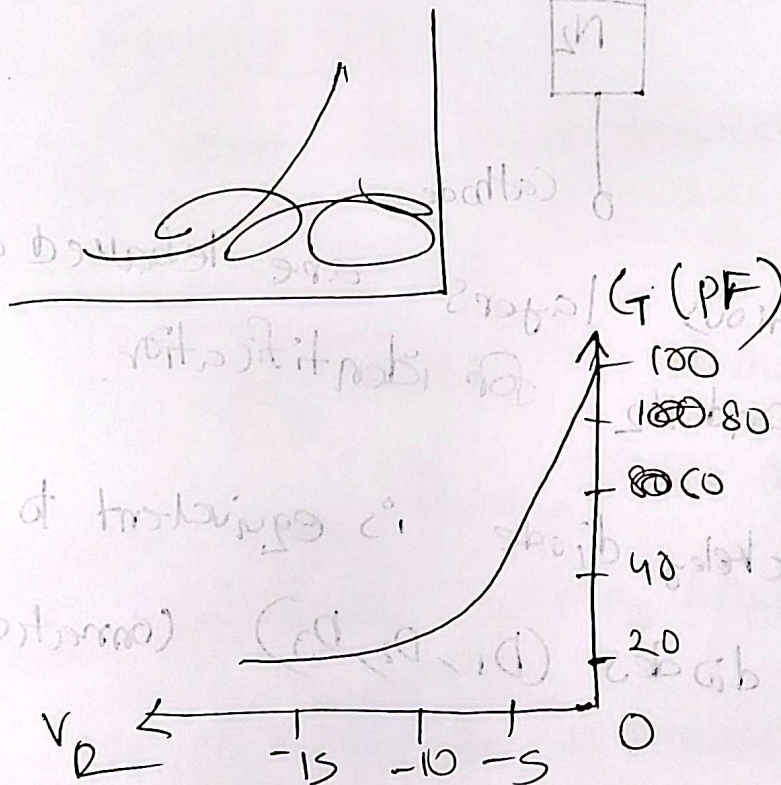
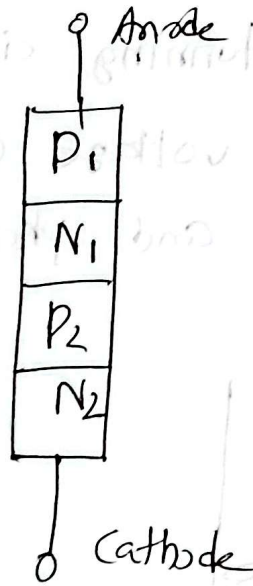


Fig shows the curve between reverse bias voltage across varactor diode and total junction capacitance C_T .

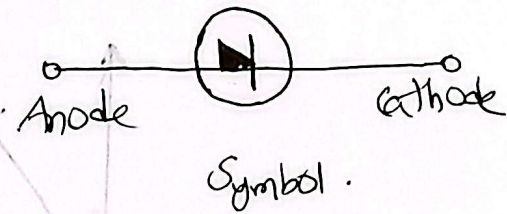
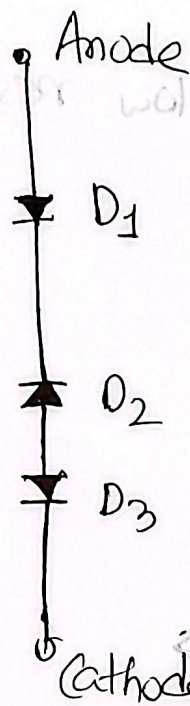
Shockley Diode:

→ The shockley diode is a four-layer (PNPN) semiconductor device with alternating P-type and N-type materials.



→ The various layers are labelled as P_1 , N_1 , P_2 and N_2 for identification.

→ The shockley diode is equivalent to three junction diodes (D_1, D_2, D_3) connected in series.



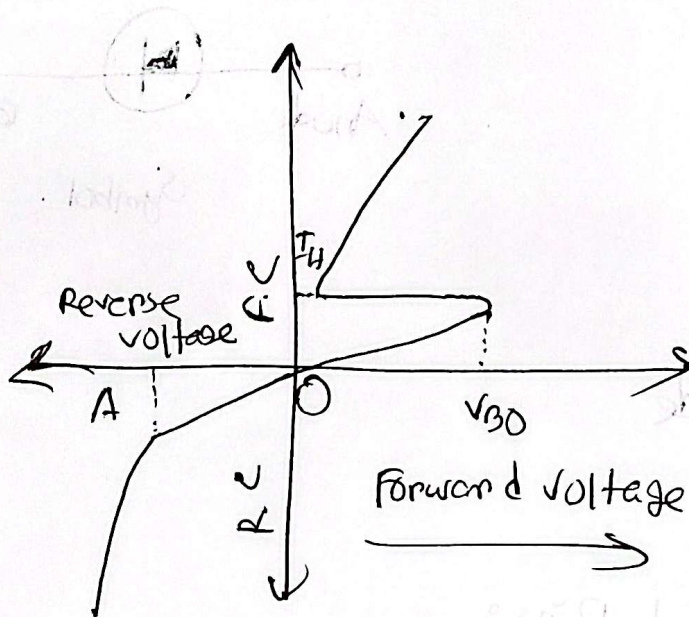
Working Principles

1. During Forward Bias

- D_1 & D_3 are forward biased
- D_2 is reverse-biased
- D_2 offers very high resistance.
- Since all three diodes are in series, the total resistance is very high.
- As forward voltage increases, the reverse bias on D_2 also increases. (A bias)
- At some forward voltage, reverse breakdown of D_2 occurs.

→ Now, the diode switches to low resistance mode

→ V-I characteristic:



2. During Reverse Bias:-

- D_1 & D_3 are reverse biased
- They offer high resistance.
- D_2 is forward biased (low resistance)
- If reverse voltage increases beyond a limit.
- D_1 & D_3 may undergo reverse breakdown (point A)
- This causes excessive current leading to thermal damage.