UNIT - II

Transistor and OPAMP

* Bipolar Junction Transistor :-
- After diode the next invention in the semiconductor devices is a Bipolar Junction Transistor.
- Transistor is a three terminal device : Base, emitter, collector.
- It can be operated in three configuration common base, common emitter and common collector.
- According to configuration it can be used f[...] voltage as well as current amplification.

* Advantages of Transistor :
- Very small size and weight, reducing equipment size
- low operating voltages.
- lower costs.
- low power consumption.
- Higher efficiency
- Very low sensitivity to mechanical shock an[...] vibration.
- Very long life.

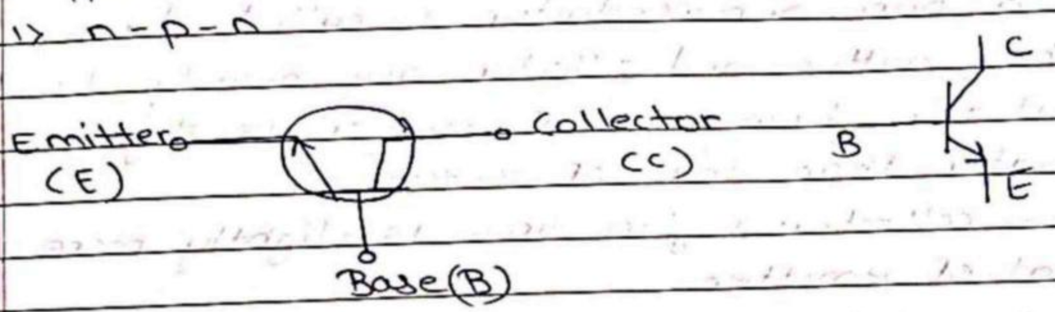
* Types of Transistor.
- Unipolar Junction Transistor (UJT)
- Bipolar Junction Transistor (BJT)

- In UJT, the current conduction is only due to one type to one type of charge carriers. majority carriers.
  e.g FET

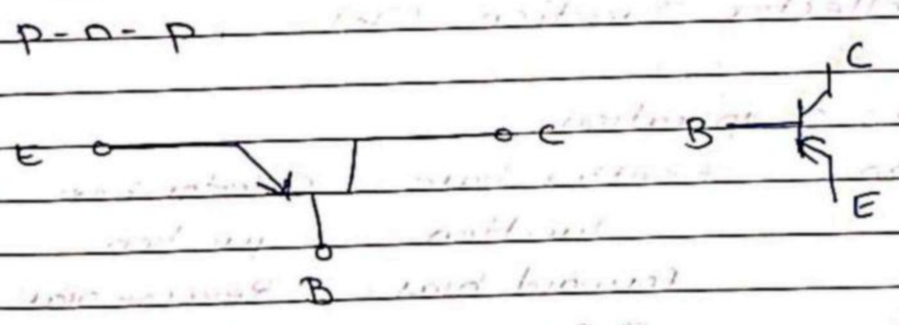
- The current conduction in BJT is ~~be~~ of both types of charge carriers, holes and electrons. It is current controlled or current operating device.

* Types of BJT :-

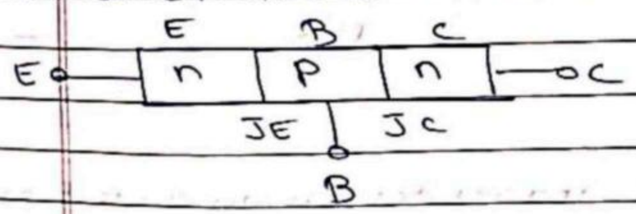
1> n-p-n



2> p-n-p



* Construction of BJT.



- single p region is sandwiching between two n region.

fig. a) n-p-n

- The n region is sandwiching betwe two p-regions

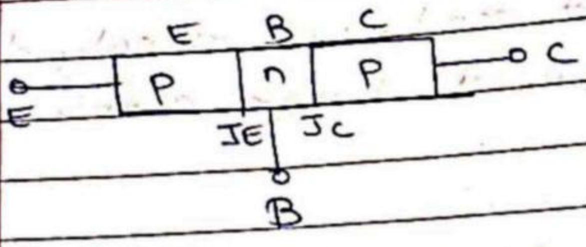


Fig. b> p-n-p

- The middle region of each transistor type i called base of the transistor. This region is very thin and lightly doped.
- The process by which impurities are added to a pure semiconductor is called doping.
- The emitter and collector are heavily doped But the doping level in emitter is slightly greater than that of collector.
- The collector region-area is slightly more than that of emitter.
- A transistor has two p-n junctions.
  a> Emitter Junction (JE)
  b> Collector Junction (Jc)

* Regions of operation

	Region	Emitter-base Junction	Collector-base junction	Applicati
1.	Active	Forward bias	Reverse bias	Amplif
2.	Cut-off	R.B.	F.B.	OFF Swit
3.	Saturation	F.B.	F.B.	On Swit
4.	Inverse active	R.B.	F.B.	-

In order to operate transistor as an amplifier it is necessary to bias it in the active region.

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* Working of npn and pnp Transistors.

* Working of npn Transistor.

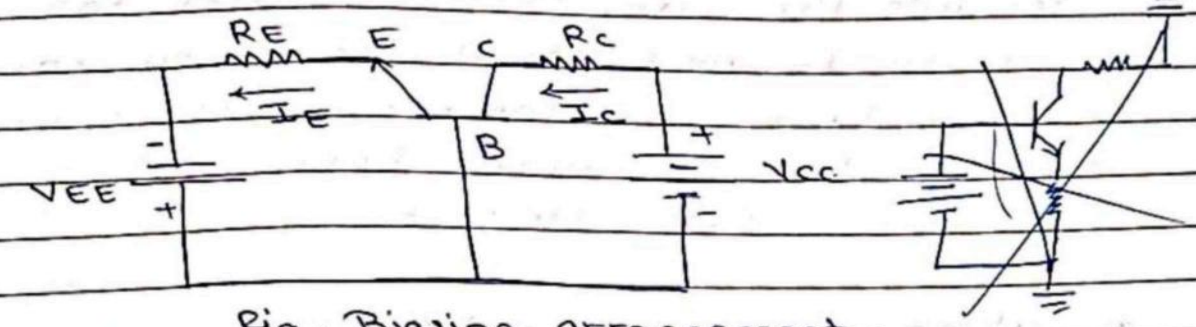


Fig. Biasing arrangement.

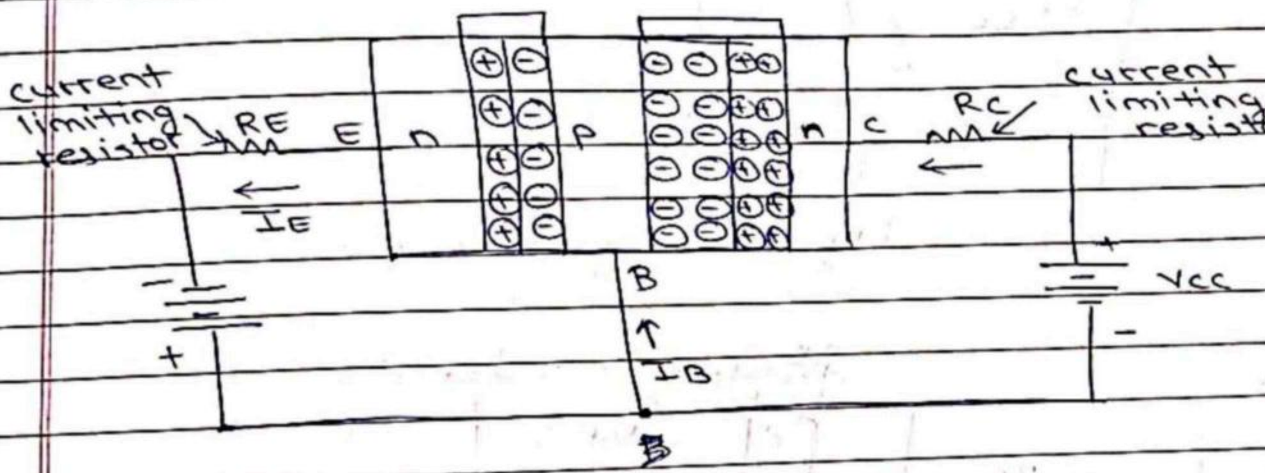


Fig. Operation of npn transistor in active region.

- The supply voltage VEE forward biases the emitter junction (JE) and the supply voltage Vcc reverse biases the collector junction (Jc)
- The base to emitter junction is forward biased by the d.c. source VEE. Thus, the width of depletion region at this junction is small.
- The collector to base junction is reverse biased and hence width of depletion region at this junction is large.

- The forward biased EB junction causes the electrons in the n-type emitter to flow towards the base. This constitutes the emitt current IE. As these electrons flow through the p-type base, they tend to combine with holes in p-region (base).

$$I_E = I_B + I_C$$

* Working of pnp Transistor :-

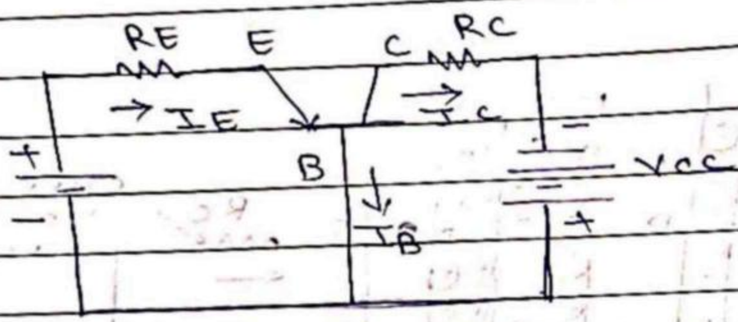
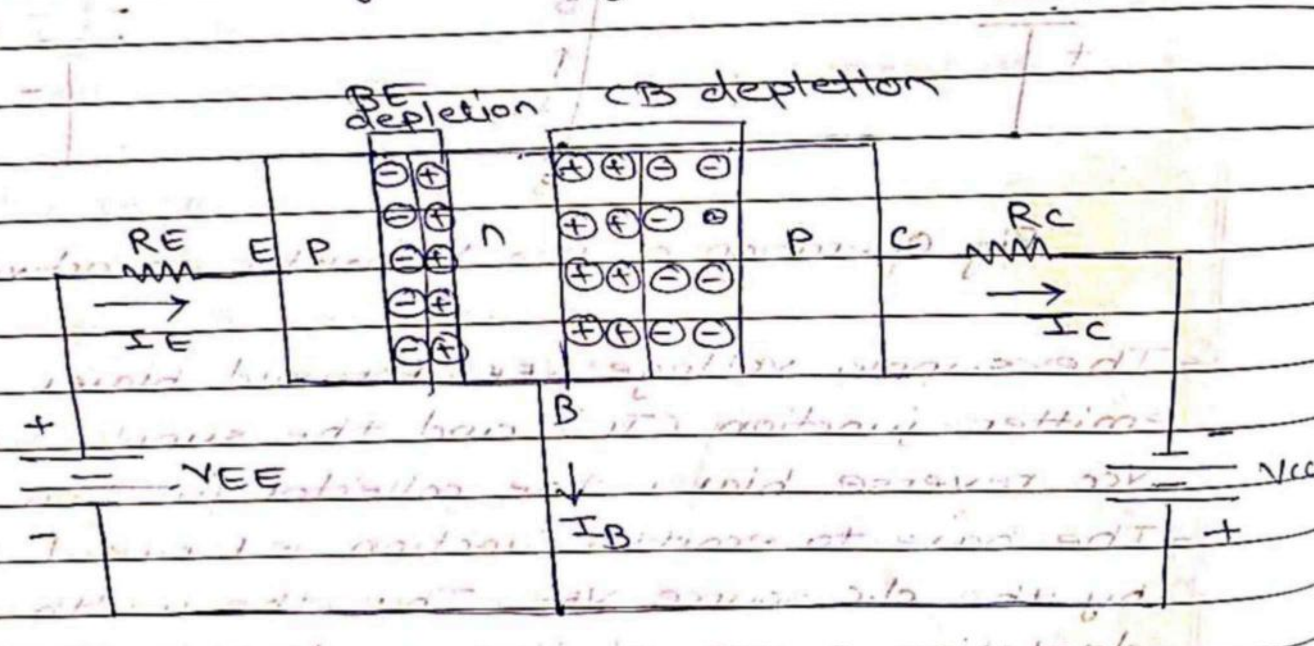


Fig. Biasing arrangement.



- The forward biased EB junction causes the holes in the p-type emitter to flow towards the base. This constitutes the emitter current IE.

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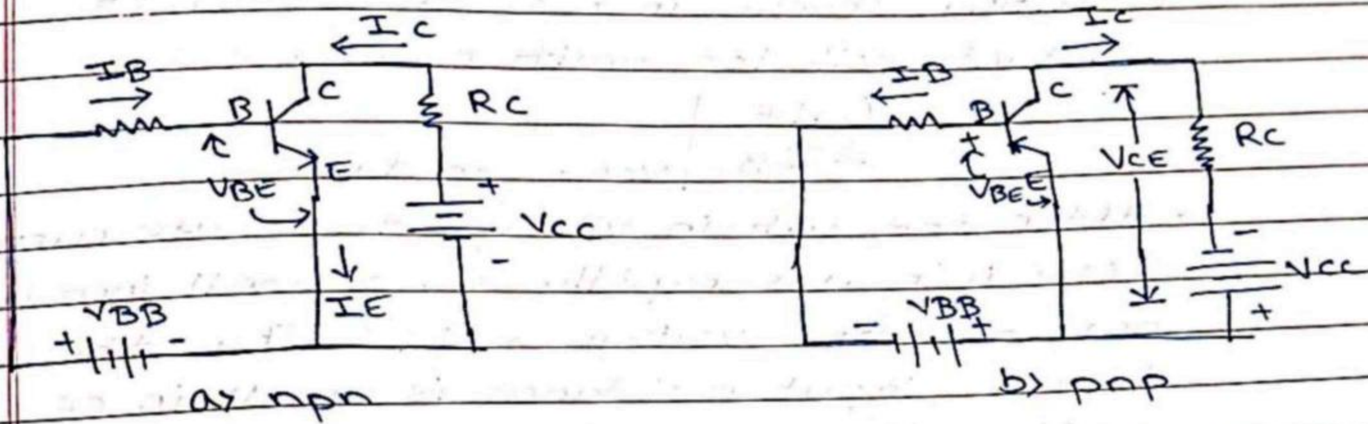
- As these holes flow through the n-type base. they lend to combine with electrons in n-region (base).
- As the base is very thin and lightly doped, very few of the holes injected into the base from the emitter recombine with electrons to constitute base current, I_B.
- The remaining large number of holes cross the depletion region and move through the collector region to the negative terminal of the external dc.source. This constitutes collector current I_C
- Forward biased EB junction also causes electrons to flow ~~through~~ from n-type base to p-type emitter. But as base is lightly doped electron becomes the minority carriers. Thus the hole flow constitutes the dominant current in an pnp transistor.

$$I_E = I_B + I_C$$

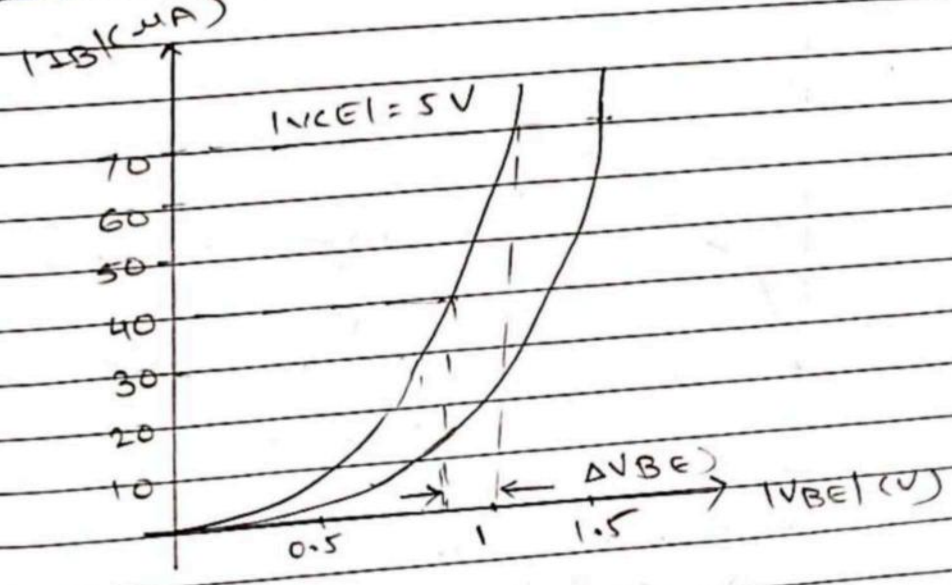
* CB, CE, CC configuration and V-I characteristics
- The transistor can be connected in a circuit in the following three configurations:-
1) Common base configuration
2) Common emitter configuration.
3) Common collector configuration.

2) Common Emitter Configuration:



- In this configuration input is applied between base and emitter, and output is taken from collector and emitter.
- Here, emitter of the transistor is common to both, input and output circuits, and hence the name common emitter configuration.

Input Characteristics of CE Configuration:-

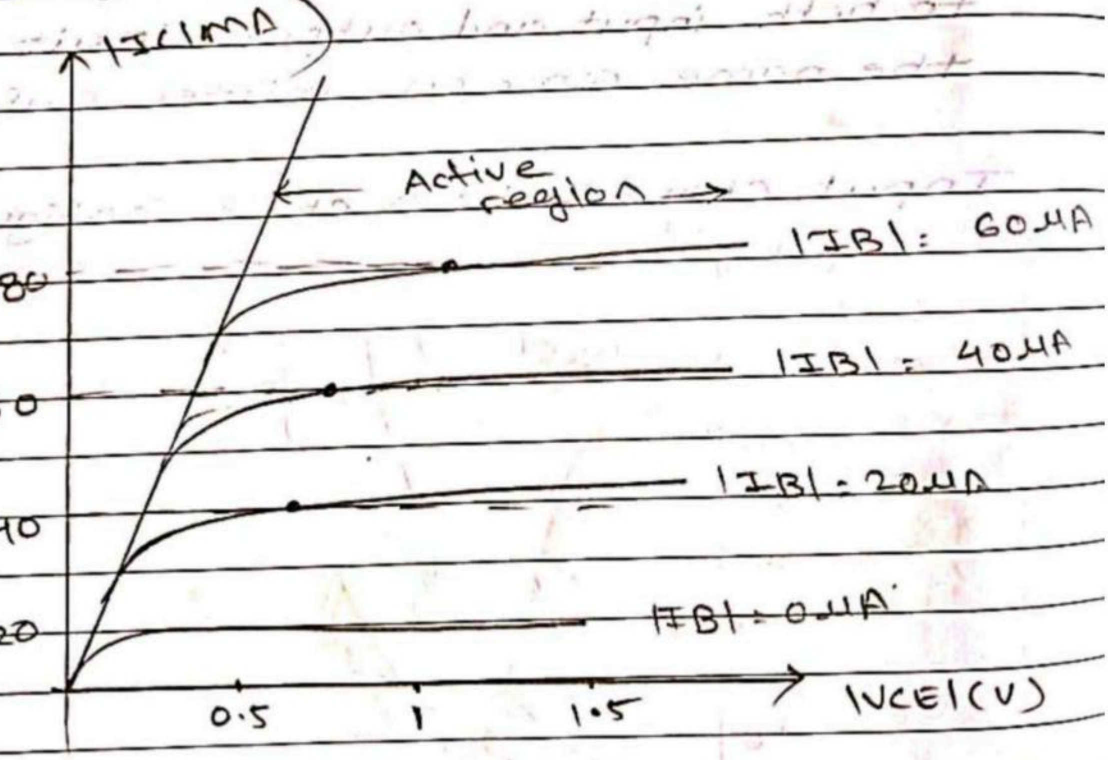


- The input resistance is the ratio of change in base-emitter voltage (ΔV_{BE}) to the resulting change in base current (ΔI_B) at constant collector emitter voltage V_{CE}

$$r_i = \left.\frac{\Delta V_{BE}}{\Delta I_B}\right|_{V_{CE} = \text{Constant}}$$

- After the cut-in voltage, the base current (I_B) increases rapidly with small increase in base-emitter voltage (V_{BE}). Thus the dynamic input resistance is small in CE configuration.
- For a fixed value of V_{BE}, I_B decreases as V_{CE} is increased.

Output characteristics of CE configuration:



O/P Dynamic resistance:-

$$r_o = \left.\frac{\Delta V_{CE}}{\Delta I_C}\right|_{I_B = \text{Constant OR } \Delta I_B = 0}$$

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a) Active Region :-

- For the operation in active region, J_E is F.B and J_C is in R.B.
- I_C rise more sharply with increasing V_{CE} in the linear region of output characteristics of CE transistor.

b) Saturation Region :

- In this region, J_E & J_C both are F.B.
- The saturation value of V_{CE}, designated $V_{CE(sat)}$ usually ranges between 0.1V to 0.3V.

c) Cut - OFF region :

- The region below $I_B = 0$ is the cut-OFF region of operation for the transistor.
- In this region, both junctions are in R.B.

For saturation region :

$$I_B > \frac{I_C}{\beta dc}$$

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

For cut-OFF :

$$I_B = 0$$

For active region :

$$V_{CE} > V_{CE(sat)}$$

1. Alpha (α):

- it is defined as the ratio of the collector current resulting from carrier injection to the total emitter current.

$$\alpha_{dc} = \alpha = \frac{I_{C(INJ)}}{I_E} = \frac{I_C}{I_E}$$

Since $I_C < I_E$ the value of α_{dc} is always less than unity

$$\alpha = \frac{I_C}{I_E} = \frac{I_E - I_B}{I_E} = 1 - \frac{I_B}{I_E}$$

Since $I_B << I_E$,

α is nearly equal to 1.

$$\therefore I_C = \alpha_{dc} I_E + I_{CBO}$$

2. Beta (β)

- It is defined as the ratio of the collector current to the base current.

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

$$I_C = \beta_{dc} I_B + (1 + \beta_{dc}) I_{CBO}$$

$$I_C = \beta_{dc} I_B + I_{CEO}$$

3. Relationship between α and β

w.k.t. $\beta = \frac{I_C}{I_B}$

we have, $I_E = I_C + I_B$

i.e. $I_B = I_E - I_C$

$$\beta = \frac{I_C}{I_E - I_C}$$

Dividing N & D of R.H.S. by I_E, we get

$$\beta = \frac{I_C / I_E}{I_E/I_E - \frac{I_C}{I_E}}$$

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

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W.K.t. $\alpha = \frac{I_C}{I_E}$ and $I_E = I_B + I_C$

$$\alpha = \frac{I_C}{I_B + I_C}$$

Dividing N & D of R.H.S. by I_B we.

$$\alpha = \frac{I_C/I_B}{I_B/I_B + I_C/I_B}$$

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

e.g. Calculate values of I_C & I_E for BJT with $\alpha_{dc} = 0.98$ and $I_B = 50\,\mu A$. Also determi β_{dc} for BJT.

→ Given,

$\alpha_{dc} = 0.98$

$I_B = 50\,\mu A$

To Rind : β_{dc}, I_C & I_E

$$\beta = \beta_{dc} = \frac{\alpha_{dc}}{1-\alpha_{dc}}$$

$$= \frac{0.98}{1-0.98}$$

$$= 49$$

$I_C = \beta I_B = 49 \times 50\,\mu A$

$= 2.45\,mA.$

$I_E = I_B + I_C$

$= 50\,\mu A + 2.45\,mA = 2.5\,mA.$

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4 Gamma (γ)

- The current gain of CC configuration is given by.

$$\gamma = \frac{I_E}{I_B} = \frac{I_B + I_C}{I_B}$$

$$= 1 + \frac{I_C}{I_B}$$

$$= 1 + \beta$$

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

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

* BJT as a switch:

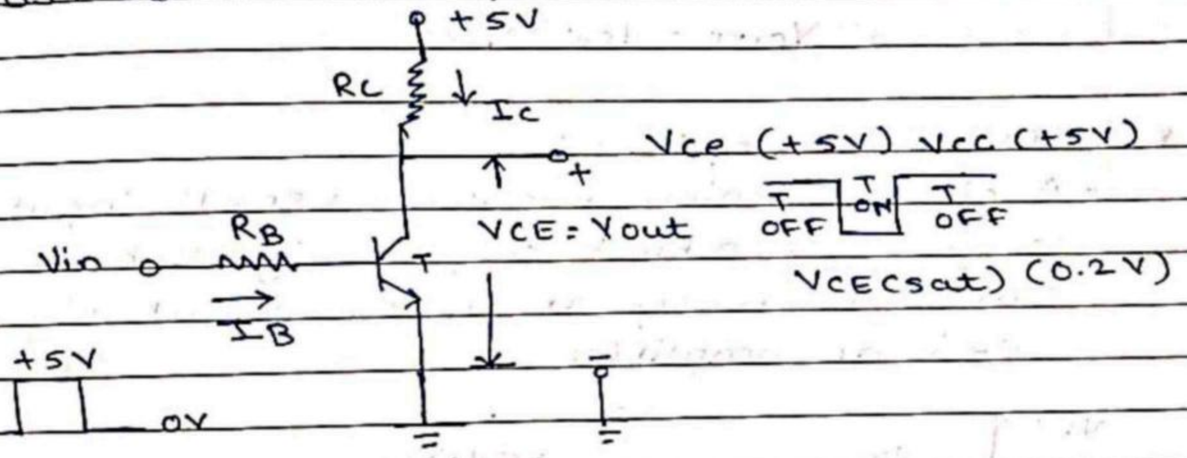


Fig. Transistor as a switch

- In this circuit, when input is HIGH emitter junction is forward biased and base current flows. It is greater than I_C/β, hence transistor is operated in saturation.
- In saturation condition, voltage between collector and emitter, $V_{CE(sat)}$ is typically 0.2V to 0.3V and hence transistor acts as a closed switch.

- The minimum value of base current need to operate transistor in saturation is

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta}$$

- When input is low, emitter junction and collector junction both are reverse biased and hence transistor is operated in cut-off.
- In cut-off base current is zero and hence collector current is also zero, and transistor acts as an open switch.
- Applying KVL to the collector circuit we have,

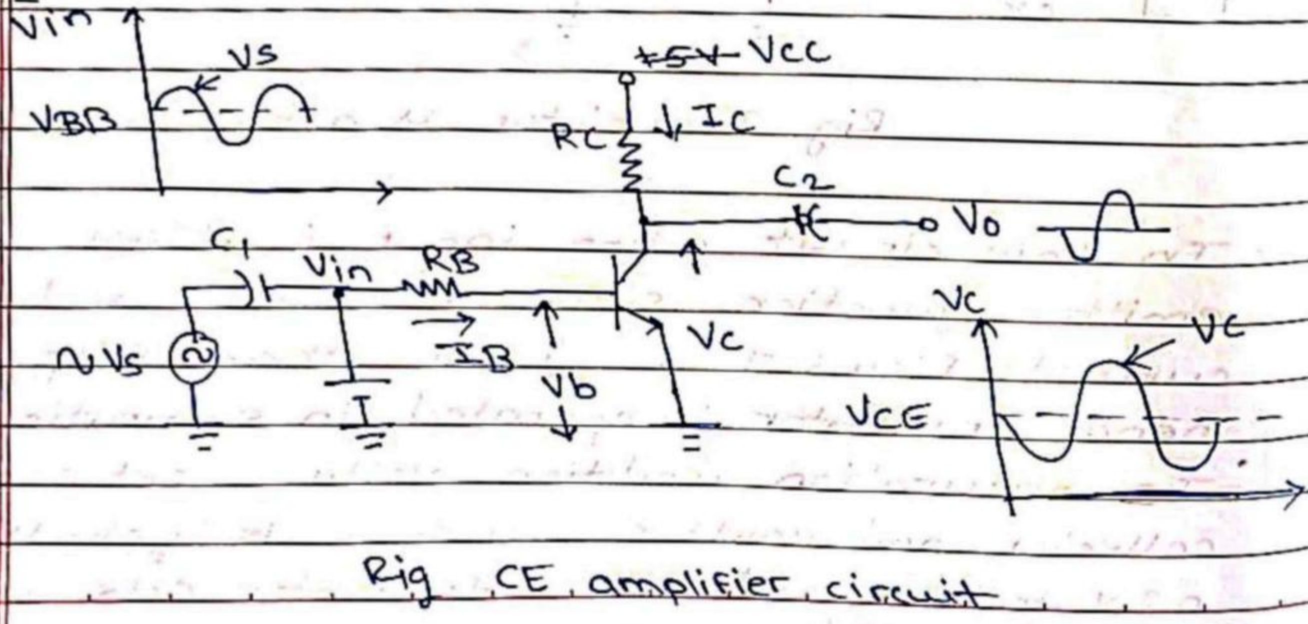
$$V_{CC} = I_C R_C + V_{CE}$$

Since $I_C = 0$, we have

$$V_{OUT} = V_{CE} = V_{CC}$$

* BJT as CE Amplifier :-

- A circuit which amplifies a small input signal to give magnified output signal having same frequency as that of input signal is called an amplifier.



Rig. CE amplifier circuit

- The ratio of magnitude of output signal to input signal is called the voltage gain of the amplifier.
- It is important to note that the values of R_B and R_C are chosen to operate transistor in active region.
- As shown in fig a small signal ac voltage, V_s is superimposed on the dc bias voltage V_{BB} by capacitive coupling.
- The small ac input voltage produces an ac base current, which result in a much larger ac collector current.

$$\Delta I_B = \frac{\Delta V_{in}}{R_B}$$

- The corresponding change in collector current, I_C is given by,

$$\Delta I_C = \beta \Delta I_B = \beta \frac{\Delta V_{in}}{R_B}$$

- The change in the output voltage due to change in the input voltage is given by,

$$\Delta V_o = \Delta I_C R_C$$

$$\because \Delta I_C = \beta \frac{\Delta V_{in}}{R_B}$$

$$= \beta \frac{\Delta V_{in}}{R_B} R_C$$

$$= \beta \frac{R_C}{R_B} \Delta V_{in}$$

$$A_V = \frac{\Delta V_o}{\Delta V_{in}} = \frac{\beta R_C}{R_B}$$

- The CE amplifier operated in the active region acts as on voltage amplifier

* ~~Appl~~

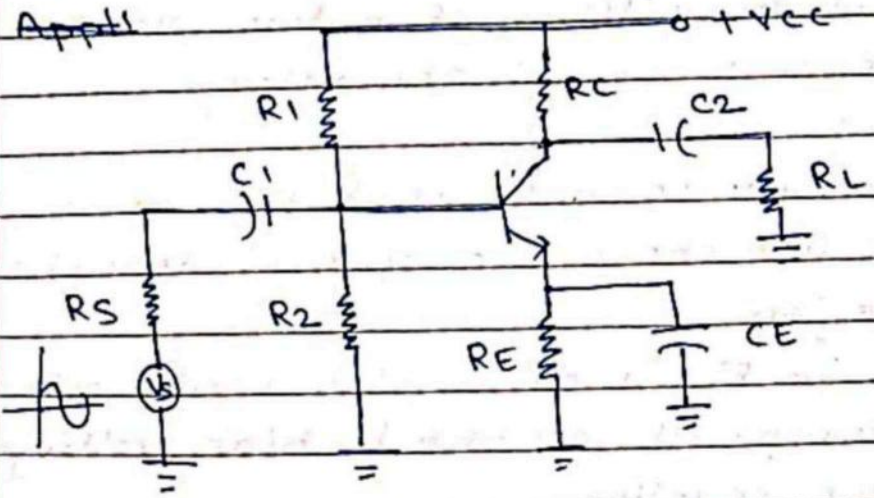


Fig. Pratical C.E. amp^r circuit

- Biasing circuit:-
  R1, R2 and RE forms the voltage divider biasing circuit for CE amplifier. It sets proper operating point for the CE amplifier.
- Input Capacitor C1:-
  This capacitor couples the signal to the base of the transistor. It blocks any d.c component present in the signal and passes only a.c. signal for amplification.
- Emitter bypass capacitor CE:-
  CE is connected in parallel with the RE. RE to provide a low reactance path to the amplified a.c. signal.
- Output coupling capacitor C2:
  C2 couples the output of the amplifier to load or to the next stage of amplifier. It blocks d.c. and passes only a.c. part of the amplified signal.

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* Applications of BJT :
- Transistor can be used as a switch.
- used as an amplifier.
- used as a current and voltage amplifier.
- As a switch. in SMPS and digital circuits.
- used in oscillator circuits and feedback amplifiers.

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Metal Oxide Semiconductor Field Effect Transistor (MOSFET)

- The MOSFET can be made very small and hence can be used to design high density VLSI circuits.
- The MOSFET differs from the JFET in that it has no p-n junction structure; instead the gate of the MOSFET is insulated from the channel by a silicon dioxide (SiO_2) layer. Due to this the input resistance of MOSFET is greater than JFET. Because of the insulated gate, MOSFETs are also called IGFETs.

* Types of MOSFET

- The two basic types of MOSFETs are:-

a) Depletion (D) MOSFET

b) Enhancement (E) MOSFET

- MOSFETs suitable for high power applications are called power MOSFETs.

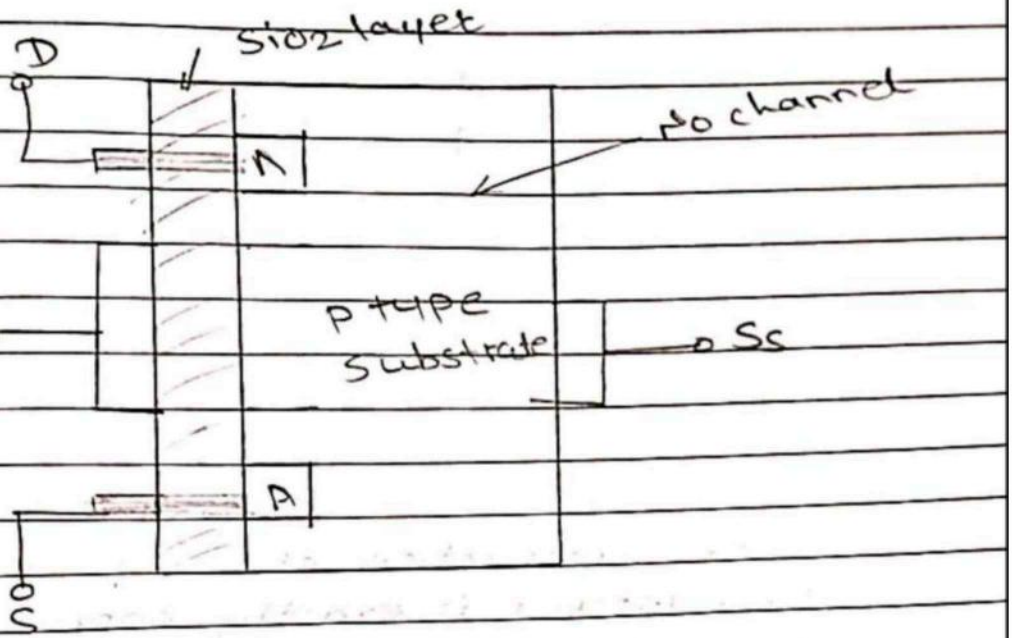
Power MOSFET

LDMOSFET | VMOSFET | TMOSFET

- MOSFET Designed for RF Amplifications
  - Dual Gate MOSFET.

Substrate is a foundation layee that supports the transistoe structure. substrate is used to control V_T

* E-MOSFET :-



- Fig. shows construction of n-channel enhancement type MOSFET
- Two highly doped n-regions are diffused into a lightly doped p-type substrate. The source and drain are taken out through metallic contacts to n-doped regions.
- The channel between two n-regions in absent in the enhancement type MOSFET. The SiO_2 layer is still present to isolate the gate metallic platform from the region between the drain and source, but now it is simply separated from a section of the p-type material.
- It differs in construction from the depletion MOSFET in that it has no physical channel.

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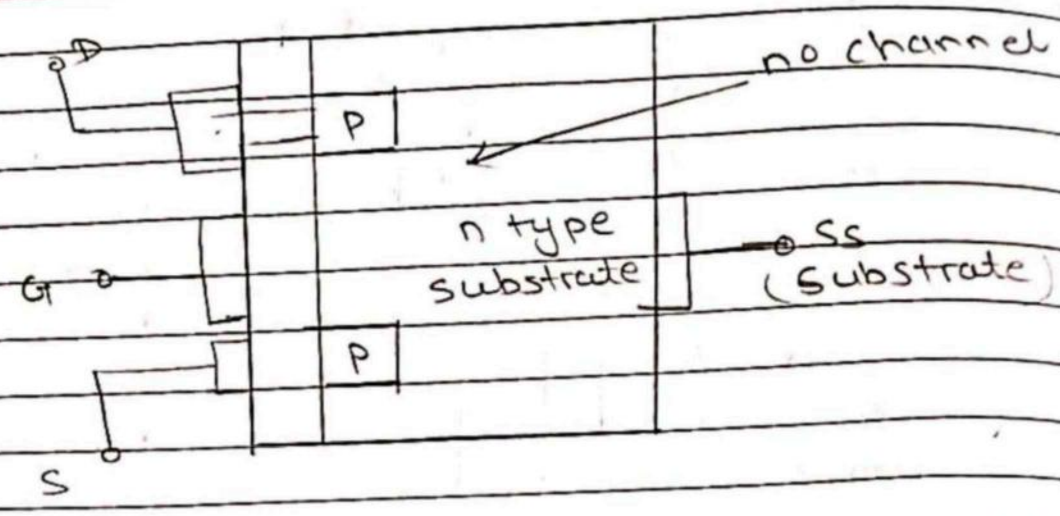
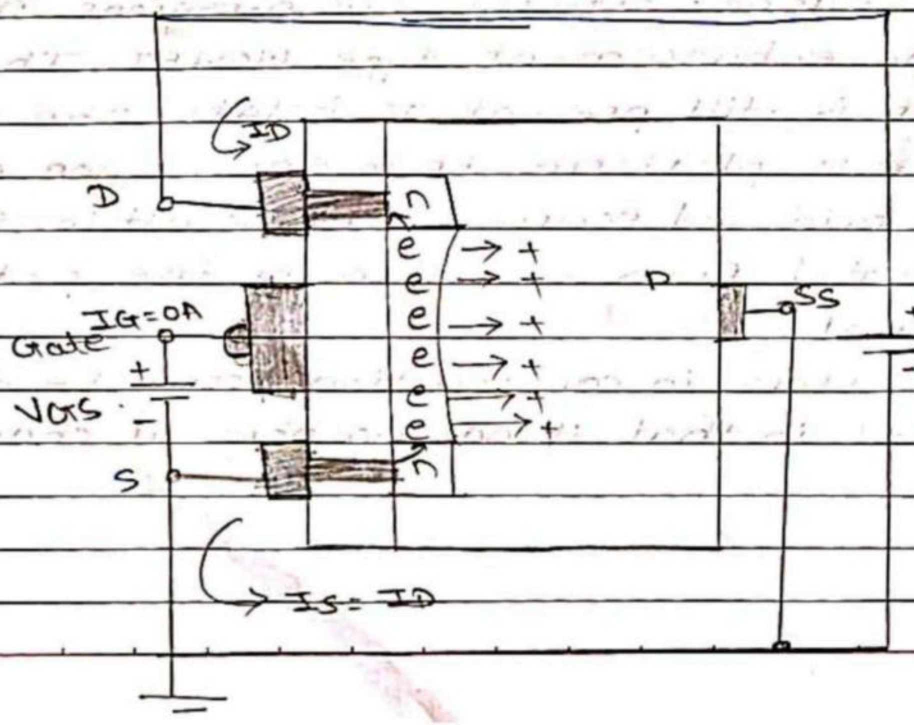


- The construction of the p-channel enhancement type MOSFET is exactly opposite to that of n-channel enhancement type MOSFET.
- Here, the substrate is of n-type and regions are of p-type

* Operation :-
- This type of MOSFET operates only in the enhancement mode and has no depletion mode



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- $V_{GS} = 0$:

On application of drain to source voltage V_{DS} and keeping gate to source voltage zero by directly connecting gate terminal to the source terminal, pratically zero current flows, quite different from the depletion type MOSFET.

- $V_{GS} > 0$:

If we increase magnitude of V_{GS} in the +ve direction, the concentration of electrons near the SiO_2 surface increases. At a particular value of V_{GS} there is a measurable current flow between drain & source.

This minimum value of V_{GS} at which I_D starts flowing is called threshold voltage denoted by V_T.

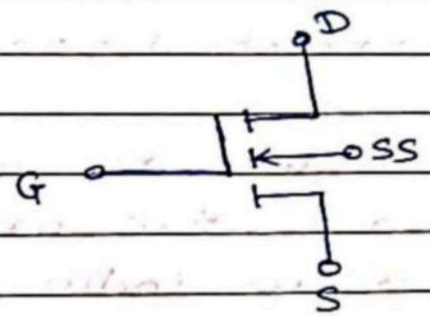
Thus we can say that in an enhancement type n-channel MOSFET, a positive gate voltage above a threshold value induces a channel and hence the drain current by creating a thin layer of negative charges in the substrate region adjacent to the SiO_2 layer.

$V_{GS} = 0$ - No conduction

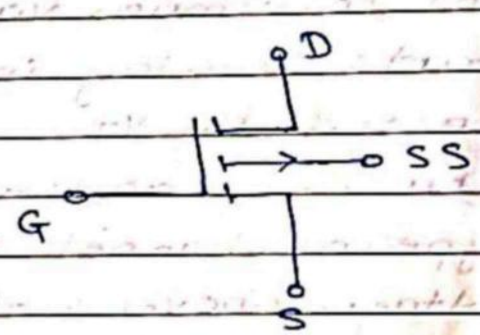
$V_{GS} > 0$ ... e^- near SiO_2 start to flow current.

- The conductivity of the channel is enhanced by increasing the gate to source voltage & thus pulling more electrons into the channel. For any voltage below the threshold value, there is no channel
- Since the channel does not exist with V_{GS} and ~~en~~ enhanced by the application of a positive gate to source voltage, this type of MOSFET is called an enhancement type MOSFET.

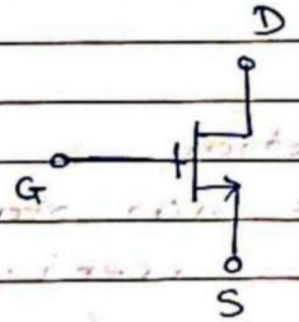
Symbols:- Enhancement MOSFET



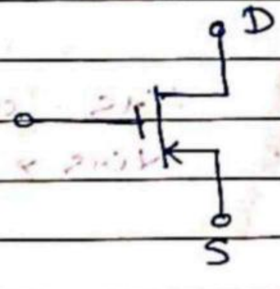
n-channel



p-channel



Simplified n-channel



Simplified p-channel

V-I characteristics of n-channel EMOSFET

a) Transfer characteristics.

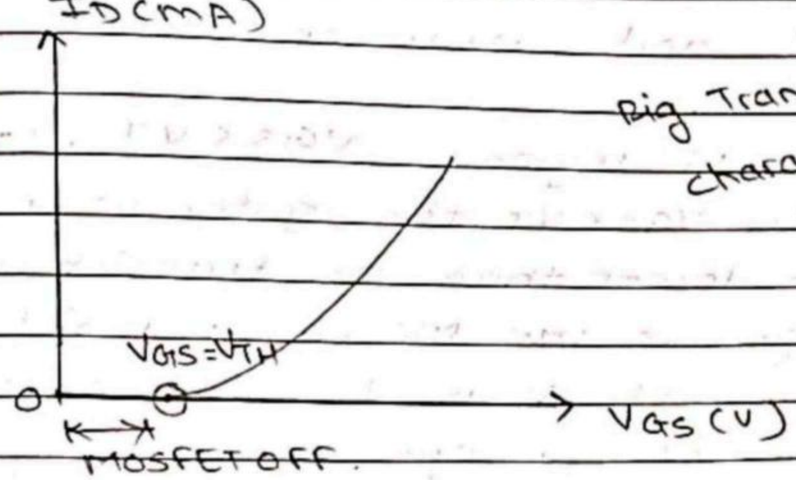


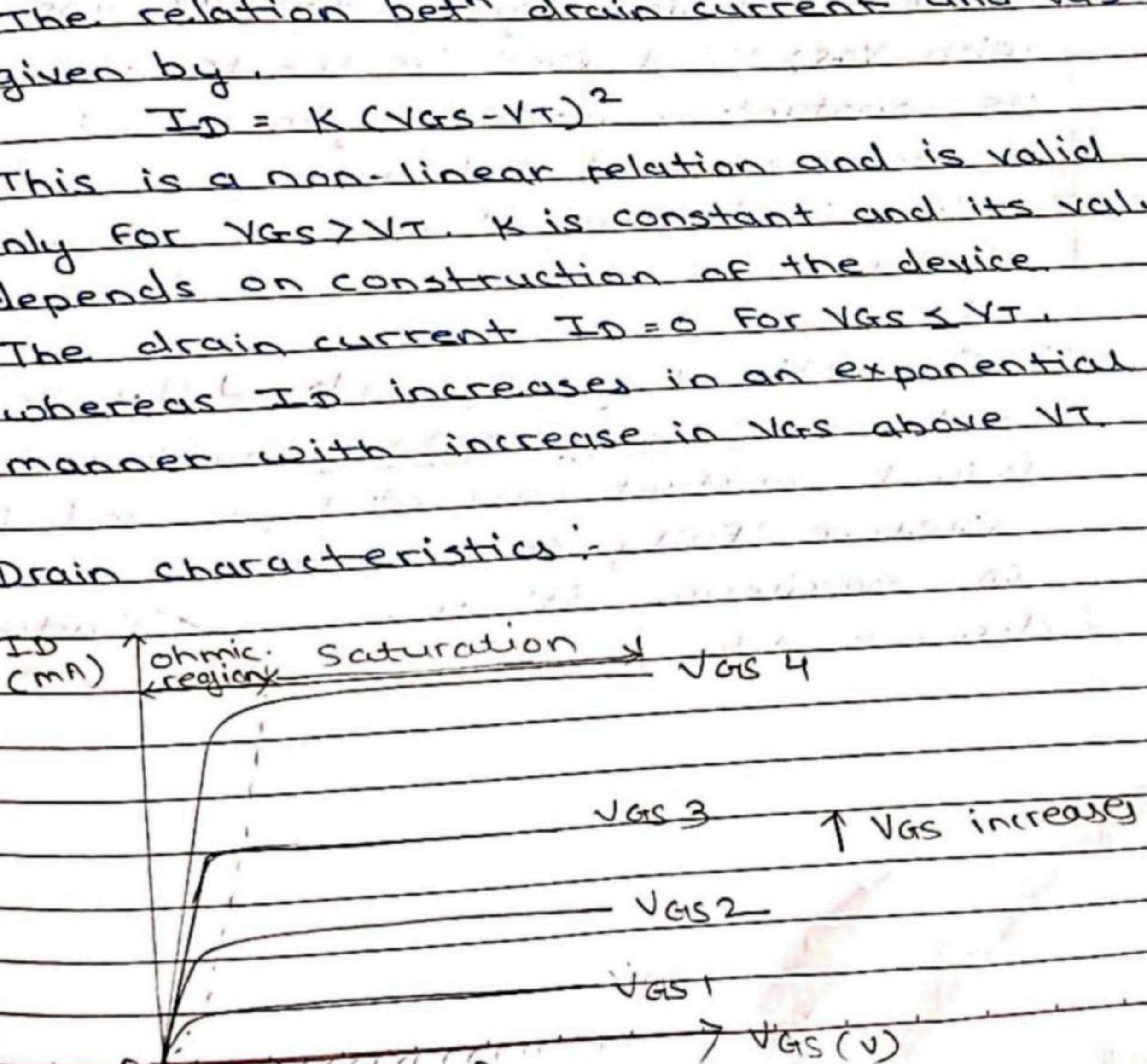
Fig Transfer characteristics

- It is now totally in the positive V_{GS} region and remains zero till $V_{GS} = V_T$ (Threshold vtg)
- The relation betn drain current and V_{GS} is given by.

$$I_D = K(V_{GS} - V_T)^2$$

- This is a non-linear relation and is valid only for $V_{GS} > V_T$. K is constant and its value depends on construction of the device.
- The drain current $I_D = 0$ for $V_{GS} \leq V_T$, whereas I_D increases in an exponential manner with increase in V_{GS} above V_T.

b) Drain characteristics:-



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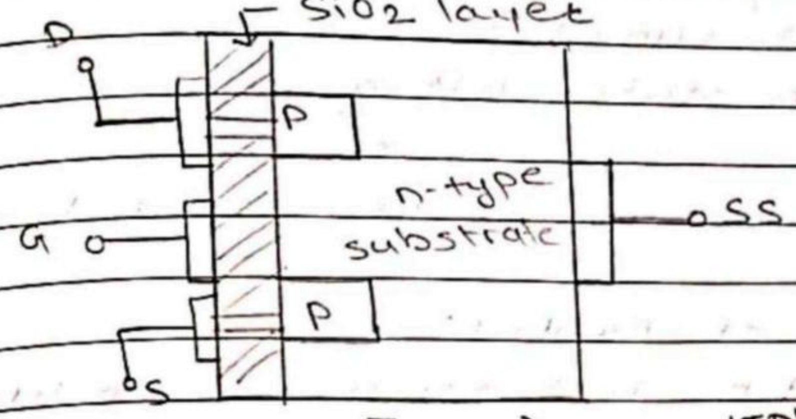
- The drain characteristics has been divided into three regions viz. cut-OFF, Linear / ohmic and saturation region.

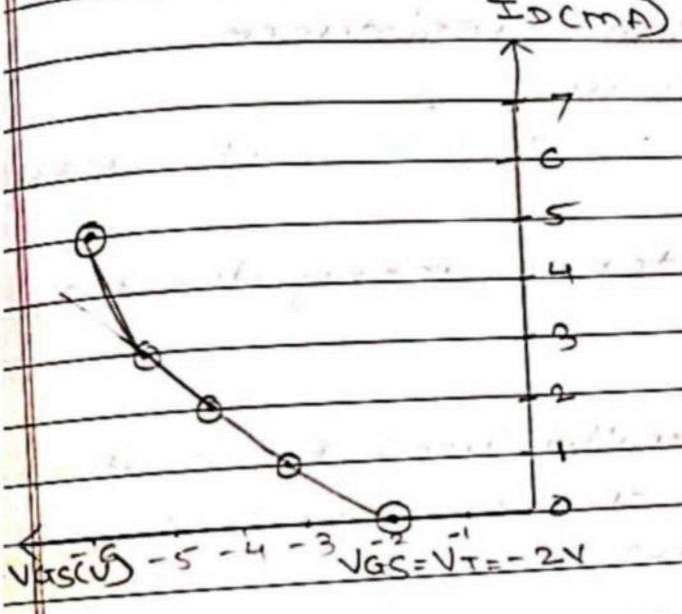
i) Cut-OFF region $V_{GS} < V_T$, $I_D = 0$, open s/w
with $V_{GS} < V_T$ the gate-source voltage is much lower than the transistors threshold voltage so the MOSFET transistor is switched 'Fully-OFF' thus $I_D = 0$, with the transistor acting like an open switch regardless of the value V_{DS}.

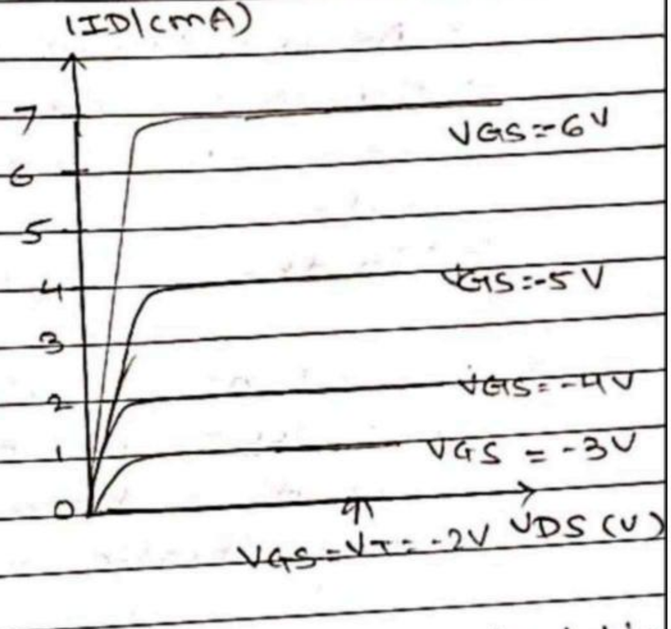
ii) Linear (Ohmic) Region $V_{GS} > V_T$, $V_{DS} < V_{GS}$
with $V_{GS} > V_T$ & $V_{DS} < V_{GS}$ the transistor is in its constant resistance region behaving as a voltage controlled resistance whose resistive value is determined by the gate voltage, V_{GS} level.

iii) Saturation Region : - closed s/w
with $V_{GS} > V_T$ & $V_{DS} > V_{GS}$ the transistor is in its constant current region and is therefore 'Fully-ON'. The drain current I_D = maximum with the transistor acting as closed switch.

* P-channel E-MOSFET :







Drain characteristic

Transfer ch^s

Advantages of MOSFET :-

- Very high input resistance (Few GΩ)
- Very low gate current is required.
- Better thermal stability.
- Small size
- can operate at a very high frequencies.
- low internal noise.

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Disadvantages of MOSFET :-
- High input capacitance
- large on state voltage drop.
- More power loss in the device.
- Handling precautions are required to be Follo

Applications of MOSFET:
- As a switch, high frequency amplifier.
- As a voltage variable resistance.
- Constant current source.
- In the logic circuits such as inverter, NAND gate.
- In the semiconductor memory devices.

* MOSFET as a switch :-
- E-MOSFET are generally used for switching applications because of their threshold characteristic VGS(th)

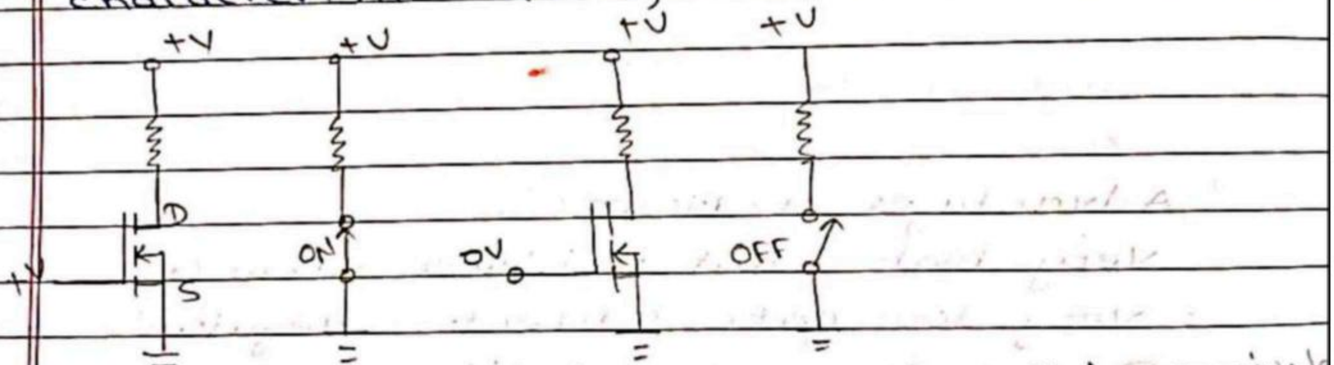


Fig. n channel MOSFET & switch equivale

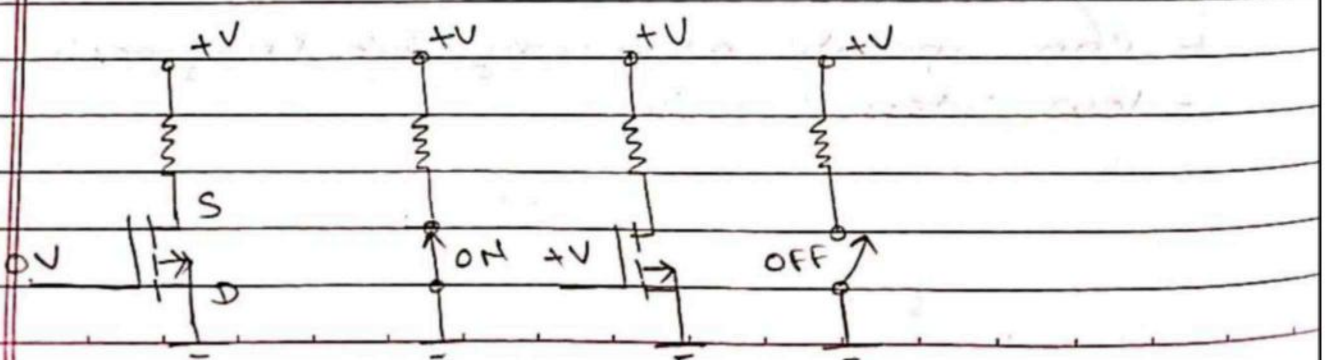


Fig. p channel MOSFET & switch equivalent.

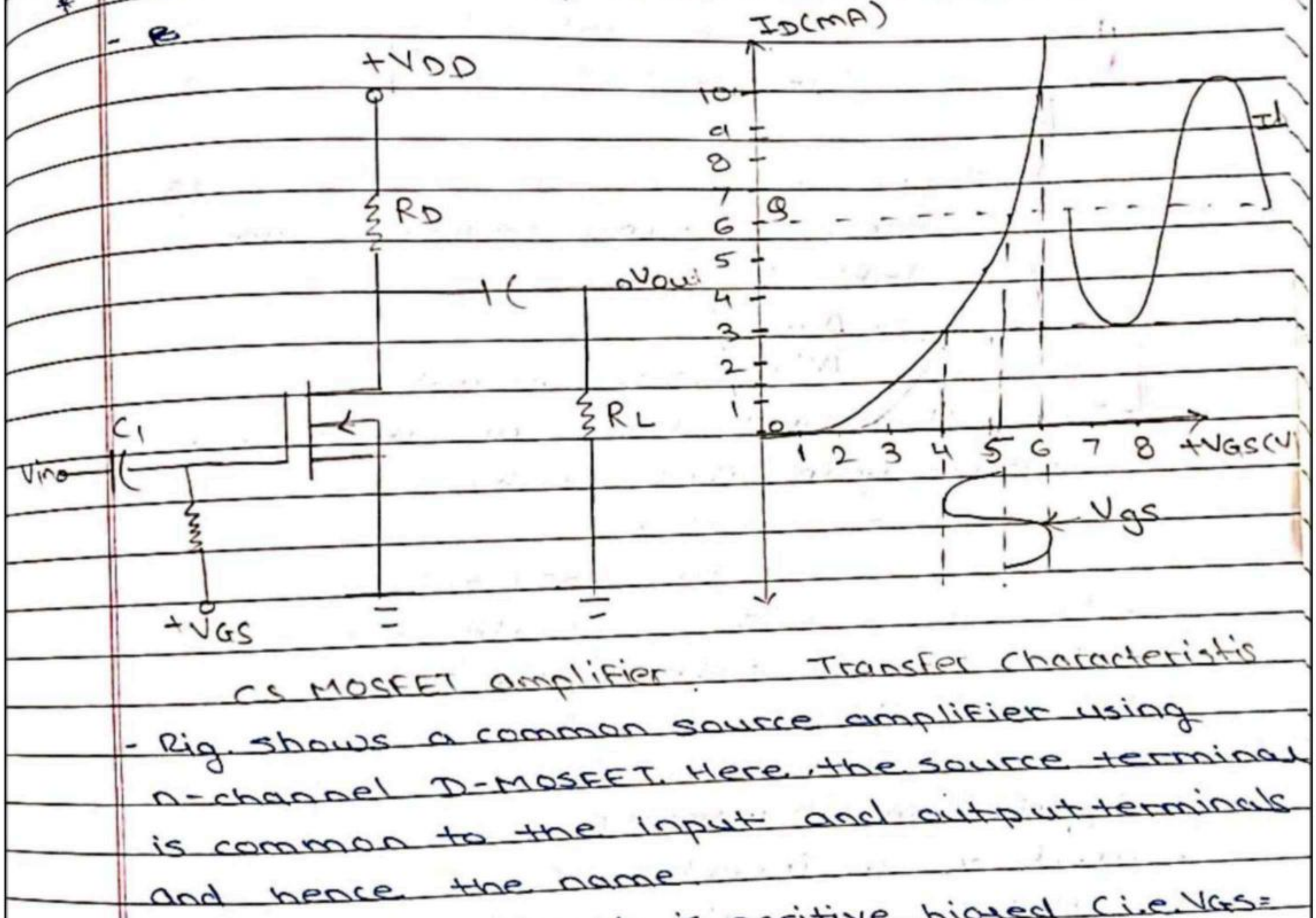
$(V_{GS} < V_T) \rightarrow$ S/W OFF

- When the gate-to-source voltage is less than the threshold value, the MOSFET is OFF.

$V_{GS} > V_T$ S/W ON

- When the gate-to-source voltage is greater than the threshold value, the MOSFET is on.
- When V_{GS} is varied between $V_{GS(th)}$ and $V_{GS(ON)}$ the MOSFET is being operated as a switch.

* MOSFET as an Amplifier :-



CS MOSFET amplifier. Transfer Characteristics

- Fig. shows a common source amplifier using n-channel D-MOSFET. Here, the source terminal is common to the input and output terminals and hence the name.
- The amplifier circuit is positive biased (i.e. V_{GS} = 5V) with an a.c. source coupled to the gate through the coupling capacitor C_1.
- When a.c. input signal is absent, the gate is at 5V d.c. and the source terminal is grounded, thus V_{GS} = 5V.