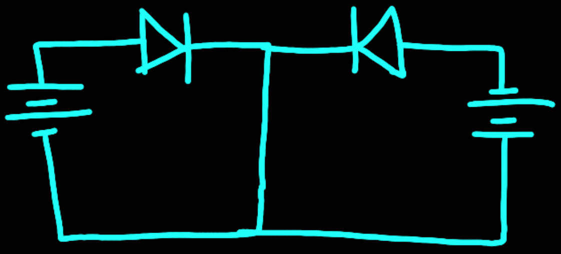
Transistor

- Transfer
- Resistor



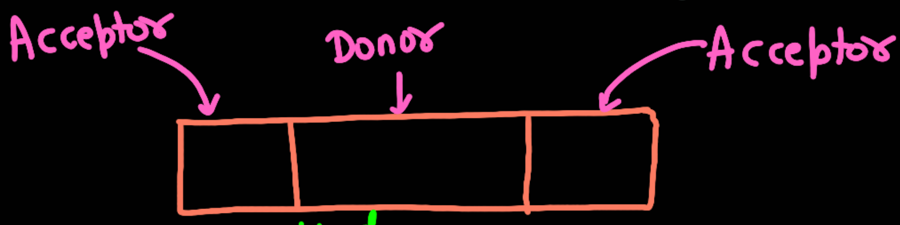
I_{small} R_{small} R_{Large} I_{small}

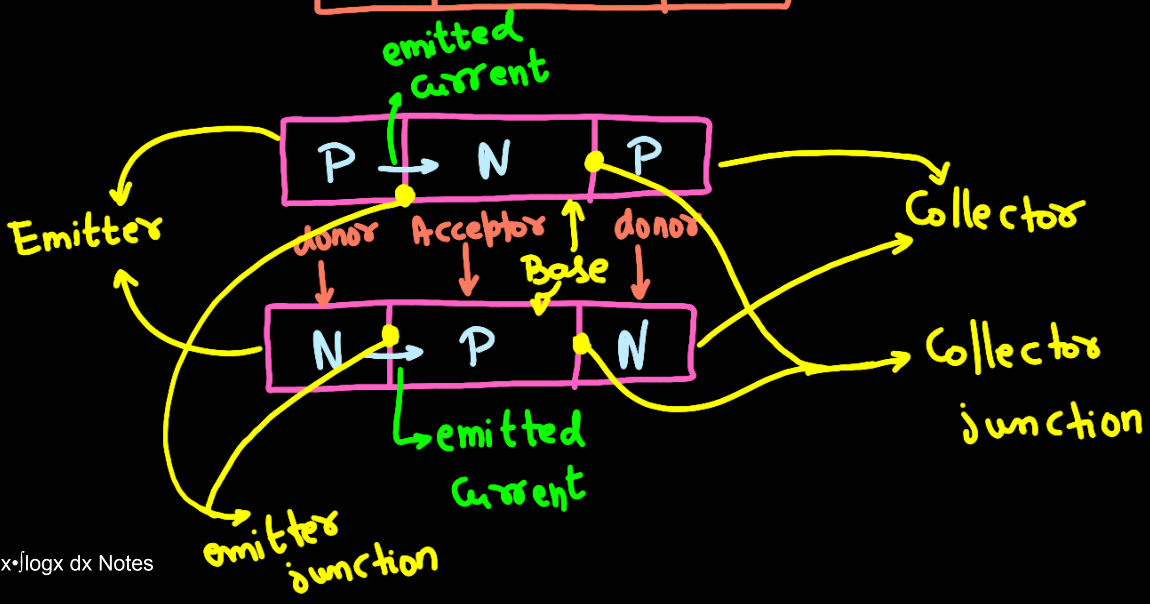
These are equal

$$\boxed{\text{Gain} = \frac{O/P}{I/P}}$$

Transistor

- Single crystal made of Si or Ge
- Crystal is continuous, such that 2 junctions are formed
- Can be either PNP or NPN





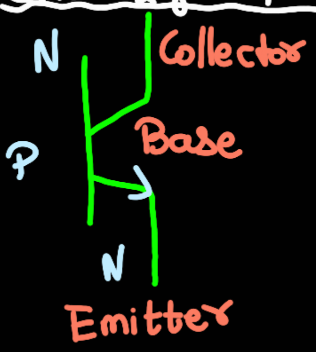
★ There are three regions in transistor :-

① Emitter :- Provides large numbers of charge carriers. Heavily doped and moderately sized

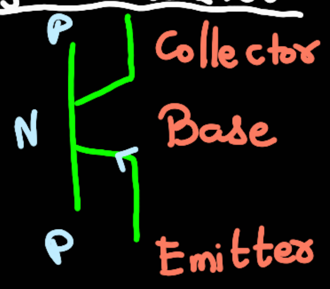
② Base :- Very thin & lightly doped

③ Collector :- large in size & moderately doped

Ckt symbol of transistor :-



N-P-N transistor



P-N-P transistor

Note: Arrow always in dirn of forward Bias, i.e. from P to N

Transistor Configurations :-

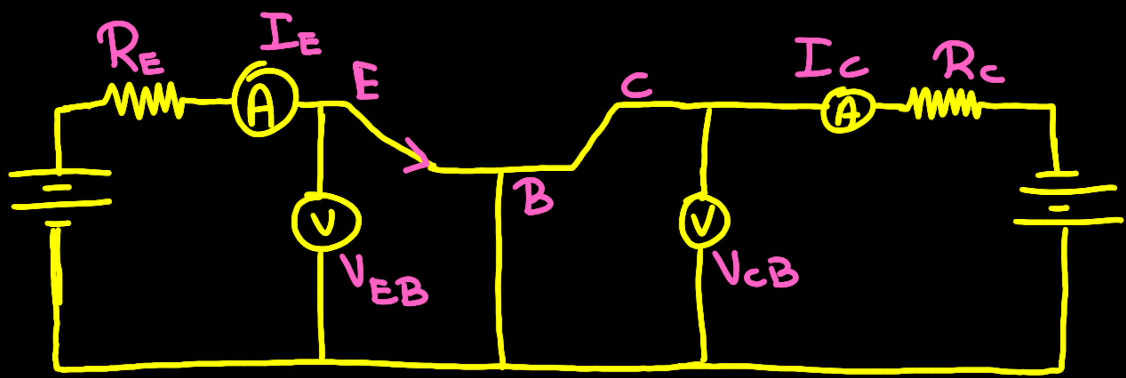
① Common Base (CB)

② Common Emitter (CE)

③ Common Collector (CC)

4 H Parameters:
Input Impedence
Reverse Voltage Ratio } I/P
&
Output Admitance
Forward Current Gain } O/P

Common Base (CB) Configuration:-

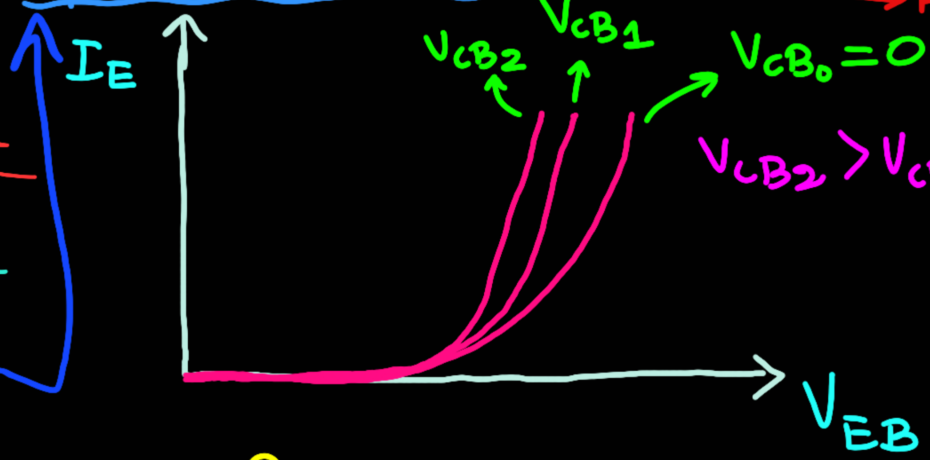


Input Circuit (V_{EB}, I_E) → I/P characteristics

Output circuit (V_{CB}, I_C) → o/P characteristics

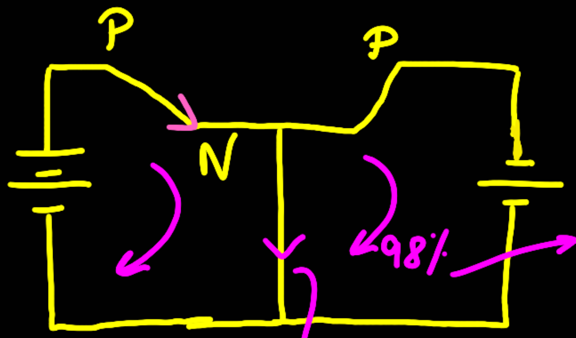
★ I/P characteristics:-

In input characteristics i/p is constant & o/p is varying



Always before V_{CB0}!!!

$V_{CB2} > V_{CB1} > V_{CB0}$



98% → Collector current

2% base current

Note

Emitter j^n → F.B ; Collector j^n is reverse biased

I/P resistance

$R_I = \frac{V_{EB}}{I_E}\Big|_{V_{CB}}$ → Static

$r_i = \frac{\Delta V_{EB}}{\Delta I_E}\Big|_{V_{CB}}$ → Dynamic

Dynamic → I/P resistance, I/P impedance

H-parameters:-

↳ A way of measuring → alternative for ohm's law

① h_{ib}

h → h-parameter

i → I/P impedance

b → Base configuration

$$\boxed{h_{ib} = \frac{\Delta V_{EB}}{\Delta I_E}\Big|_{V_{CB}}}$$

② Reverse voltage ratio (h-parameter)

↳ $\frac{o/p}{i/p}$

↳ But here ∵ reverse ratio its $\frac{i/p}{o/p}$

h_{rb}

h → h-parameter

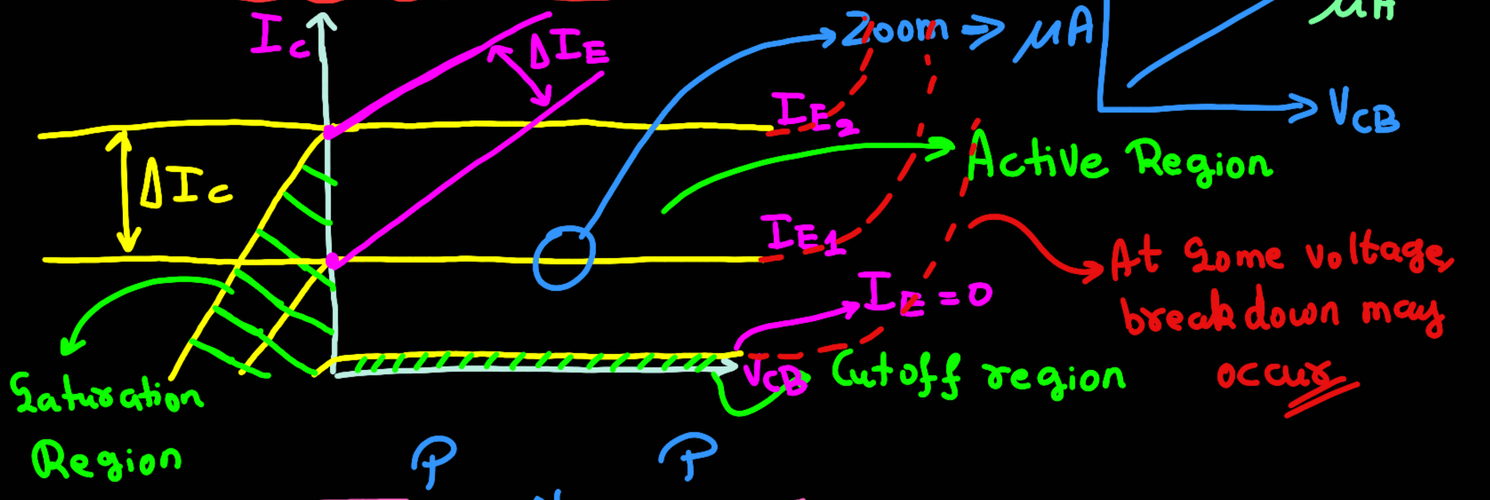
r → reverse voltage ratio

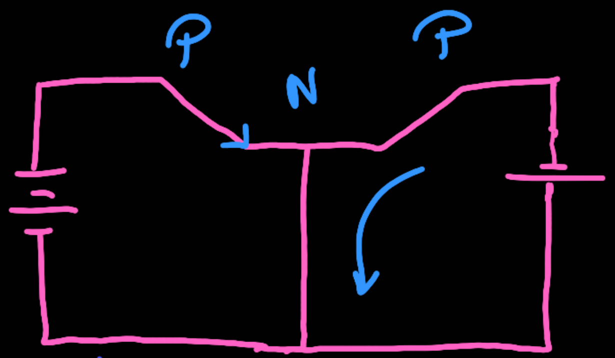
b → Common base configuration

$$\boxed{h_{rb} = \frac{\Delta V_{EB}}{\Delta V_{CB}}\Big|_{I_E}}$$

Δv•x•∫logx dx Notes

Output characteristics:-





① O/P impedence

$$R_o = \frac{V_{CB}}{I_C}\Bigg|_{I_E}$$

h-parameter

① $$h_{ob} = \frac{\Delta I_C}{\Delta V_{CB}}\Bigg|_{I_E}$$

o/p admittance

Common base configuration

In o/p char o/p is constant & i/p keeps on varying.

h-parameter

② $$h_{fb} = \frac{\Delta I_C}{\Delta I_E}\Bigg|_{V_{CB}} = \alpha \rightarrow AC$$

forward current gain

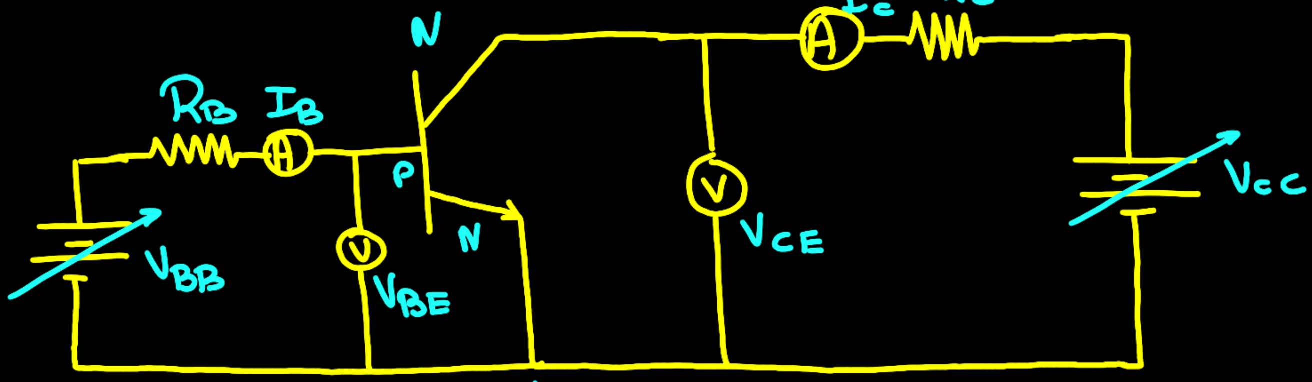
Common Base config

$$\alpha_{DC} = \frac{I_C}{I_D}$$

→ $\dfrac{\text{Output current}}{\text{Input current}}$

$\dfrac{\text{Output}}{\text{Input}}$

Common Emitter (CE) Configuration :-

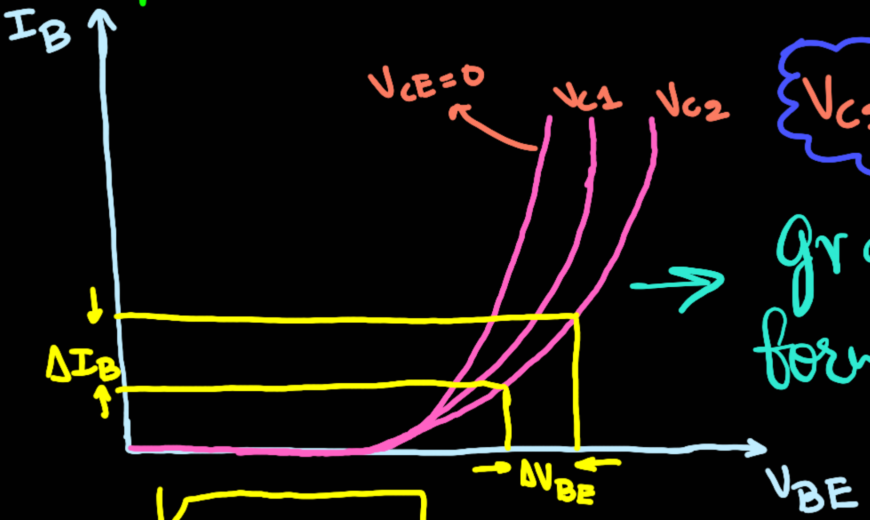


I/P ckt (V_{BE}, I_B)

O/P ckt (V_{CE}, I_C)

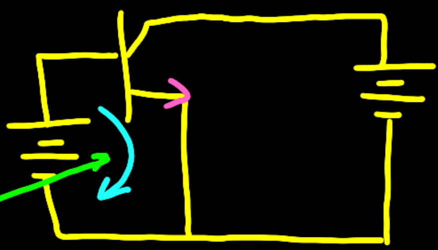
Emitter j^n is F.B
Collector j^n is R.B

☆ Input Characteristics



$V_{c2} > V_{c1} > V_{CE\,0}$

→ graph goes forward as o/p ↑, (unlike CB, where graph goes backward)



Current flow dir^n

① $h_{ie} = \left.\dfrac{\Delta V_{BE}}{\Delta I_B}\right|_{V_{CE}}$

h-parameter

I/P impedance

CE config

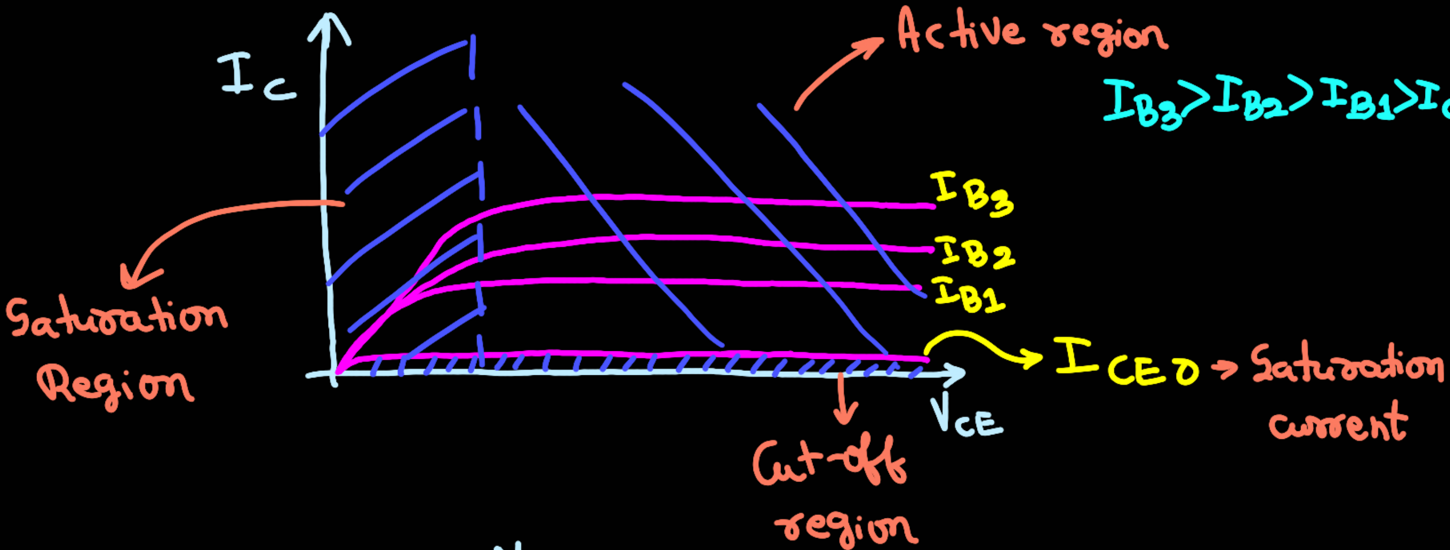
② $h_{re} = \left.\dfrac{\Delta V_{BE}}{\Delta V_{CE}}\right|_{I_B}$

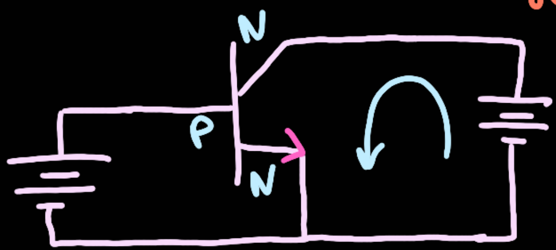
h-parameter

reverse voltage ratio

CE config

✯ Output characteristics :-





① $h_{oe} = \left.\dfrac{\Delta I_C}{\Delta V_{CE}}\right|_{I_B}$ → o/p admittance

② $h_{fe} = \left.\dfrac{\Delta I_C}{\Delta I_B}\right|_{V_{CE}} = \beta$ → forward current gain

Relation b/w α & β :-

W.K.T :- $I_E = I_B + I_C$) ÷ I_C throughout

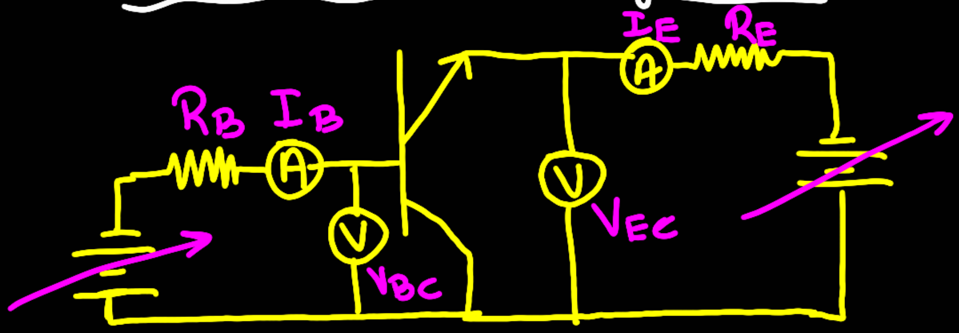
$$\frac{I_E}{I_C} = \frac{I_B}{I_C} + \frac{I_C}{I_C}$$

→ $\alpha = \dfrac{I_C}{I_E}$ | $\beta = \dfrac{I_C}{I_B}$

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

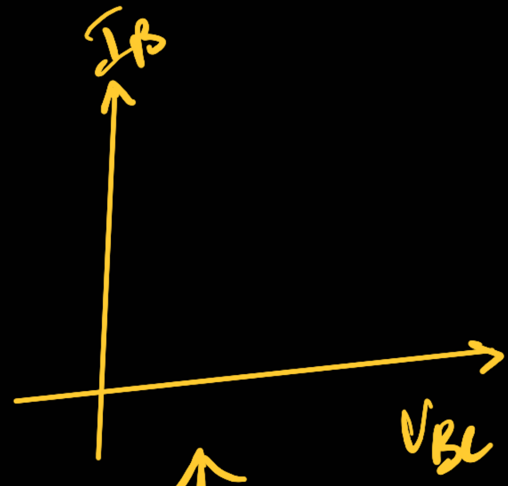
→ Required relation

Common Collector Configuration :-

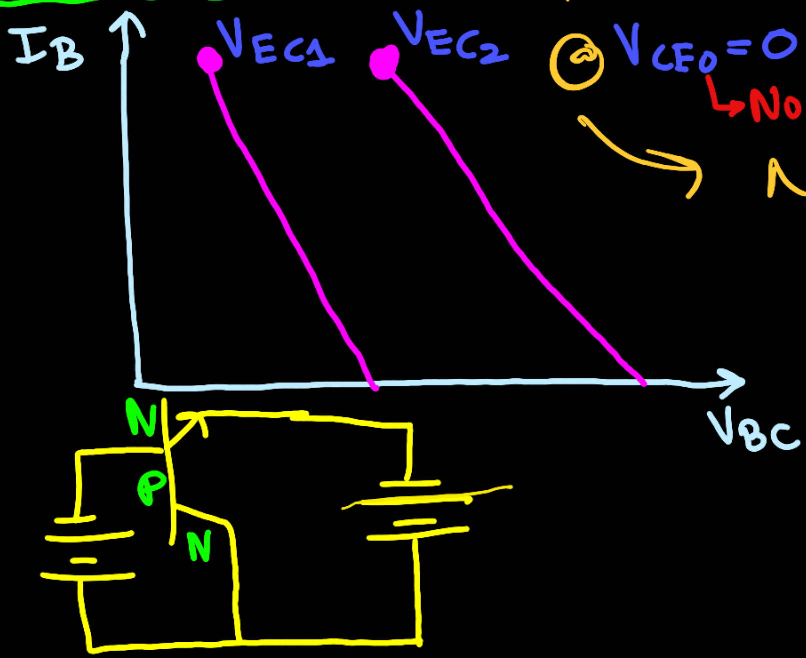


I/P ckt | O/P ckt

V_{BC}, I_B | V_{EC}, I_E



I/P characteristics :-



@ $V_{CEO} = 0$

No current flow

No plotting

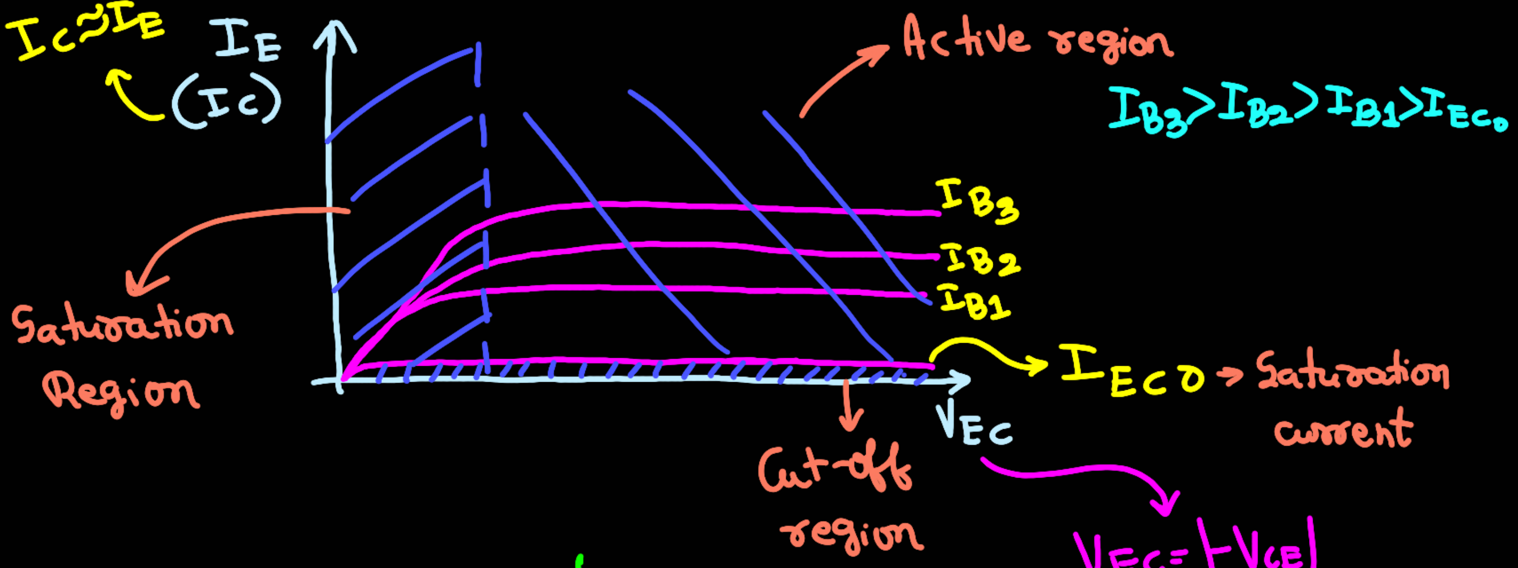
① $h_{ic} = \left.\dfrac{\Delta V_{BC}}{\Delta I_B}\right|_{V_{EC}}$

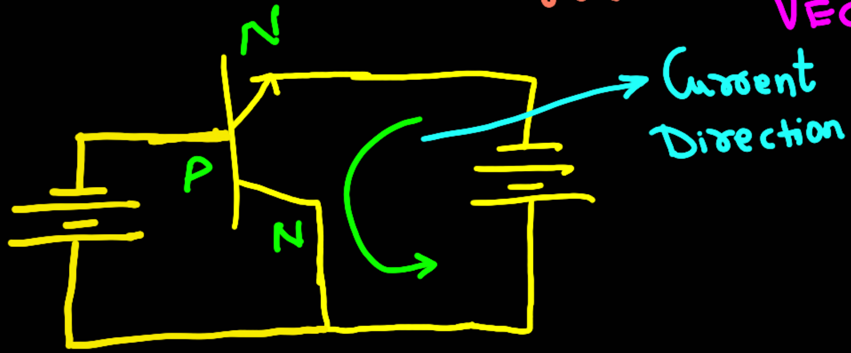
I/P impedance

② $h_{rc} = \left.\dfrac{\Delta V_{BC}}{\Delta V_{EC}}\right|_{I_B}$

Reverse voltage ratio

✪ O/P characteristics:-





① $h_{oc} = \left.\dfrac{\Delta I_E}{\Delta V_{EC}}\right|_{I_B}$

↓ O/P admittance

② $h_{fc} = \left.\dfrac{\Delta I_E}{\Delta I_B}\right|_{V_{EC}} = \gamma$

↓ forward current gain

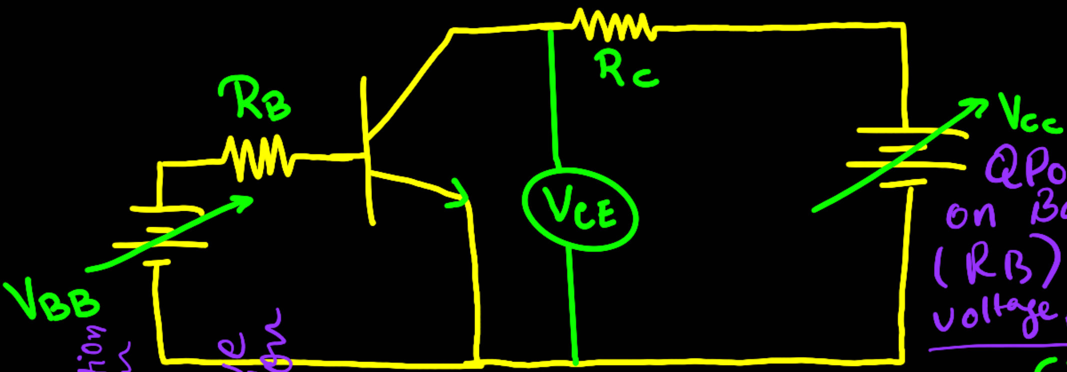
Relation b/w α, β, γ:-

$$\boxed{\gamma = \beta + 1} \qquad \boxed{\gamma = \frac{1}{1-\alpha}}$$

*Derivation not necessary

DC analysis:-

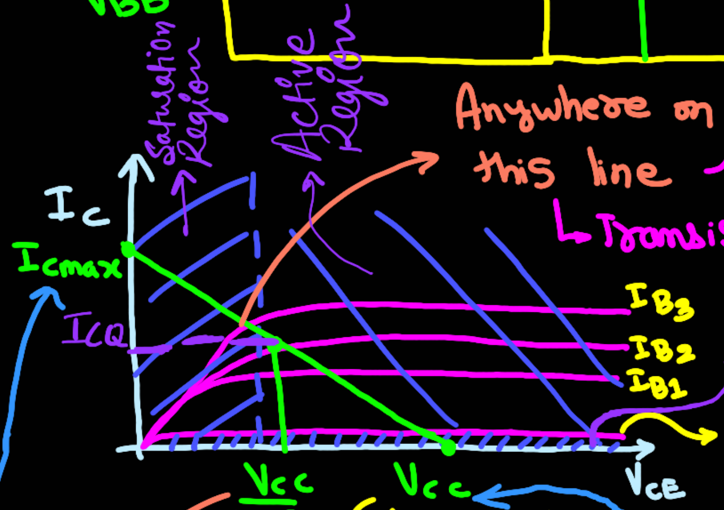
Consider CE configuration & its O/P characteristics



QPoint depends on Base Resistance (R_B) & output voltage (V_{CC})

CE config

Best amplifier configuration



Anywhere on this line Called load line

↳ Transistor can work

$(V_{CEmax}, 0)$

Corresponding point on graph for V_{CC}

$$\text{Gain} = A_V = \frac{O/P\ \text{voltage}}{I/P\ \text{voltage}}$$

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

Best operating point Called (Point Q)

$\boxed{V_{CEQ}, I_{CQ}}$

$\boxed{\frac{V_{CC}}{2}}$

Must be very stable!!

$I_{CE(max)}$ implies $V_{CE} = 0$

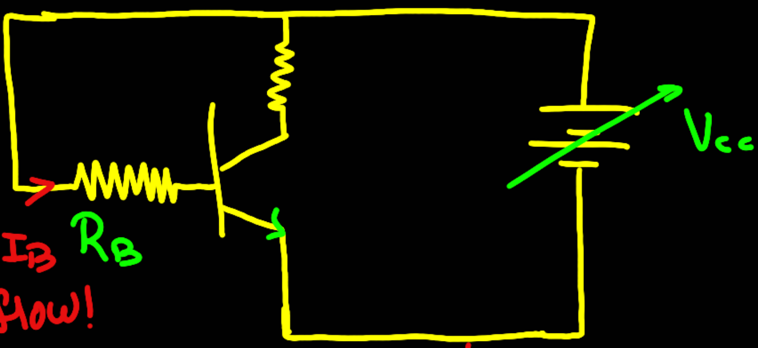
$$I_{C\,max} = \frac{V_{CC}}{R_C}$$

Amplifier gives no O/P power in saturation region & cutoff region

★ Transistor can work as an amplifier b/w these two points (V_{CC} & I_{Cmax})

★ Load Line:- Locus of the transistor operating points

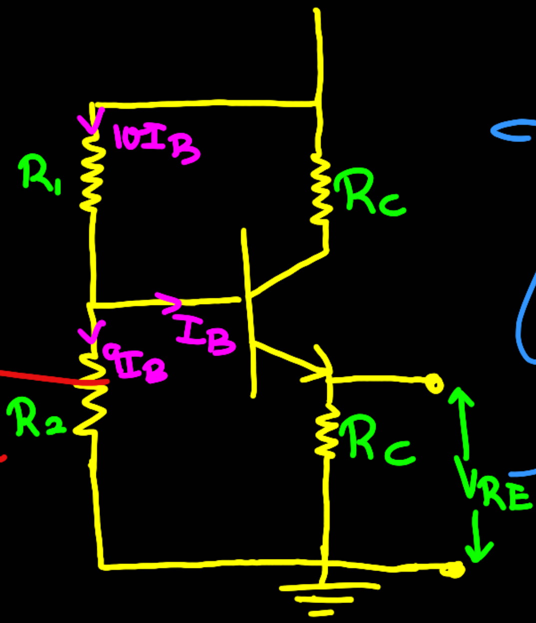
$$V_{CEQ} = \frac{V_{CC}}{2} \; ; \; I_{CQ} = I_C$$



Due to ripple from rectifier O/P, I_B & I_C can vary accordingly

1-10 I_B can flow!

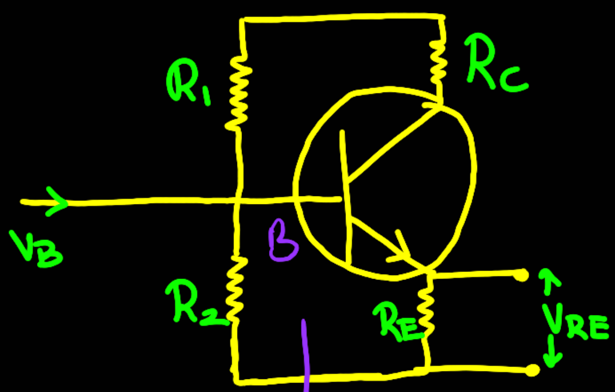
↳ To avoid & maintain constant I_B in Base, add voltage divider



Bias method

Excess current deviated

★ Bias method:-



Common Emitter Configuration

$$R_B = \frac{R_1 + R_2}{R_1 R_2}$$

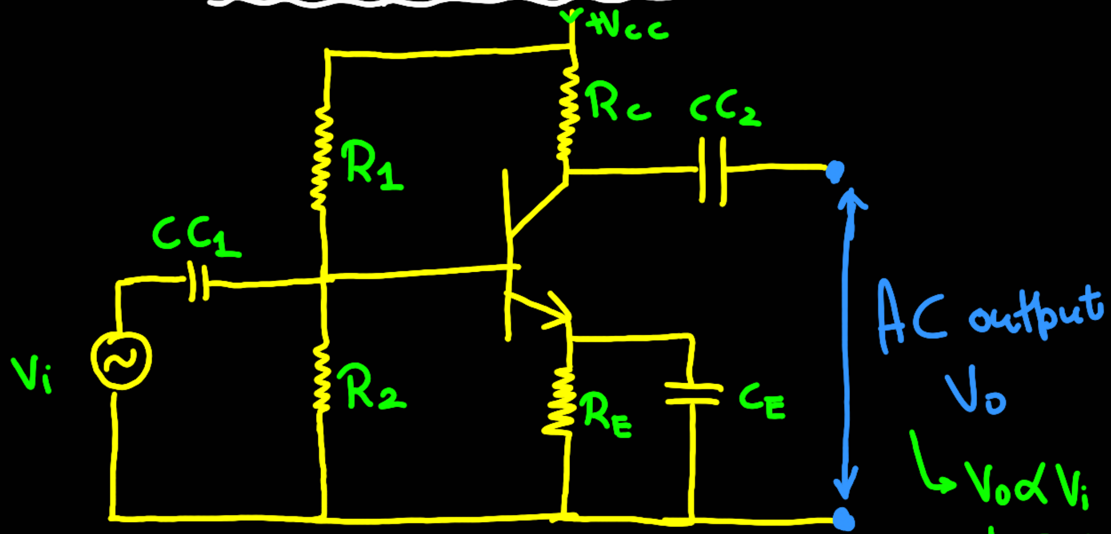
Functions :-

i) R_C :- Limit Collector current; Act as load resistor

ii) R_1 & R_2 :- Are biasing resistor (Voltage divider bias)

iii) R_E :- Emitter resistor used for stabilising Q point

RC coupled amplifier :-



↳ $V_o \propto V_i$

↳ Replicating I/P voltage

↗ Refer

Functions :- ① Rc ② R1 & R2 ③ RE Bias method on top

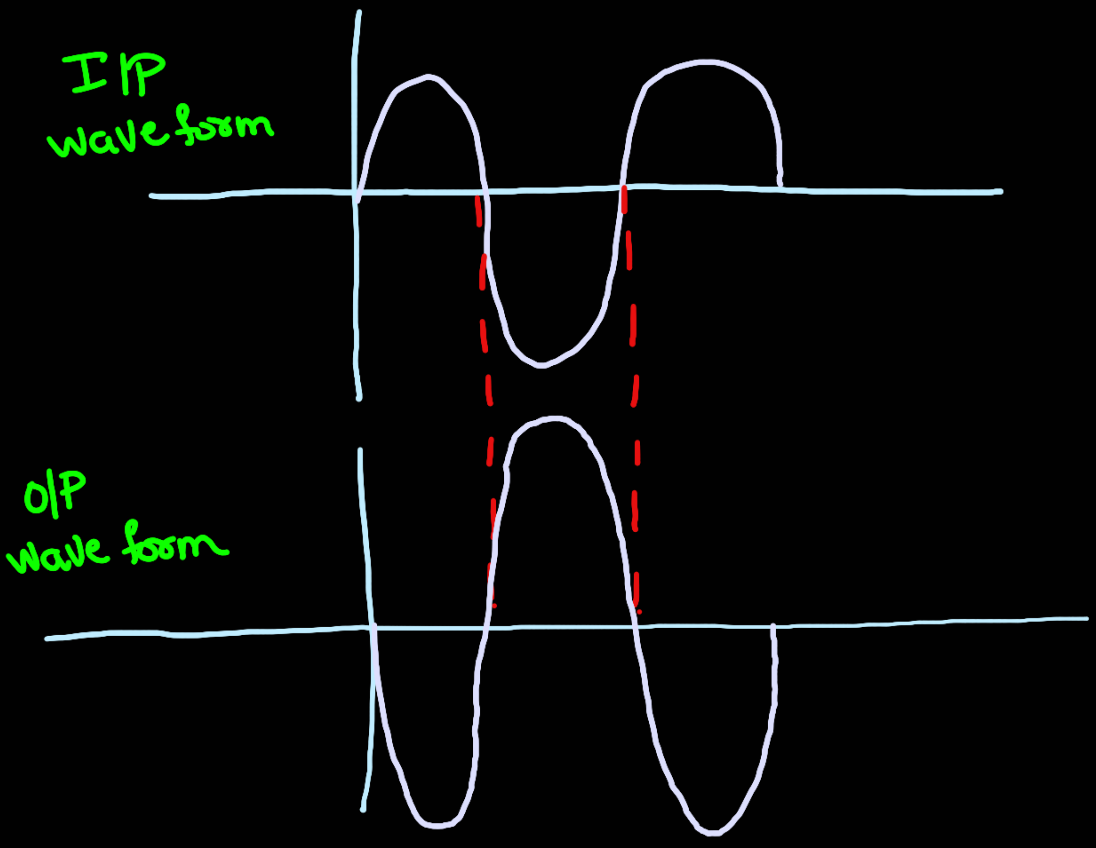
④ CC_1 & CC_2 :- Coupling capacitors; Blocks DC voltage and allow only AC voltage & improve AC gain

⑤ C_E :- Bypass Capacitor acts as shunt across R_E

$$\text{Voltage gain} = A_v = \frac{V_o}{V_i} \Rightarrow V_o = A_v V_i$$

∴ O/P voltage V_o is A_v times the input voltage V_i

* Wave forms:-

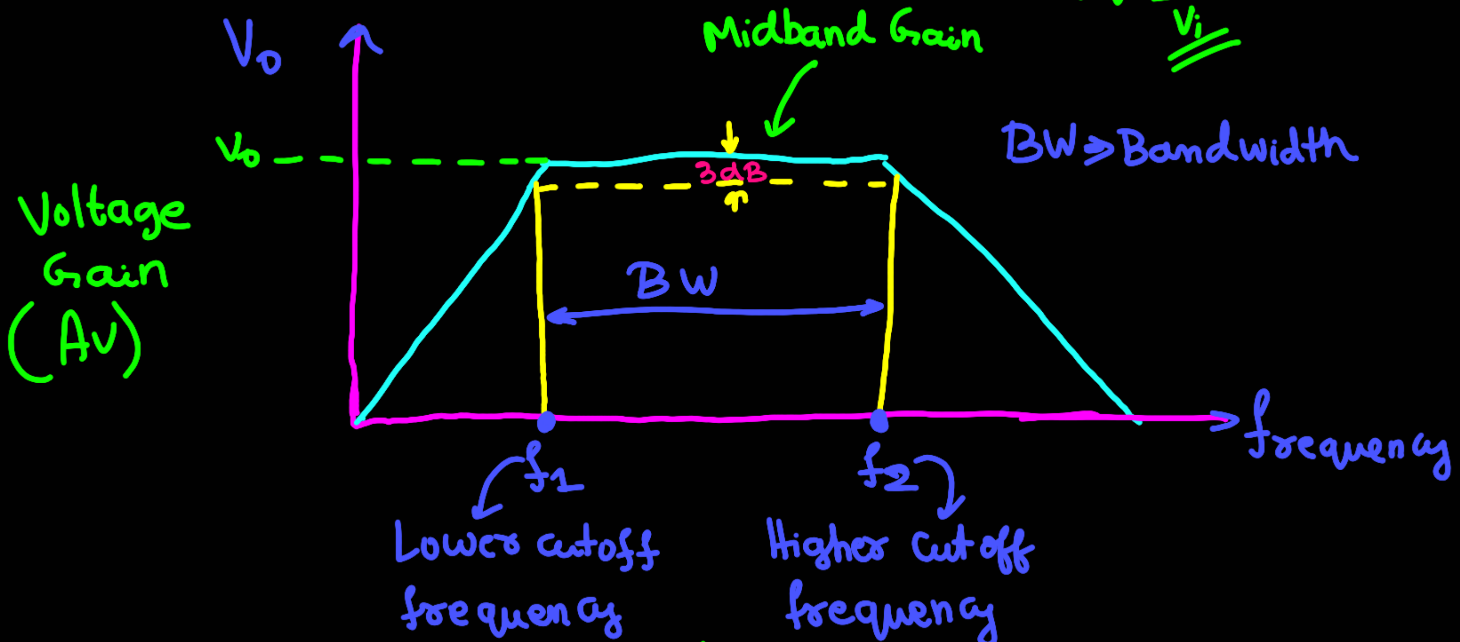


O/P is out of phase by 180°

I/P ↑es ⇒ O/P ↓es

* Understanding frequency response:-

$A_v = \frac{V_o}{V_i}$



Keep I/P voltage V_i constant & vary the I/P frequency

DC is blocked by capacitor. At 0 frequency, there is 0 O/P voltage.

$$\boxed{X_c = \frac{1}{2\pi f C}} \Rightarrow X_c \downarrow \Rightarrow f \uparrow$$

Increase in frequency, reactance reduces, O/P voltage increases

At one point it stabilises at V_o for a certain frequency range called Bandwidth. → For a larger BW, we sacifice gain and vice-versa

$$A_{v(dB)} = 20 \log_{10} \frac{V_o}{V_i} \ dB$$

↳ Voltage gain in dB

A.K.A midband gain

Gain Bandwidth Product = GBW

$\Rightarrow$ $GBW = A_v \times BW$ → for a given amplifier, GBW is constant

Junction Field Effect Transistor (JFET) :-

Simply referred to as FET

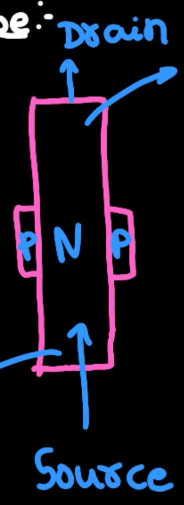
- FET
  - JFET
  - MOSFET → Metal Oxide Semiconductor Field Effect Transistor

★ **JFET**: Consist of silicon semiconductor bar either N-type or P-type with opp type of semiconductor material diffused on either side of the bar.

i.e → for N-type bar → P-type is diffused

for P-type bar → N-type is diffused

★ **Consider N-type** :-



Minority charge carrier is due to thermal agitation ⇒ e^- are sourced

e^- move in one dir^n based on biasing
↓
but always from -ve to +ve

Semiconductor bar consist of two terminals
★ Source
★ Drain

P-type diffused to the bar forms a terminal called "Gate"

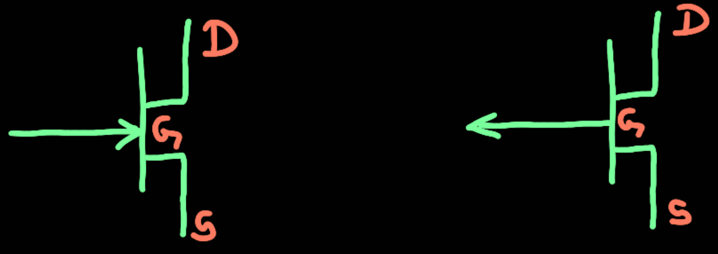
∴ JFET is a three terminal device consisting of source, drain & gate

e^- move from source to drain when proper voltage is applied b/w source & drain.

source	drain
↓	↓
-ve voltage	+ve voltage

★ JFET is either N-channel or P-channel
(The bar is the channel)

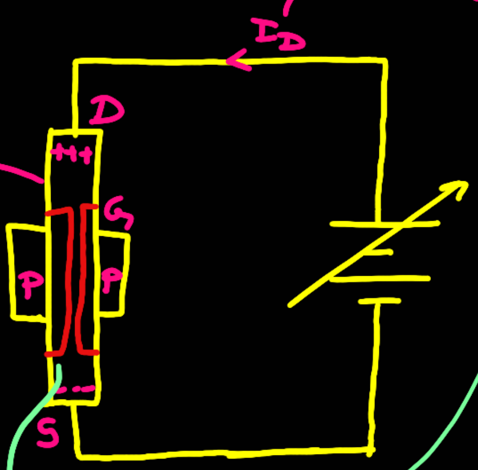
Circuit symbol for JFET:-



N-channel FET   P-channel FET

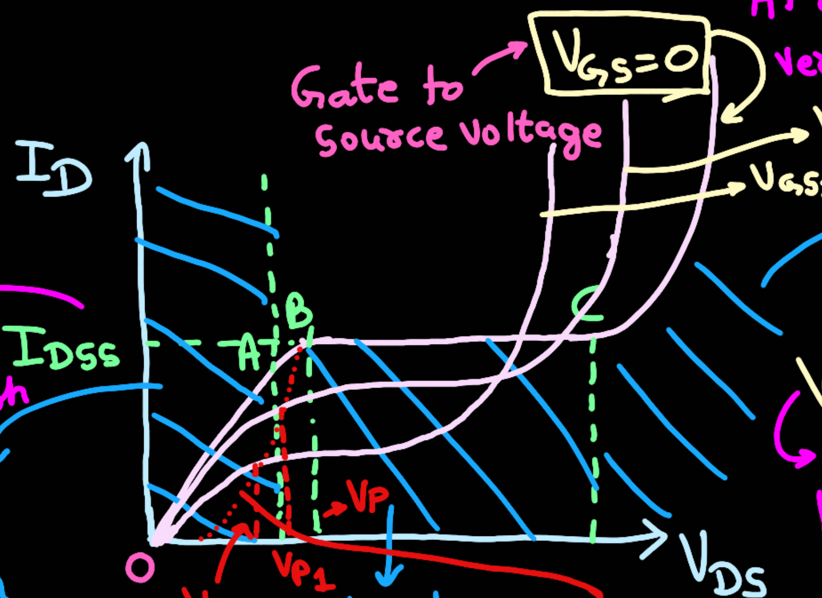
Characteristics of JFET:- → O/P characteristics

Consider N-channel FET, +ve voltage applied to drain, -ve voltage applied to source.



↑e in voltage → more e^- near Drain

Depletion region formed penetrates through channel → Conducting path reduces. At one stage it is very small.



Max current through transistor (I_{DSS})

Breakdown Region

$V_{GS2} < V_{GS1} < V_{GS0}$ ∴ Reduction in pinch off voltage value

Ohmic Region ↳ Acts as a resistor → Obey Ohm's Law

Saturation region

Locus of pinch off points

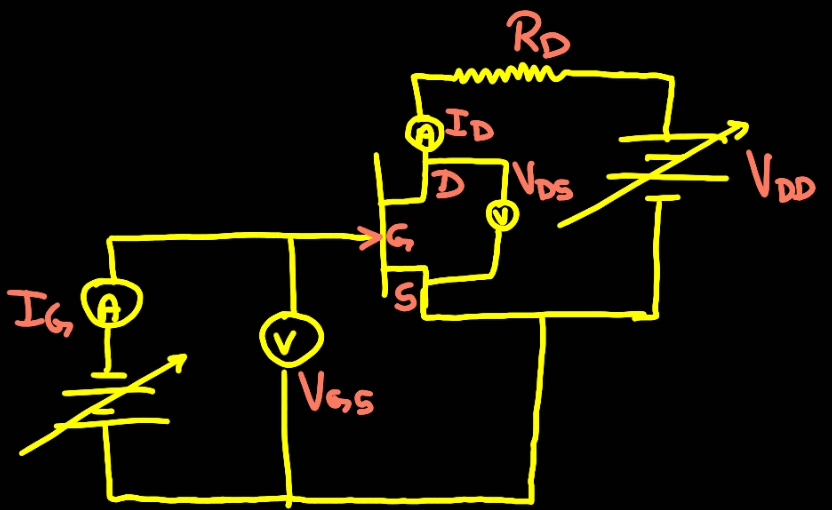
Attaining larger voltage ⇒ Depletion layer breaksdown

* O to A → Ohmic Region
* A to B → Drain keeps decreasing because of depletion region b/w gate & drain

* At B, drain current is pinched off.

Point B is called Pinchoff point

The drain to source to source voltage (V_{DS}) at B is Pinchoff voltage



Therefore, there is no I/P characteristics

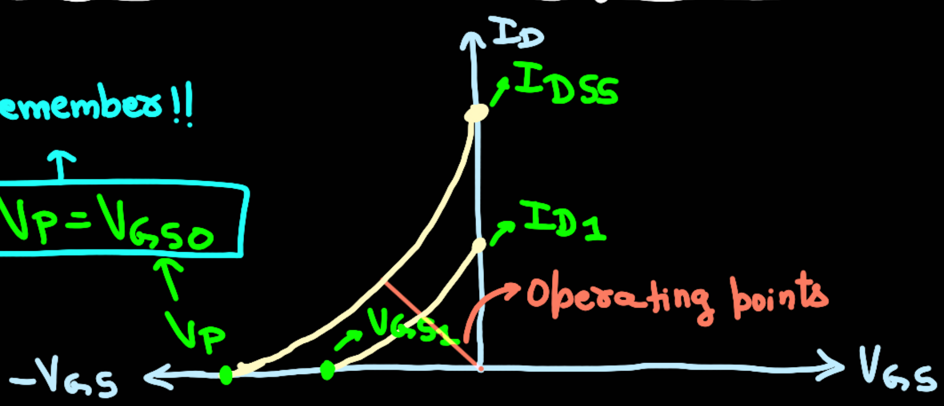
$I_G = 0$ as P-N junction here is operated in reverse bias
Only a very small negligible saturation current flows which is ≈ Zero

$$\boxed{\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}}}$$ → Amplification factor

Transfer characteristics of JFET:-

Remember!!

$$\boxed{V_P = V_{GSO}}$$



★ O/P resistance $= r_d = \dfrac{\Delta V_{DS}}{\Delta I_D}$
(From O/P char)

★ Transconductance $(G_m) = \dfrac{I_D}{V_{GS}}$ → Static

★ Transconductance $(g_m) = \dfrac{\Delta I_D}{\Delta V_{GS}}$ → Dynamic

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

$$= \underbrace{\frac{\Delta V_{DS}}{\Delta I_D}}_{r_d} \times \underbrace{\frac{\Delta I_D}{\Delta V_{GS}}}_{g_m}$$

$$\boxed{\therefore \mu = r_d \cdot g_m}$$

Current Equation of JFET:-

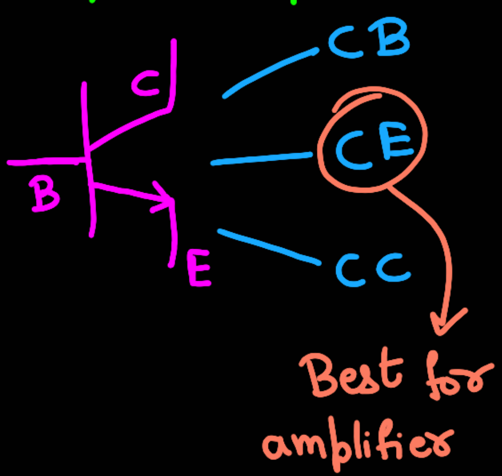
$$\boxed{I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2}$$

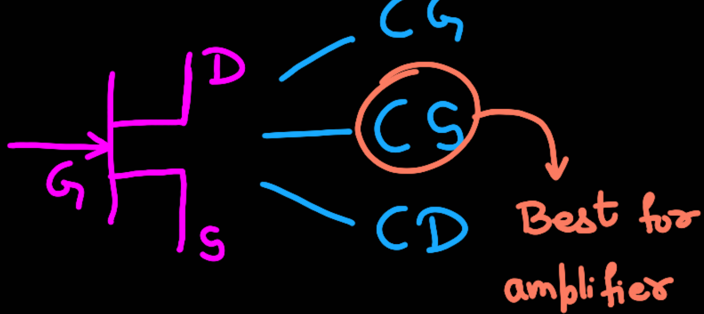
To remember

$$\boxed{\begin{aligned} V_{DS} &= V_{DD} - I_D(R_S + R_D) \\ V_{GS} &= -V_S = I_S R_S = I_D R_S \\ V_{DS} &= V_D - V_S \end{aligned}}$$

Difference b/w BJT & JFET:-

BJT	FET
★ Current operated device	★ Voltage Operated Device
★ Both majority & minority carriers are used for conduction. Thus "Bipolar"	★ Only majority carriers are used for conduction. Thus "Unipolar"



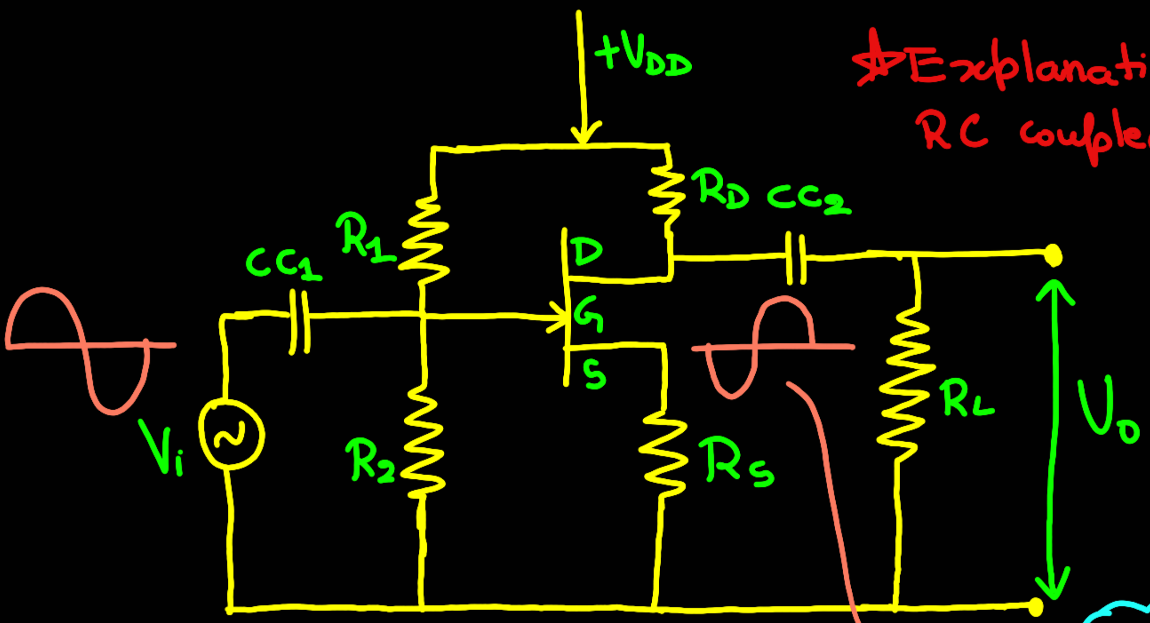


CS amplifier:-

Common Source amplifier

↳ Gate to Source → Reverse Bias

★ Explanation Same as RC coupled CF



Phase shift b/w I/P & O/P voltage is 180°

$I_D = I_S$

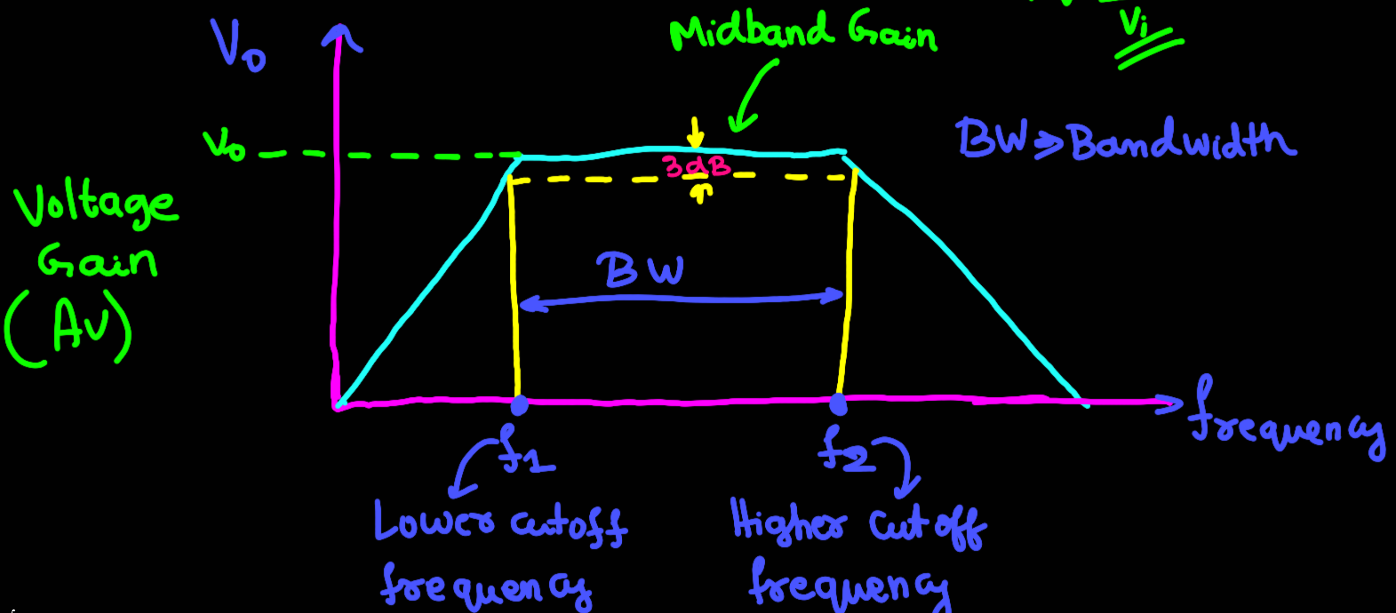
$$V_{DD} = I_D R_D + V_{DS} + I_S R_S$$

$$\Rightarrow V_{DD} = V_{DS} + I_D(R_D + R_S)$$

$$\therefore \mu = \frac{\Delta V_{DS}}{\Delta V_{GS}} \Rightarrow \boxed{V_{DS} = \mu V_{GS}}$$

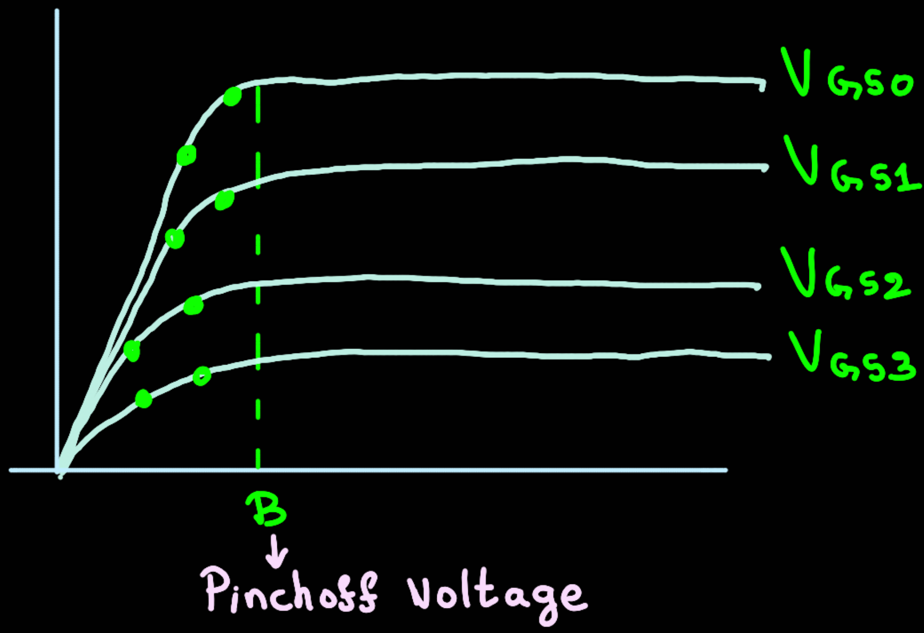
★ Understanding frequency response:-

$$A_V = \frac{V_o}{V_i}$$

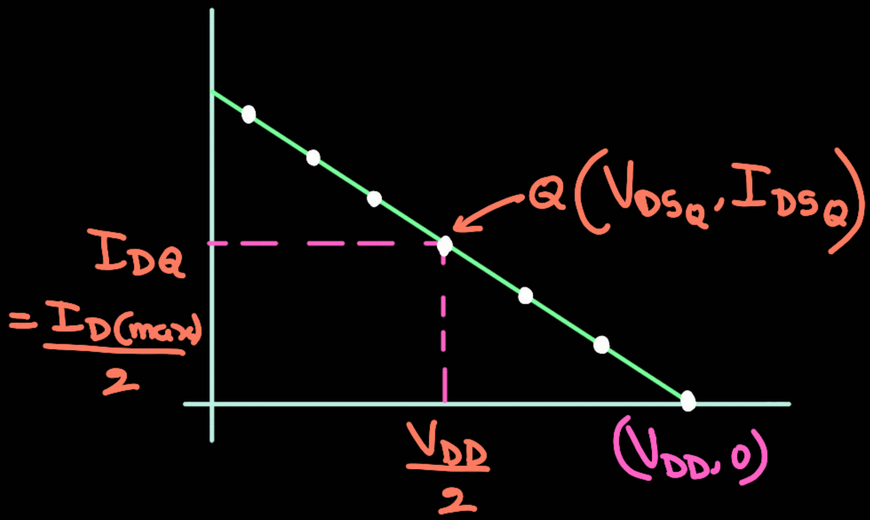


Keep I/P voltage V_i constant & vary the I/P frequency

DC analysis:-



V_{GS0}
V_{GS1}
V_{GS2}
V_{GS3}
B
Pinchoff voltage



$Q(V_{DS_Q}, I_{DS_Q})$
$I_{DQ} = \frac{I_{D(max)}}{2}$
$\frac{V_{DD}}{2}$
$(V_{DD}, 0)$

MOSFET:-

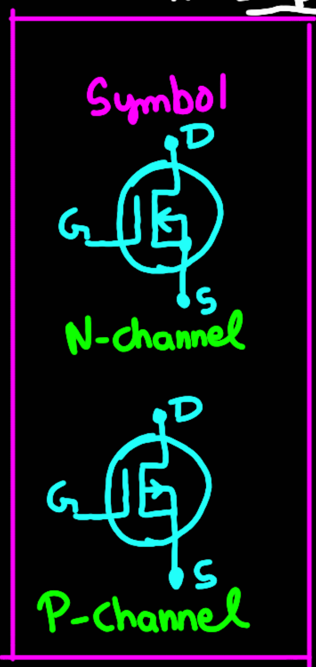
↳ Metal Oxide Semiconductor Field Effect Transistor

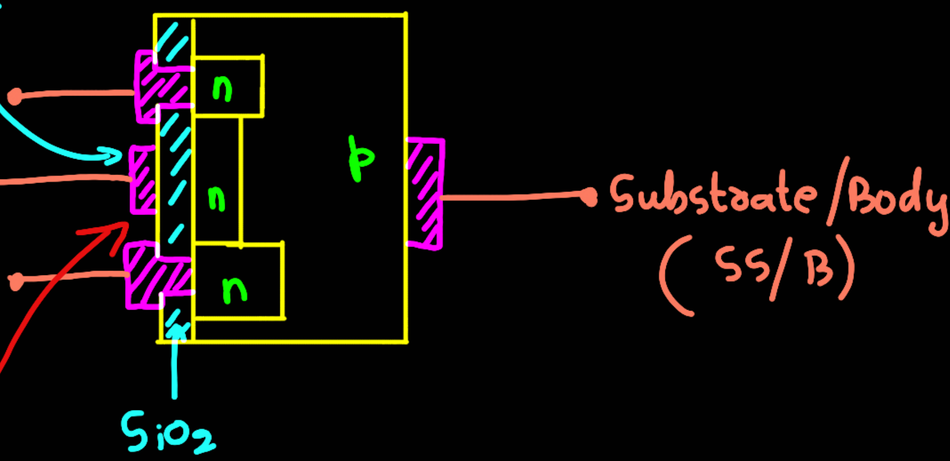
Active Device → Ability to control the flow of e^-s

MOSFET

Similar construction with key differences {
- ↳ Depletion Type → n-channel / p-channel
  Channel b/w D & S ✗
- ↳ Enhancement Type → n-channel / p-channel
  Channel b/w D & S ✓

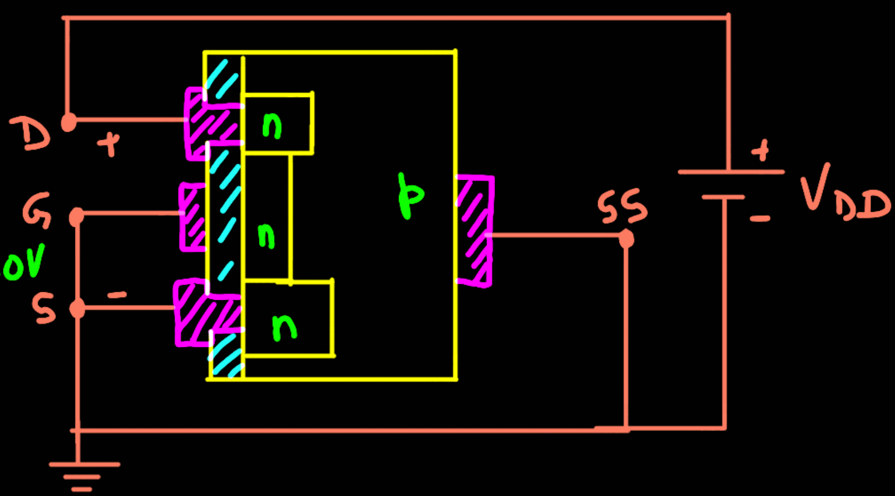
Depletion Type MOSFET:- Consider N-channel





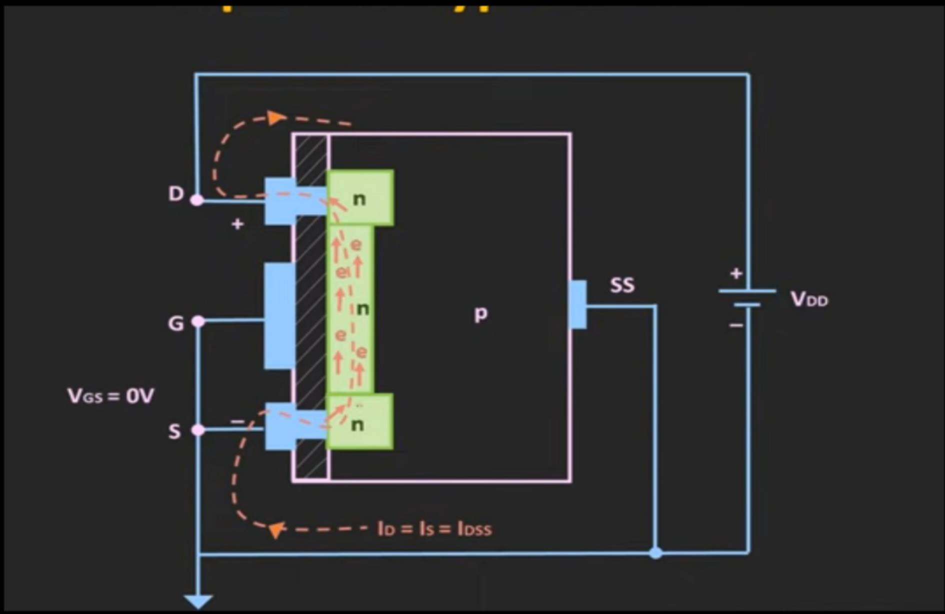
No connection b/w Gate & channel, it is isolated. High impedance; Higher than FET

Working of Depletion Type MOSFET:-



Initially $V_{GS} = 0V$

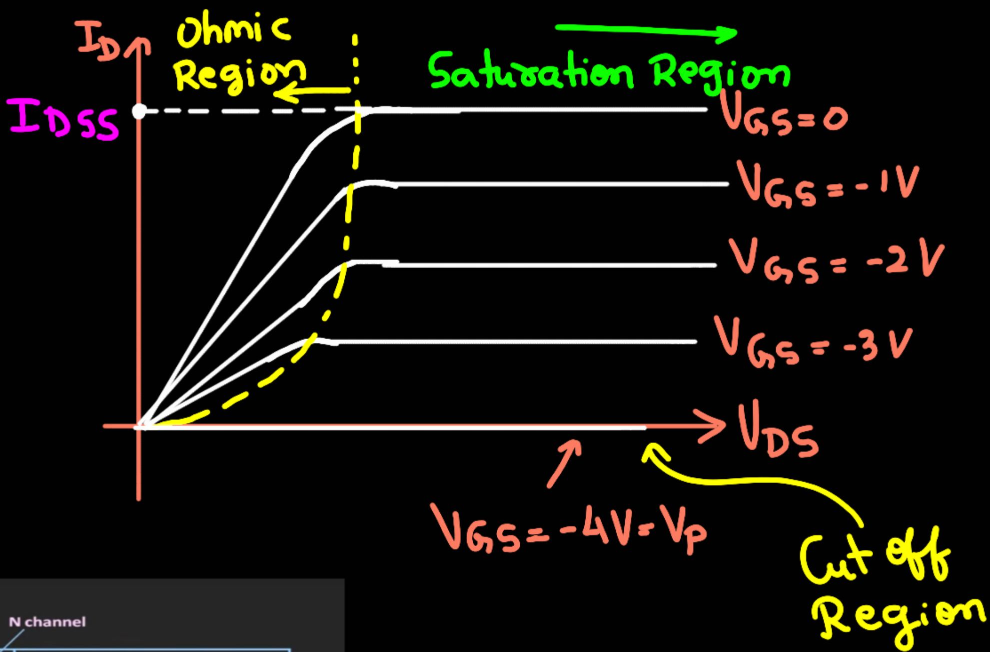
e^- in n-channel get attracted to +ve terminal

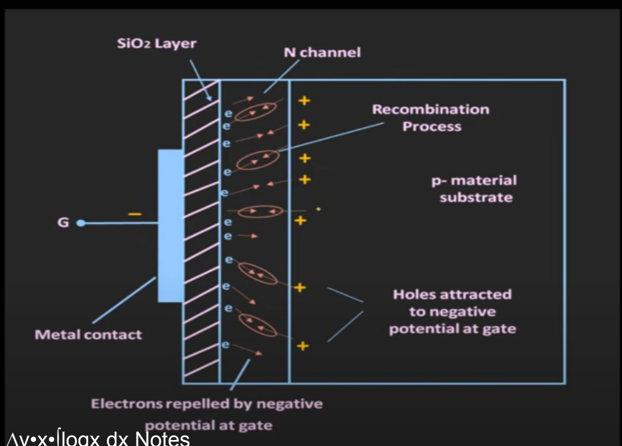


This process continues until all e^- have contributed to flow of current

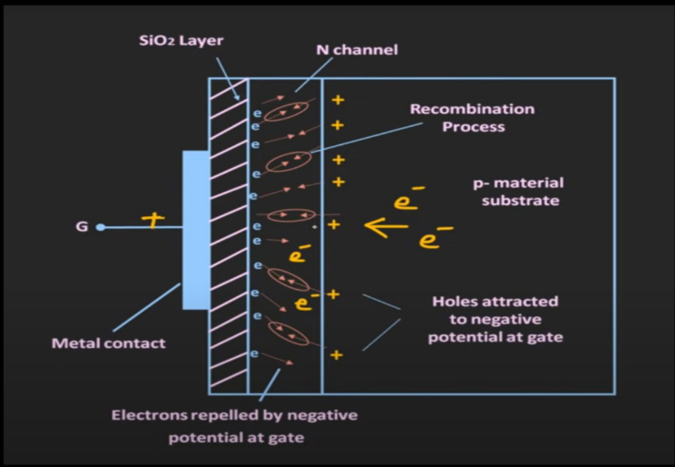
Later on ↑ Voltage, Current will be constant

★ Drain/o/p characteristics:-

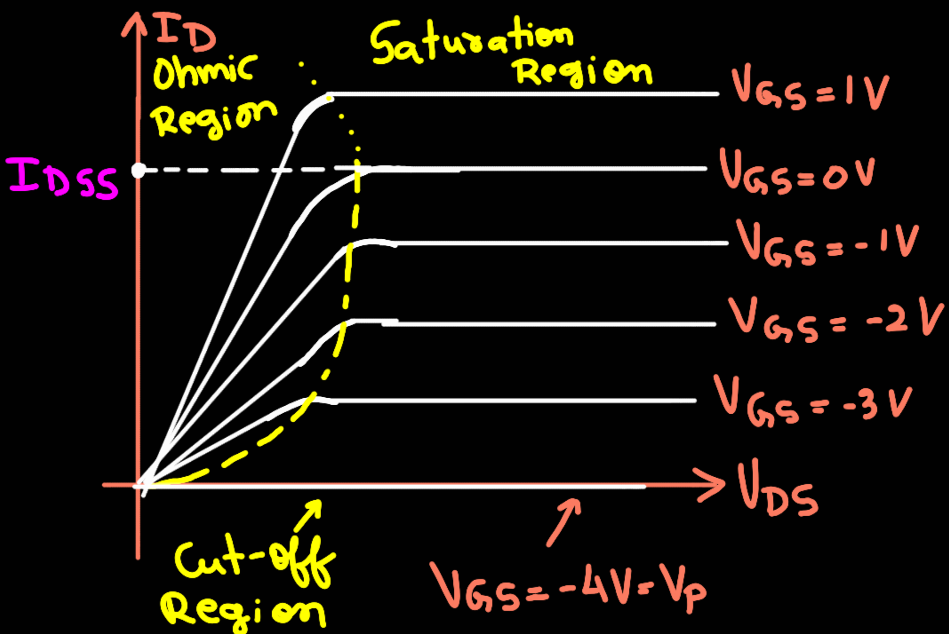




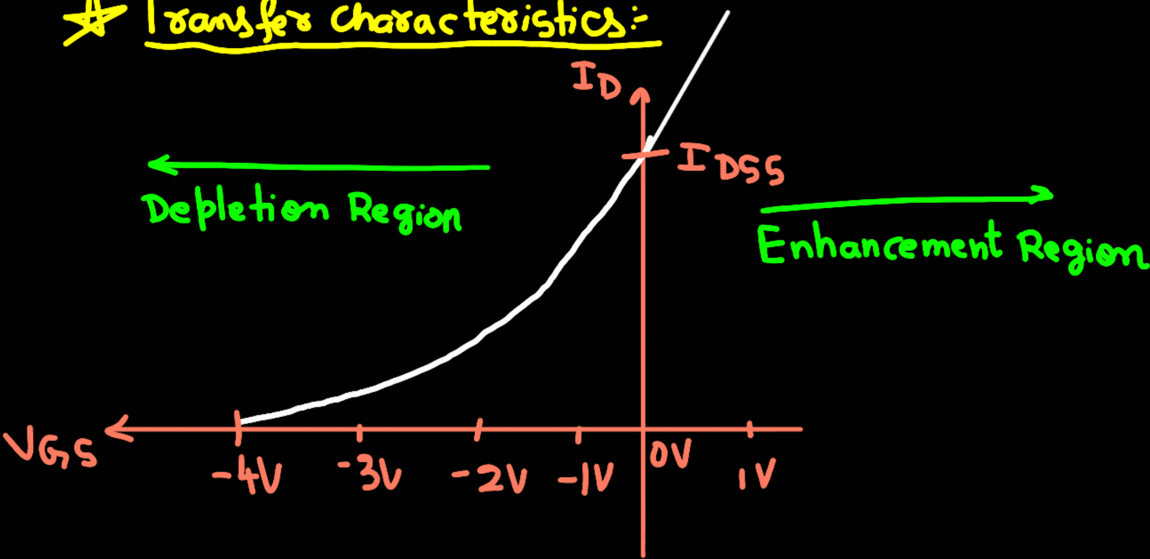
Application of -ve voltage



Application of +ve voltage



★ Transfer characteristics:-

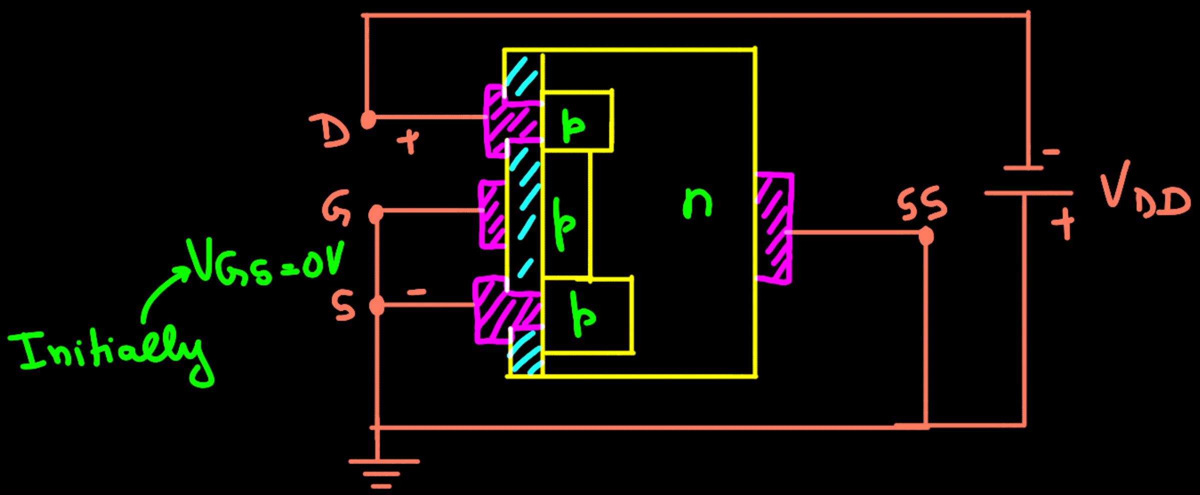


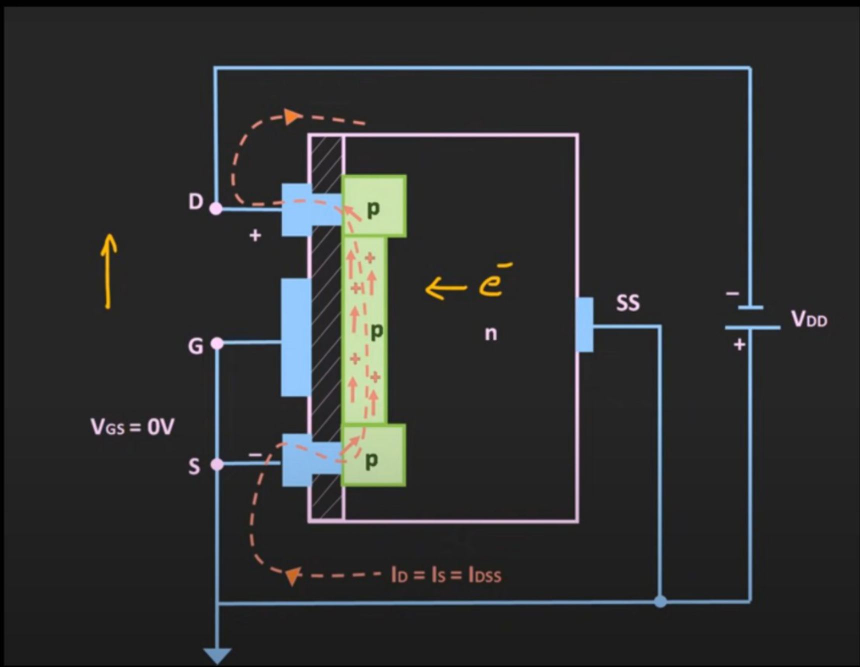
$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

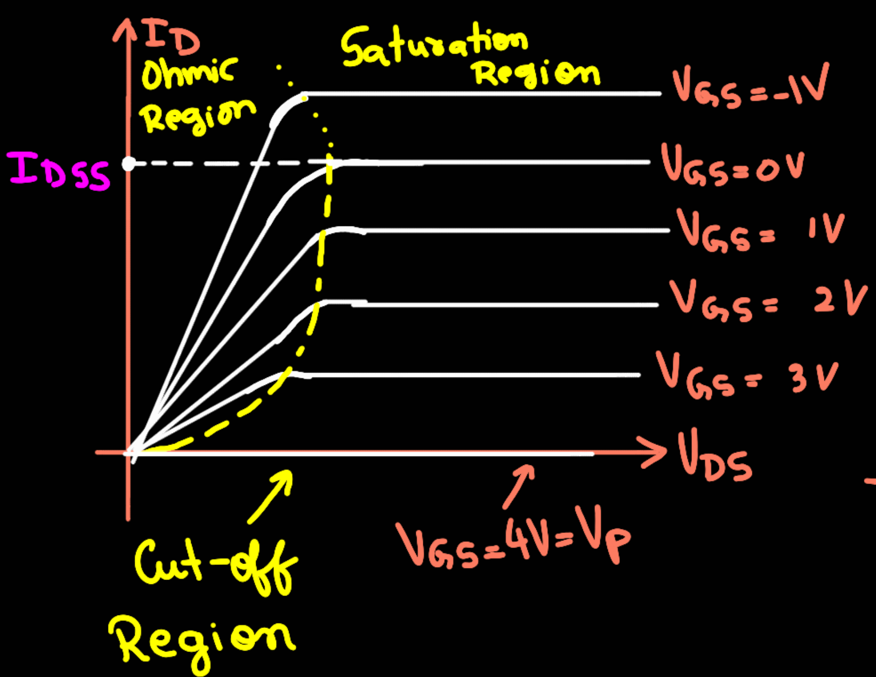
Eq^n for Depletion type MOSFET.
Same as JFET

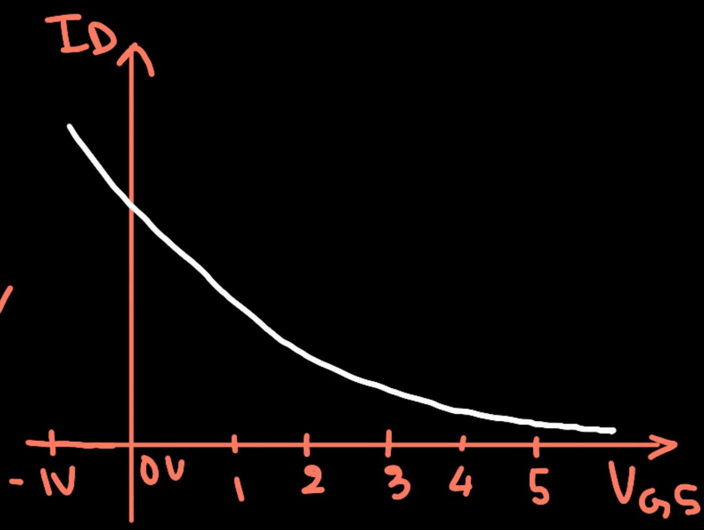
★ Depletion type P-channel MOSFET

Same as N-channel but polarity reversed

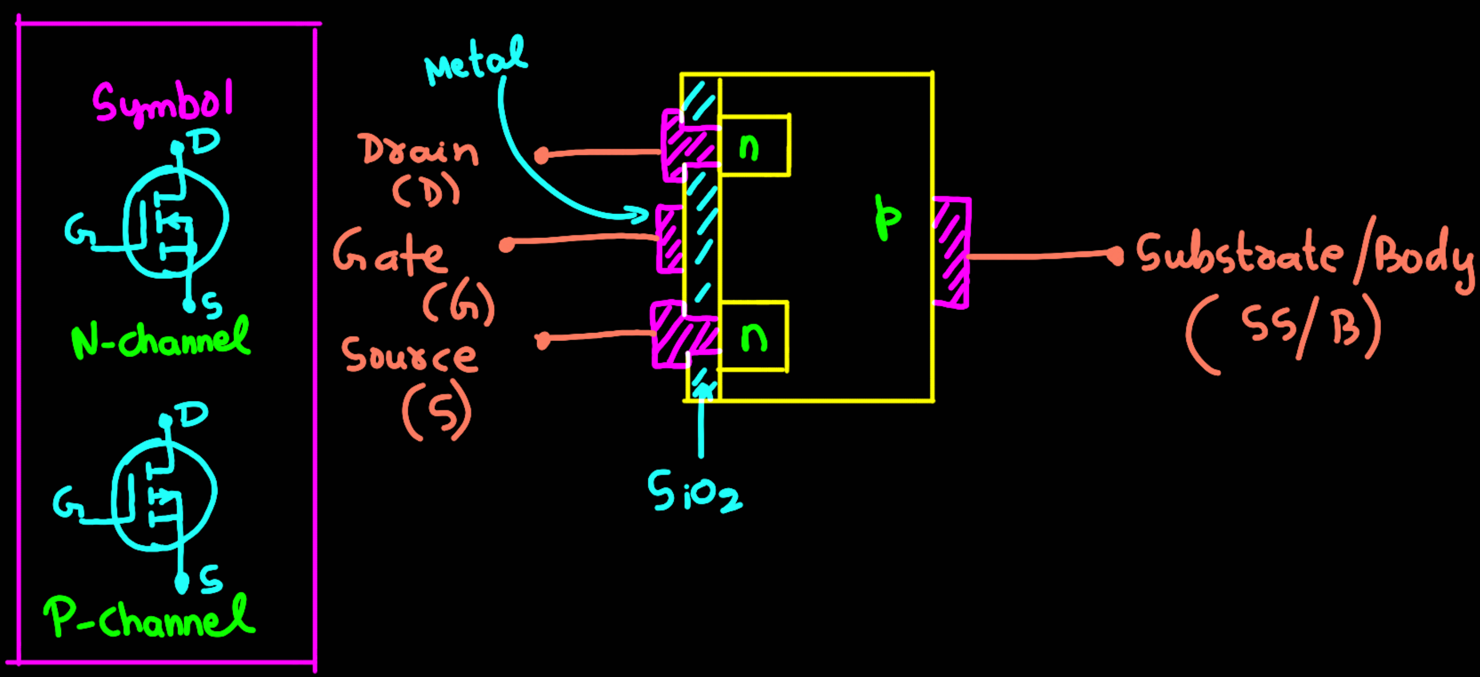




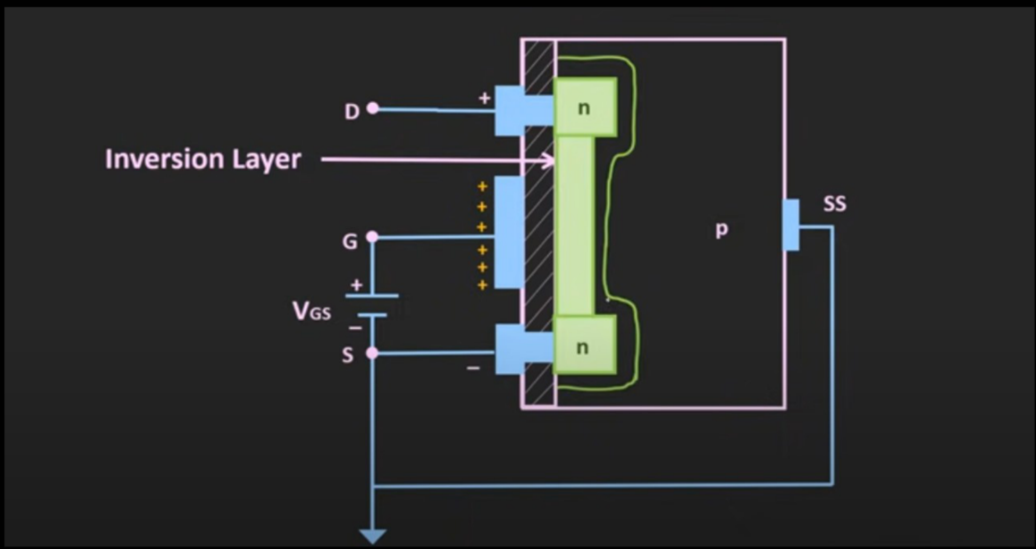




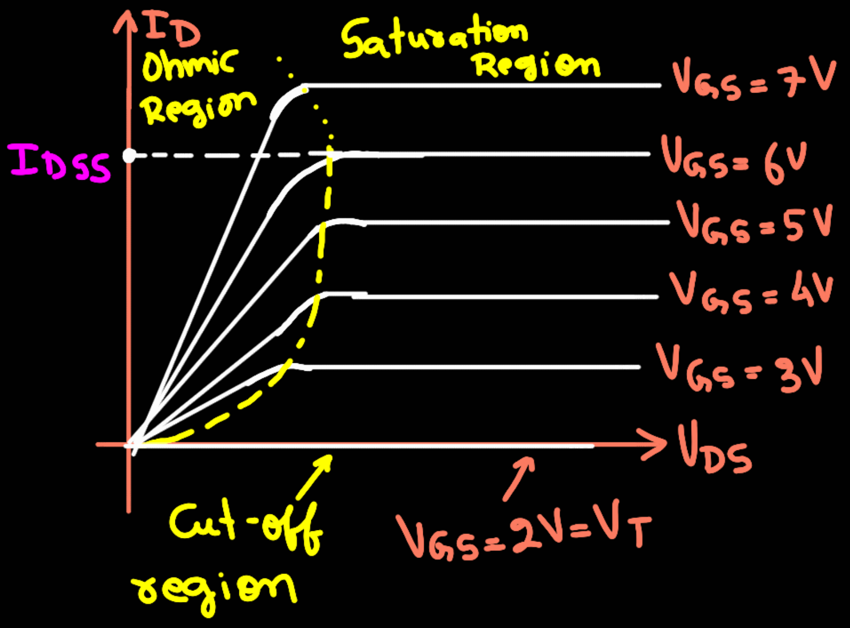
Enhancement type MOSFET:-



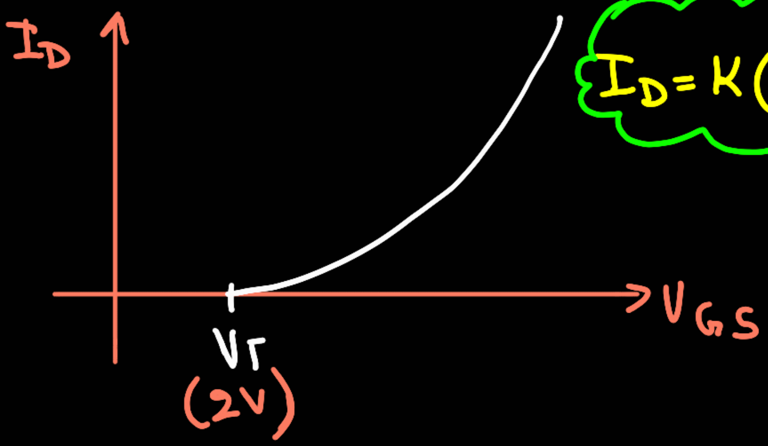
Threshold Voltage (Vth): The key feature of an enhancement MOSFET is the threshold voltage. For an N-channel MOSFET, when the gate-to-source voltage (V_GS) is greater than the threshold voltage (Vth), a conductive channel forms between the drain and source, allowing current to flow. For a P-channel MOSFET, the gate-to-source voltage needs to be less than the threshold voltage to turn on the device.



★ Drain Characteristics



★ Transfer Characteristics



Eq^n for Enhancement Type

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

$K \rightarrow$ Device Constant

P Channel MOSFET is Similar
Just Change the Polarity ☺

OR

Refer below notes for MOSFETS

transfer conductance $= \frac{\Delta I_D}{\Delta V_{GS}} = g_m$

Output impedance, $r_0 = \left.\frac{\Delta V_{DS}}{\Delta I_D}\right|_{V_{GS}}$

Amplification factor :-

$$\mu = \frac{O/P \text{ Voltage}}{i/p \text{ Voltage}}$$

$$= \frac{V_D}{V_{GS}} \times \frac{I_D}{I_D}$$

$$= \left(\frac{V_D}{I_D}\right)\left(\frac{I_D}{V_{GS}}\right)$$

$$= \left(\frac{\Delta V_D}{\Delta I_D}\right)\left(\frac{\Delta I_D}{\Delta V_{GS}}\right)$$

$$\boxed{\mu = r_0 \times g_m}$$

MOSFET [Metal-oxide Semiconductor field effect T.]

* It is unipolar
* operates on Voltage
* Insulator seperates the gate from channel

There are two MOSFET they are

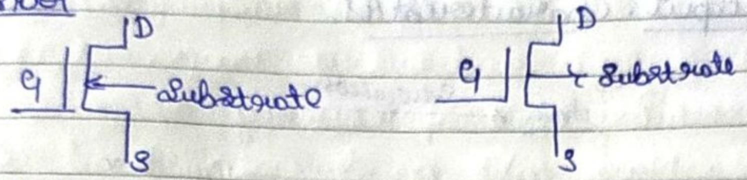
⇒ Depletion type MOSFET :-

• In this MOSFET the channel is made up of N-type of material & the substrate is of P-type of material.

• SiO_2 is the metallic contact which seperates the gate & the channel

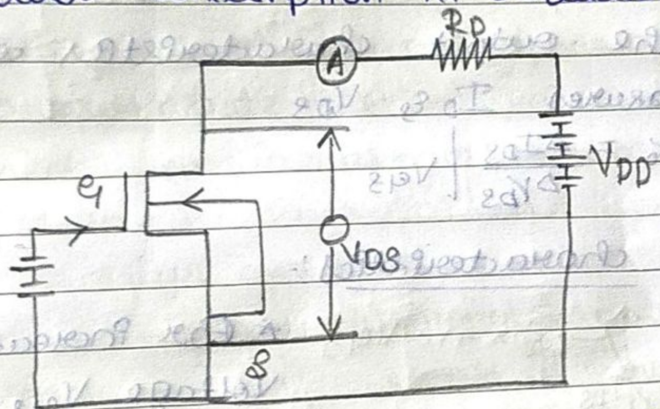
* Gate terminal is isolated from the channel due to the SiO_2 layer & partial channel setup b/w D & S

Symbol



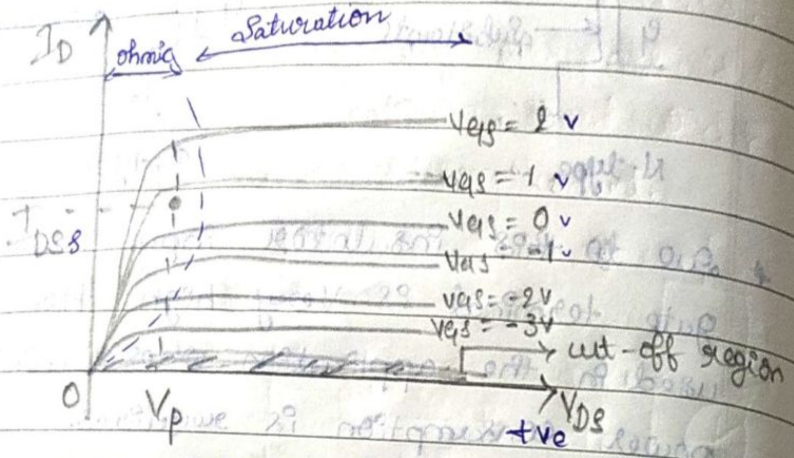
N-type P-type

* Due to this insulator input impedance of the gate terminal is very high. Hence MOSFET used in the application. where minimum power consumption is required.



* When $V_{GS} = 0$ & +ve voltage is applied b/w D & S terminal towards the one side of insulator, the other side it induces the -ve charges.
* Hence the electron in the N-channel increases results in increases in the I_D.
* The value of the saturation current for $V_{GS} = 0$ is called I_{DSS}.
* It the $V_{GS} = 0$ the point is called pinch-off voltage
* The voltage at which $V_{GS} = V_p$ is called cut-off region.
* The depletion curve also works for the +ve voltage in which I_D increases.

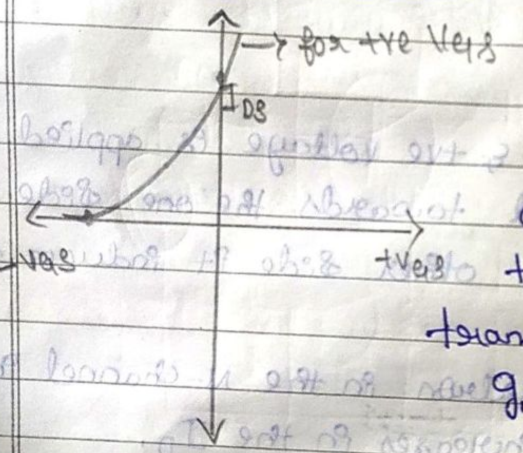
Output Characteristics:-



From the output characteristics at given V_{GS} measures I_D & V_{DS}

$$r_0 = \frac{\Delta I_{DS}}{\Delta V_{DS}}\bigg|_{V_{GS}}$$

Transfer characteristics:-



* For increase in +ve voltage V_{GS} the current measures & hence the curve is extended towards right side.

transconductance,

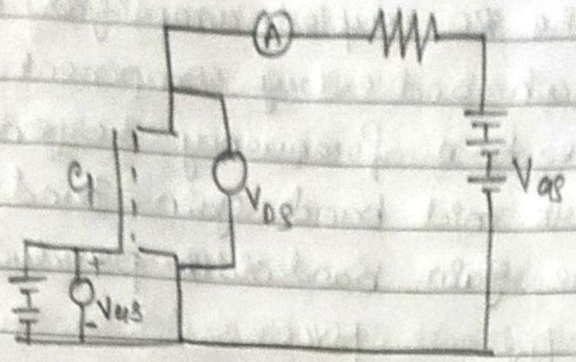
$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}\bigg|_{V_{DS}}$$

Amplification factor

$$\mu_0 = g_m * r_0$$

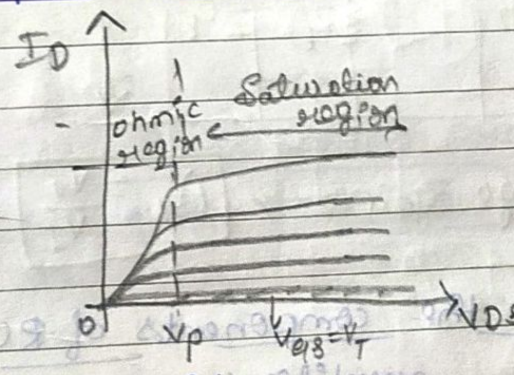
Enhancement type MOSFET:-

* Substrate is made up of p-type semiconductor
* SiO_2 isolates the gate terminal & p-substrate
* there is no channel b/w D & S
* When the controlled voltage is applied b/w G & S then channels is formed.



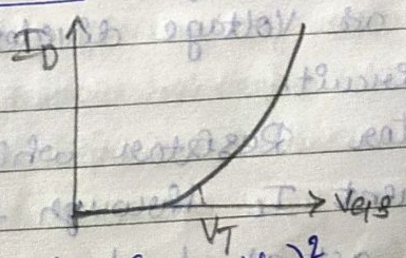
* When $V_{GS} = 0$ the voltage is applied b/w D & S then current flows in MOSFET
* When +ve voltage applied b/w G & S then holes near the G pushed away & e- attacted towards gate terminal.
* When V_{GS} increases more & more channel is created.
* The value of V_{GS} at which the current ↑ses is called threashold voltage.
* When $V_{GS} > V_{TH}$ width of channel will ↑ses.
* The voltage V_{DS} at which the pinch-off condition occurs is called saturation voltage.

Output characteristics



$$r_0 = \frac{\Delta I_D}{\Delta V_{DS}} \Big| V_{GS}$$

transfer. C :-



$$I_D = k \times (V_{GS} - V_T)^2$$

Diffrence between JFET, BJT & MOSFET

Feature	JFET	MOSFET	BJT
Control Mechanism	Voltage applied to gate controls current	Voltage applied to gate controls current	Current applied to base controls current
Gate Structure	Junction gate	Metal-Oxide-Semiconductor gate	Base (with junctions)
Input Impedance	High	Very high	Low to moderate
Switching Speed	Faster than BJT	Very fast (faster than JFET)	Slower compared to FETs
Power Consumption	Low	Low	Higher due to base current
Thermal Stability	Good	Excellent	Poor
Current Type	Unipolar (one type of carrier)	Unipolar (one type of carrier)	Bipolar (both types of carriers)
Ideal Amplifier Configuration	Common Source	Common Source or Common Drain	Common Emitter