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(Autonomous)
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Electronic Devices & circuits

(1)

1a) V_T is voltage equivalent of temperature
The dependance of I_0 and V_T on temperature T is given by.

$$I_0 = KT^m e^{-V_{G0}/\eta V_T} \quad -(1)$$

k = const dependent on temp.
m = 2 for Ge and 1.5 for Si
V_{G0} | E_{G0} = Forbidden energy gap
= 0.785 V. Ge
= 1.21 V for Si

→ from eq (1) as temp increases, the value of I_0 increases hence diode current I increases.

→ To Keep diode current constant, it is necessary to reduce the applied voltage V of the diode $\left(\frac{dI}{dT} = 0\right)$

$$I = I_0\left[e^{(V/\eta V_T)} - 1\right]$$

$$I \simeq I_0 e^{V/\eta V_T} \quad -(2)$$

sub (1) in (2)

$$I = KT^m e^{-V_{G0}/\eta V_T} \cdot e^{V/\eta V_T}$$

$\therefore I = KT^m e^{(V-V_{G0})/\eta V_T}$

$(V_T = KT)$ 3m

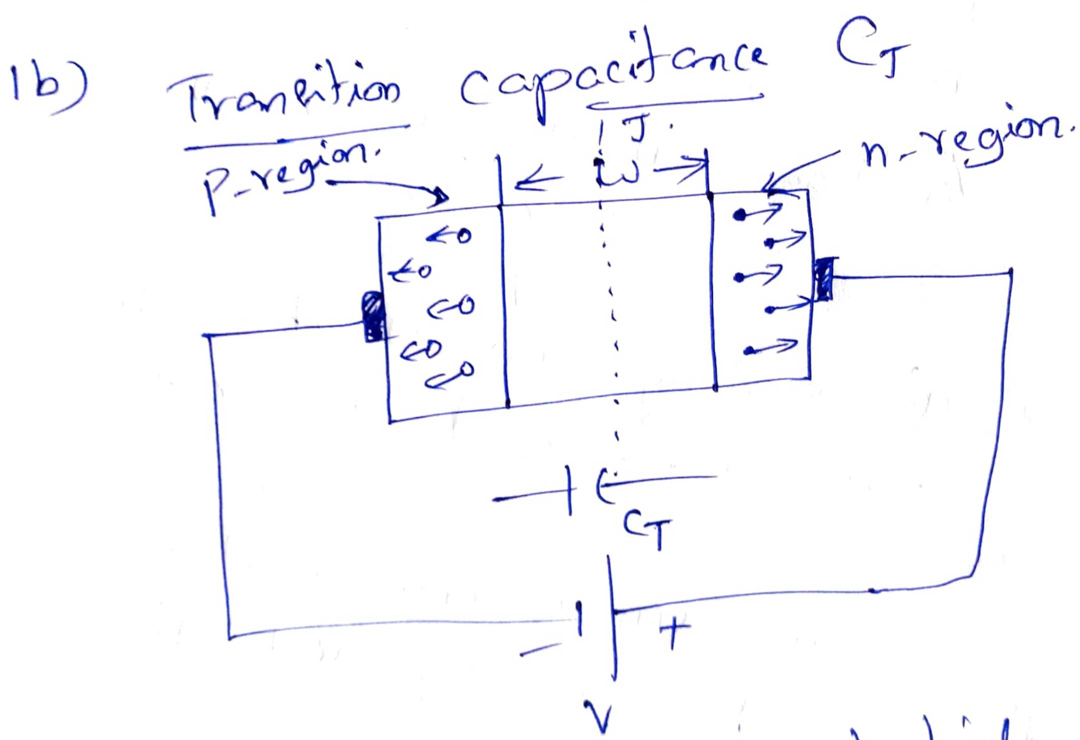
diff the above equation with respect to T

$$\frac{dI}{dT} = K\left[mT^{m-1} e^{(V-V_{G0})/\eta KT} + T^m e^{(V-V_{G0})/\eta KT} \frac{d}{dT}\left(\frac{V-V_{G0}}{\eta KT}\right)\right]$$

$$\therefore \frac{dV}{dT} = \frac{V-(V_{G0}+m\eta V_T)}{T}$$

2m

1b) Transition capacitance C_T



The relationship between potential and charge density is given by poisson's eq

as

$$\frac{d^2V}{dx^2} = \frac{qN_A}{\varepsilon} \quad -①$$

Intergrating the above equation

$$\int \frac{d^2 v}{dx^2} = \frac{q N_D}{\varepsilon}.$$

$$\frac{dv}{dx} = \frac{q N_A x}{\varepsilon}$$

Again Integrating.

$$\int \frac{dv}{dx} dx = \int_0^w \frac{q N_A}{\varepsilon} x \, dx$$

$$\boxed{V = \frac{q N_A}{\varepsilon} \frac{w^2}{2}} \quad - (2)$$

3M

The net charge Q

$$Q = N_A \cdot \text{Volume} \times q$$

$$Q = N_A A \cdot w \cdot q$$

differentiating eq (2) w.r.t v

$$1 = \frac{1}{2} \frac{N_A q}{\varepsilon} \left[\frac{dw}{dv}\right] 2w.$$

$$\frac{dw}{dv} = \frac{\varepsilon}{q N_A w}.$$

$$\frac{dQ}{dw} = N_A A q \frac{dw}{dv}$$

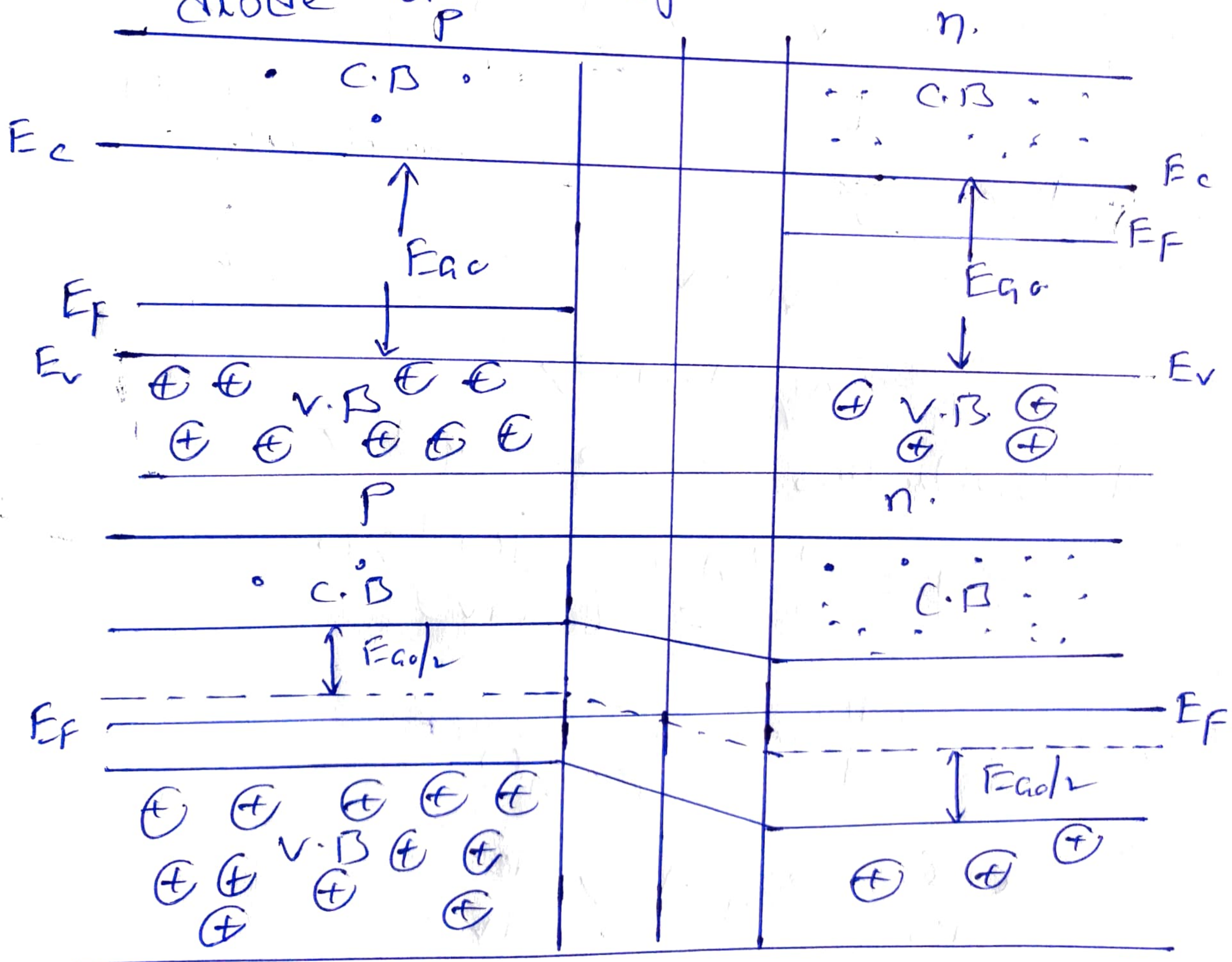
$$\frac{dQ}{dv} = N_A A q. \frac{\varepsilon}{q N_A w}.$$

$$\frac{dQ}{dV} = \frac{\varepsilon A}{W} \Rightarrow C_T = \frac{dQ}{dV} = \frac{\varepsilon A}{W}$$

$$C_T \propto \frac{1}{W}$$ — 4M

As reverse bias increases the width of the depletion region increases The Transition Capacitance C_T reduces.

2a) Energy band diagram of PN Junction diode under open circuited conditions.



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Description about the Energy band diagram before combiniging and after combining P and n regions.

About Fermi level. – 1 M

Junction potential / barrier potential.

$$V_J = V_T \ln\left[\frac{N_A N_D}{n_i^2}\right] \qquad N_A = P_p \qquad N_D = n_n$$

$$V_T = KT$$

$$\therefore \boxed{V_J = V_T \ln\left[\frac{P_p}{P_n}\right]} \quad \boxed{V_J = V_T \ln\left[\frac{n_n}{n_p}\right]}$$

– 3M

2b) Diffusion capacitance:

During foreward bias condition another capacitance comes into existance called as Diffusion capacitance. C_D

→ let us assume the p-n Junction diode in which p-side is heavily doped when compared to n-side.

Hence the majority charge carriers which constitute the total current is holes.

→ we know that the current equation is given as

$$I = I_{pn}(x) + I_{np}(x)$$

Here the current is mainly due to holes.

$$I \simeq I_{pn}(x)$$

diffusion current density due to holes is given by $J = \frac{I}{A} = -q D_p \frac{dP_n}{dx}$

$$I(x) = -q A D_p \frac{dP_n(x)}{dx} \quad -(1)$$

$$\therefore P_n(x) = P_n(0) e^{-x/L_p}$$ diff w.r.t. x.

$$\frac{d P_n(x)}{dx} = P_n(0) \frac{d}{dx}\left(e^{-\frac{x}{L_p}}\right)$$

$$= P_n(0) \times e^{-\frac{x}{L_p}} \left(-\frac{1}{L_p}\right)$$

at $x = 0$

$$= -\frac{P_n(0)}{L_p}$$

$$\therefore I(x) = -q A D_p \frac{P_n(0)}{-L_p}$$

$$I = \frac{q A D_p}{L_p} P_n(0) \quad \therefore P_n(0) = \frac{I L_p}{q A D_p}$$

The excess charge Q exists on n side is given by

$$Q = \int_0^{\infty} q A P_n(0) e^{-x/L_p} \, dx.$$

$$\therefore Q = q\, P_n(0) \left[\frac{e^{-x/L_p}}{-\frac{x}{L_p}} \right]_0^{\infty}$$

$$Q = qAL_p P_n(0)$$

$$Q = \frac{L_p^2 I}{D_p} \qquad \therefore \tau = \frac{L_p^2}{D_p}.$$

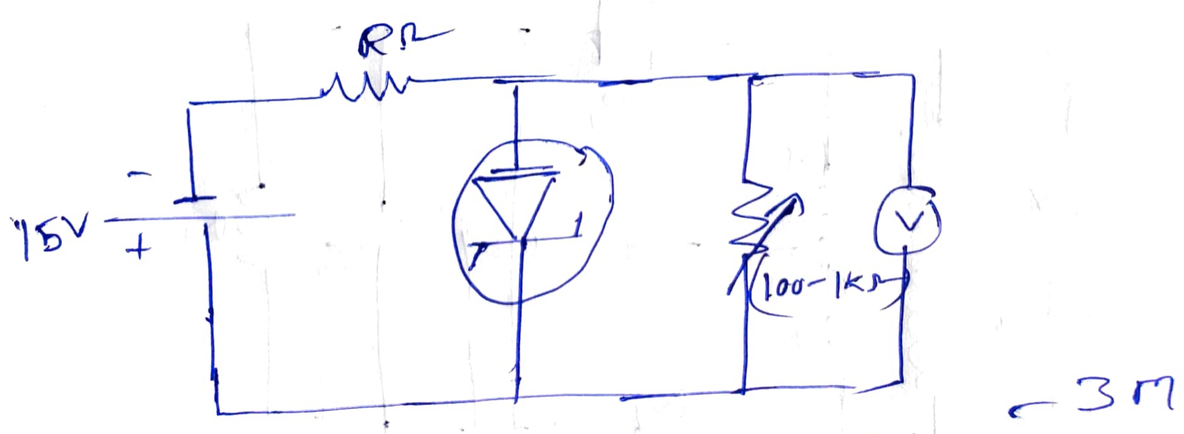
$$Q = \tau I \qquad C_D = \frac{dQ}{dV} = \frac{dQ}{dI} \times \frac{dI}{dV}$$

$$\frac{dQ}{dI} = \tau \qquad I = I_0 \left[e^{V/\eta V_T} - 1 \right]$$

$$\frac{dI}{dV} = \frac{I_0 e^{V/\eta V_T}}{\eta V_T} = \frac{I}{\eta V_T}$$

$$\therefore C_D = \frac{dQ}{dI} \times \frac{dI}{dV} = \frac{\tau I}{\eta V_T}$$

3a) <u>Zener Diode as voltage regulator.</u>



— 3M

In the reverse bias condition

Zener diodes is used as voltage regulator in reverse bias condition.

→ Apply a fixed reverse bias voltage and vary the potential across the Zener diode. then the voltage across the load remains almost unchanged for variable resistance

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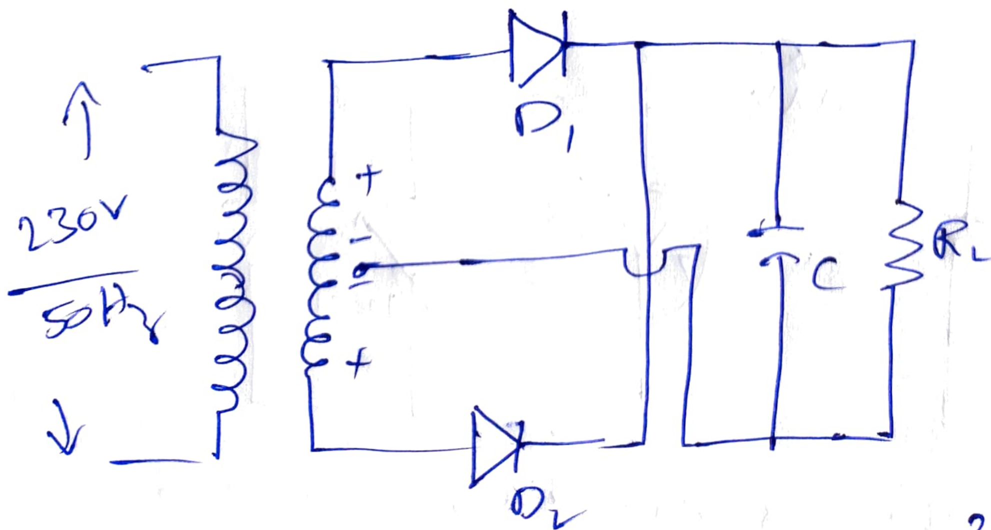
$$\%R = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100.$$

— 1M

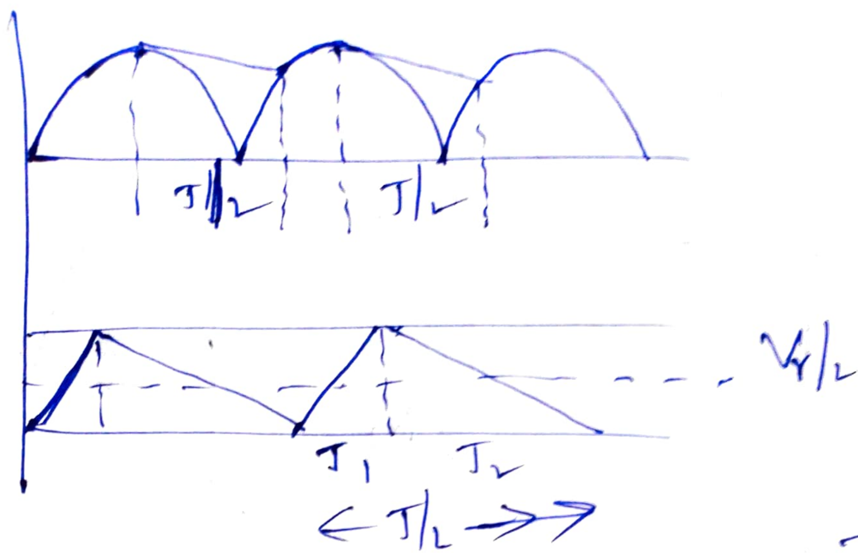
V_{NL} → V No load.

V_{FL} → V Full load.

3b) Full wave rectifier with capacitive filter



— 2M.



— 2M

ripple factor $\gamma = \dfrac{V_{r\,rms}}{V_{DC}}$ for triangle waveform $V_{r\,rms} = \dfrac{V_r}{2\sqrt{3}}$

$Q = CV_r$ $\quad Q = \int_0^{T_2} i_L \, dt = I_{dc} T_2$

$Q = I_{dc} \cdot \frac{T}{2}$ $\quad \therefore CV_r = I_{dc} \frac{T}{2}$

$\therefore V_r = \dfrac{I_{dc} T}{2C}$ $\quad I_{dc} = \dfrac{V_{dc}}{R_L}$

$\therefore V_{r\,rms} = \dfrac{V_{dc}}{2 f R_L C 2\sqrt{3}} \Rightarrow \dfrac{V_{r\,rms}}{V_{dc}} = \gamma$

$$\gamma = \frac{1}{4\sqrt{3} f R_L C}$$

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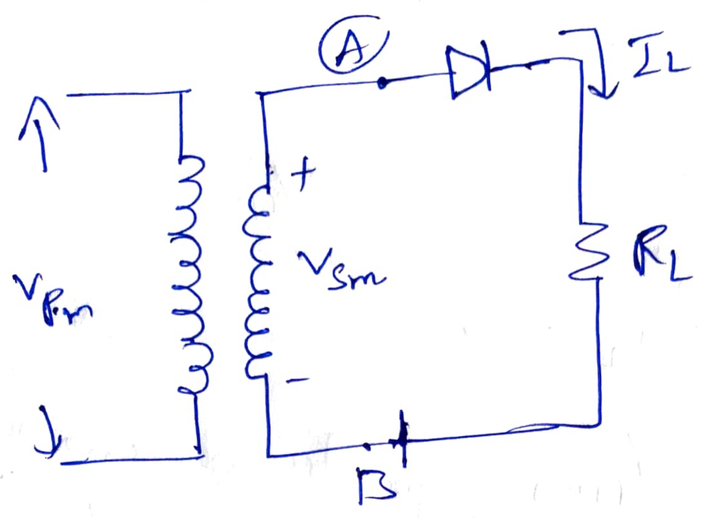
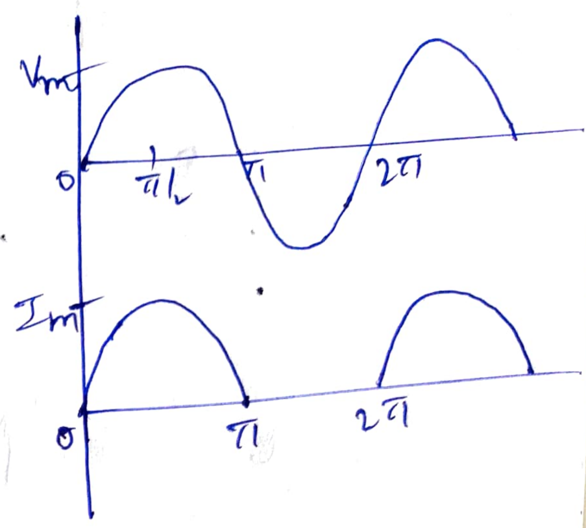
4a) Block diagram of Halfwave rectifier:





$V_{sm} = V_m \sin\omega t$.

$I_L = I_m \sin\omega t$. $(0 \le \omega t \le \pi)$

$= 0 \quad (\pi \le \omega t \le 2\pi)$

$I_m \rightarrow$ Peak value of load current

$$I_{DC} = \frac{1}{2\pi} \int_0^{2\pi} I_L \, d\omega t.$$

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

$I_L = 0$.

$$\therefore I_{DC} = \frac{I_m}{2\pi} \left[-\cos\omega t \right]_0^{\pi}$$

$$I_{DC} = \frac{I_m}{2\pi}(2) \Rightarrow \boxed{I_{DC} = \frac{I_m}{\pi}}$$

Rms value of the load current

$$I_{RMS} = \sqrt{\frac{1}{2\pi} \int_0^{2\pi} I_L^2 \, d\omega t}.$$

$$I_{Rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} I_m^2 \sin^2\omega t \, d\omega t}$$

$$I_L = I_m \sin\omega t \quad 0 \le \omega t \le \pi$$
$$= 0 \quad \pi \le \omega t \le 2\pi$$

$$\therefore I_{rms} = \sqrt{\frac{I_m^2}{2\pi}\int_0^{\pi}\left[\frac{1-\cos 2\omega t}{2}\right] d\omega t}$$

$$I_{Rms} = \sqrt{\frac{I_m^2}{2\pi}\left(\frac{\omega t}{2} - \frac{\sin 2\omega t}{4}\right)_0^{\pi}} = \frac{I_m}{2}$$

Ripple factor $\gamma = \frac{I_{ac}}{I_{DC}}$

$I_{ac} = \sqrt{I_{Rms}^2 - I_{dc}^2} \quad \therefore \gamma = \sqrt{\frac{I_{Rms}^2 - I_{dc}^2}{I_{dc}^2}}$

$$\gamma = \sqrt{\frac{\left(\frac{I_m}{2}\right)^2}{\left(\frac{I_m}{\pi}\right)^2} - 1} = \sqrt{\frac{\pi^2}{4} - 1} = 1.21$$

4b) Working principle of varactor Diode

→ As the transition capacitance of a diode varies with the applied voltage, it can be used as voltage variable capacitance in many application.

→ The diodes which shows the transition capacitance property predominantly is called varactor diodes.

$$C_T = \frac{k}{(V_J + V_R)^n}$$

2M

K = const depends on Semiconductor.

V_J = Junction potential.

V_R = reverse bias voltage.

n = 1/2 for alloy junction

= 1/3 for diffused junction — 2M

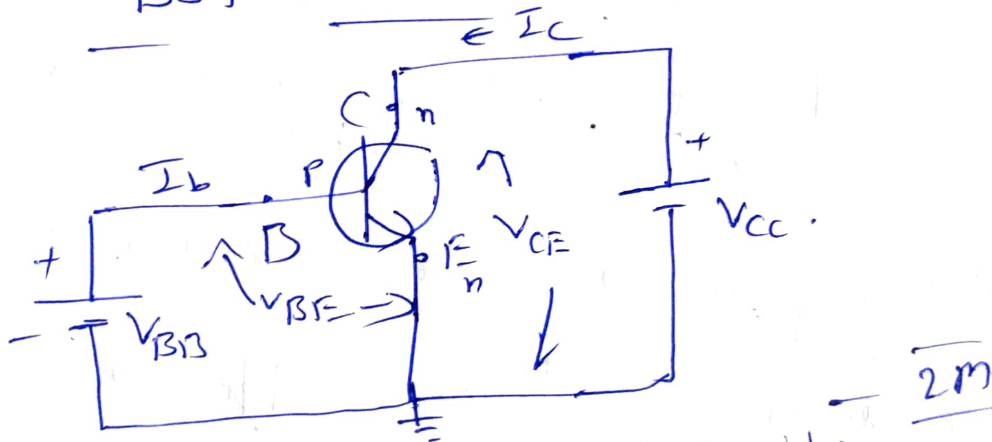
Applications:

① Tuned circuit ② FM modulator

③ Automatic frequency control devices. — 3M

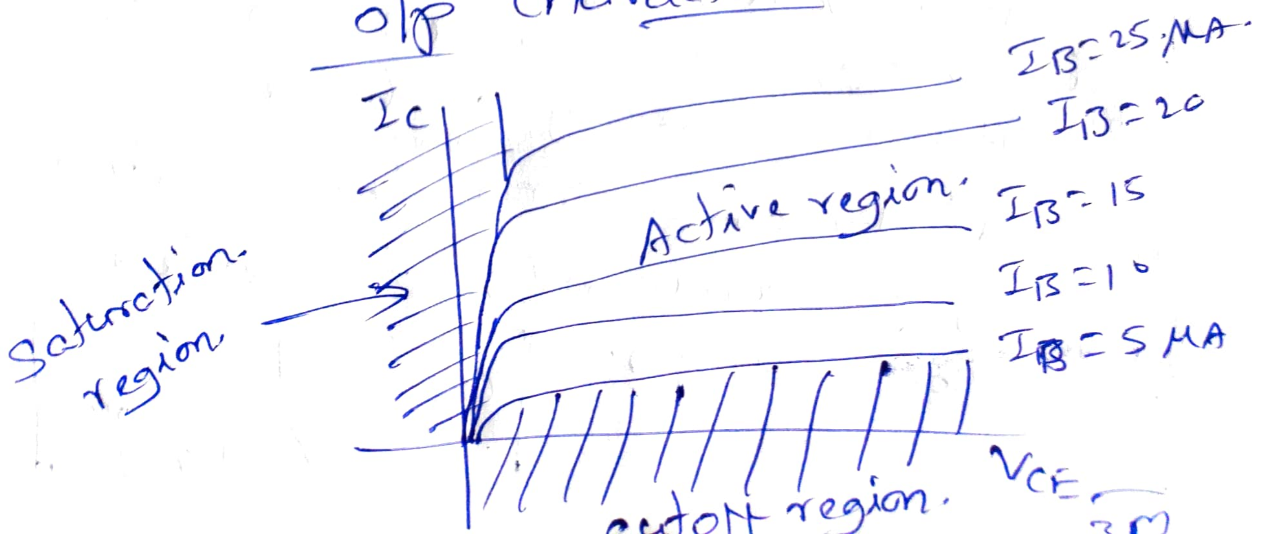
④ Television receiver

5a) BJT in C-E configuration



— 2M

o/p characteristics:



J_E	J_C	region of operation
F.B	F.B	Saturation
F.B.	R.B	Active
R.B	R.B	cut off

F.B → Foreword Bias.
R.B → reverse bias.
J_E → Emitter base Jn
J_C → collector base Jn.

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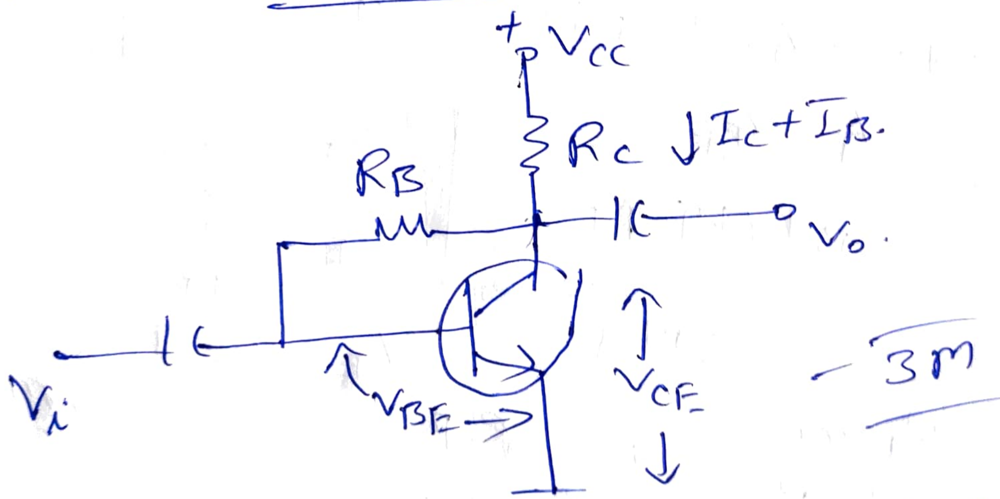
5b) Collector to base Bias:



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Applying KVL to Base ckt

$V_{CC} - (I_B + I_C)R_C - I_B R_B - V_{BE} = 0$

$V_{CC} = (R_B + R_C) I_B + I_C R_C + V_{BE}$

$\therefore I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (1+\beta) R_C}$

$I_C = \beta I_B.$

2M

Applying KVL to collector ckt:-

$V_{CC} - (I_C + I_B) R_C - V_{CE} = 0$

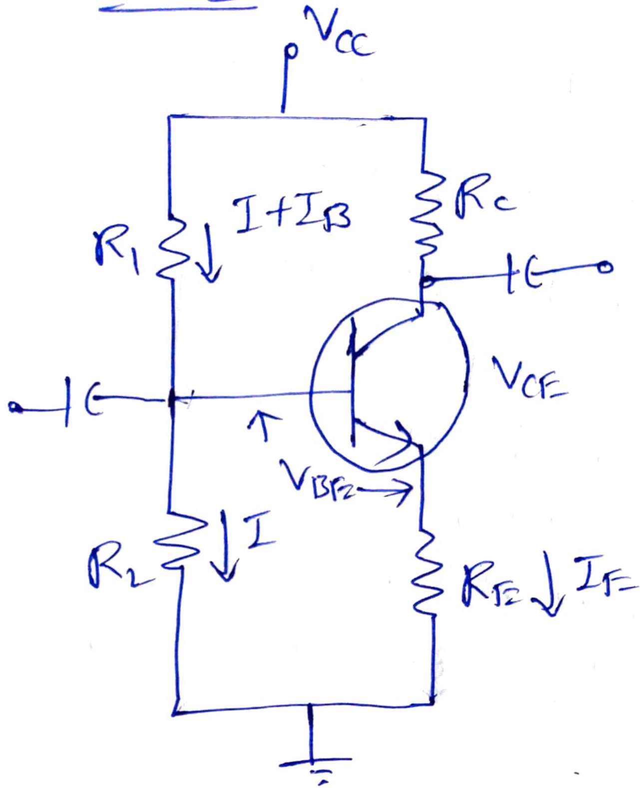
$V_{CE} = V_{CC} - (I_C + I_B) R_C$

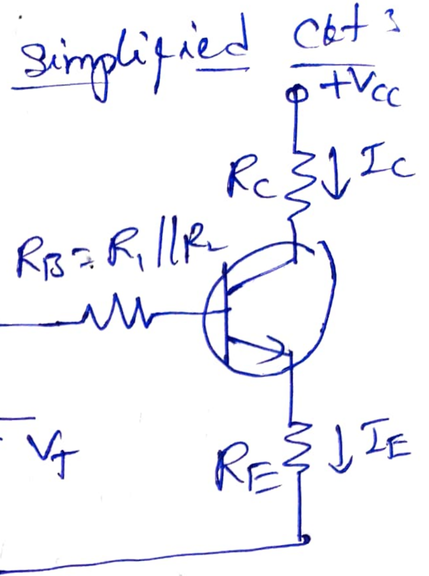
Q point (V_{CE}, I_C)

(V_{CEQ}, I_{CQ})

2M

6a) Voltage Divider Bias ckt:





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

Applying KVL to base ckt:

$$V_T = I_B R_B + V_{BE} + I_E R_E$$

$$\therefore I_B = \frac{V_T - V_{BE}}{R_B + (1+\beta)R_E}$$

— 2m

$$V_B = \frac{V_{CC} R_2}{R_1 + R_2}$$

$$V_E = V_B - V_{BE}$$

$$I_E = \frac{V_E}{R_E}$$

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

2m

$$V_T = \frac{R_2 V_{CC}}{R_1 + R_2} \qquad R_B = \frac{R_1 R_2}{R_1 + R_2}$$

$$V_T = I_B R_B + V_{BE} + (I_B + I_C) R_E$$

diff w.r.to I_C

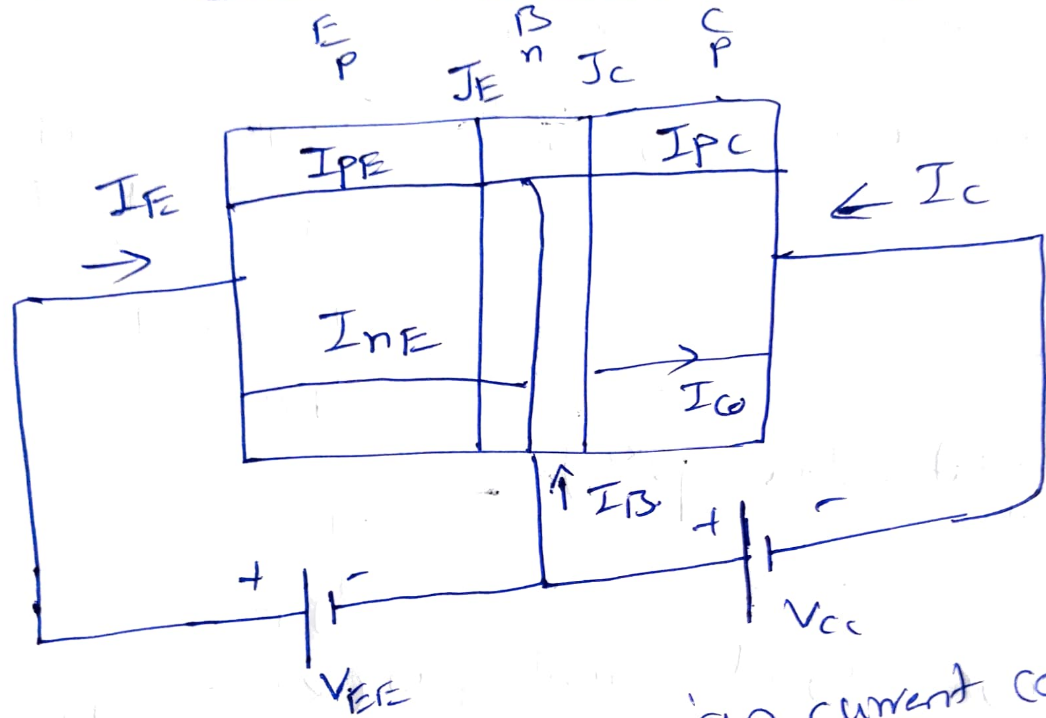
$$0 = \frac{\partial I_B}{\partial I_C} \times R_B + \frac{\partial I_B}{\partial I_C} \times R_E + R_E$$

$$\therefore \frac{\partial I_B}{\partial I_C} = \frac{-R_E}{R_E + R_B}$$

$$S = \frac{1+\beta}{1-\beta\left(\frac{\partial I_B}{\partial I_C}\right)} = \frac{1+\beta}{1-\beta\left(\frac{R_E}{R_E+R_B}\right)} \approx 1$$

3m

6b) Current components of a PNP Transistor.



→ Figure shows the various current components in the pnp transistor, which flows across the Foreward biased Emitter base Jn and Reverse biased collector base Jn(Jc)

I_E consists of I_{pE} (holes crossing from emitter to base)

I_{nE} (electrons crossing from base to emitter)

→ Thus the holes crossing emitter base Junction (JE) and crossing collector base Junction Jc constitutes the collector current (I_{pc})

→ if $I_E = 0$ $I_{PE} = 0$ hence I_{PC} becomes 0
in such condition. the base and collector acts as reverse bias diode and the collector current is equal to the reverse saturation current I_{CO}.

$$\therefore \quad I_C = -I_{PC} + I_{CO}$$

4m

Parameters of transistors:

① Emitter efficiency $(\gamma) = \frac{I_{PE}}{I_E} = \frac{I_{PE}}{I_{PC} + I_{nE}}$

$$\simeq \frac{I_{PE}}{I_{PE}} \simeq 1$$

② Transport factor $(\beta^*) = \frac{I_{PC}}{I_{PE}}$

③ Large signal current gain $(\alpha) = \frac{I_{PE}}{I_E}$

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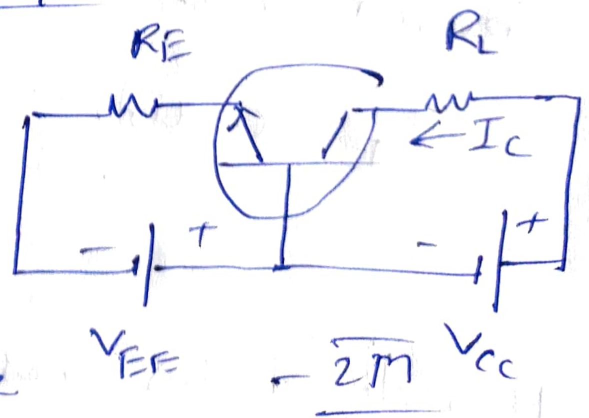
7a) Transistor as an Amplifier:

→ a small voltage change ΔV_i between emitter and base causes a relatively large emitter current change ΔI_E



2m

2m

→ Therefore the change in the output current is $\alpha \Delta I_E$ and the change in the output voltage across the load resistor $\Delta V_o = \alpha' R_L \Delta I_E$

$$\Delta V_i = r_e' \Delta I_E$$

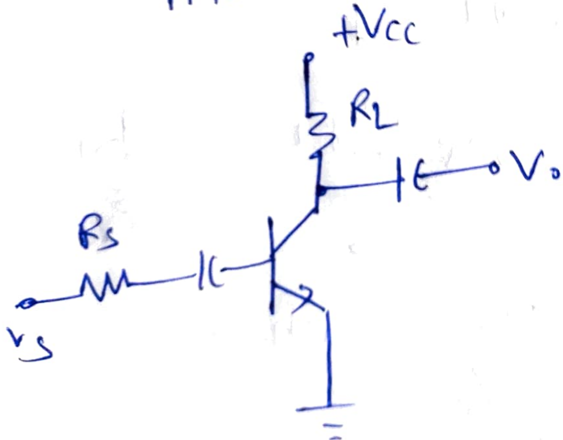
$$A = \frac{\Delta V_o}{\Delta V_i} = \frac{\alpha' R_L \Delta I_E}{r_e' \Delta I_E} = \frac{\alpha' R_L}{r_e'}$$

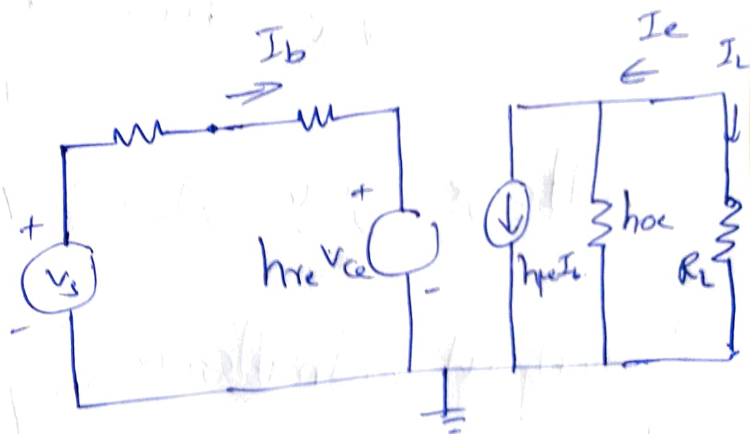
Let us assume $r_e' = 40\Omega$ $\alpha' = 1$ $R_L = 2k\Omega$

$$A = 50$$

3m

7b) Derive the expression for A_i, A_v, R_i and R_o for CE Amplifier using h-parameter model.





Current gain $A_i = \frac{I_L}{I_b} = -\frac{I_c}{I_b}$

$$I_c = h_{fe} I_b + h_{oe} V_c$$

$$I_c = h_{fe} I_b + h_{oe}(-I_c R_L)$$

$\therefore (1 + h_{oe} R_L) I_c = h_{fe} I_b$

$$\Rightarrow \frac{I_c}{I_b} = \frac{h_{fe}}{1 + h_{oe} R_L}$$

$$\boxed{A_i = -\frac{I_c}{I_b} = \frac{-h_{fe}}{1 + h_{oe} R_L}}$$

<u>Input resistance</u> $(R_i) = \dfrac{V_b}{I_b}$

$$V_b = h_{fe} I_b + h_{re} V_c$$

$$V_c = -I_c R_L = A_i I_b R_L$$

$$\therefore R_i = \frac{h_{ie} I_b + h_{re} A_i I_b R_L}{I_b}$$

$$\boxed{R_i = h_{ie} + h_{re} A_i R_L}$$

$$\boxed{R_i = h_{ie} - \frac{h_{re} h_{fe} R_L}{1 + h_{oe} R_L}}$$

<u>voltage gain</u> (A_v): $\dfrac{V_c}{V_b} = \dfrac{A_i I_b R_L}{V_b} = \dfrac{A_i R_L}{R_i}$

<u>output Admittance</u>: $(Y_o) = \dfrac{I_c}{V_c}$ with $V_s = 0$.

$$I_c = h_{fe} I_b + h_{oe} V_c$$

dividing by V_c

$$Y_o = \frac{I_c}{V_c} = \frac{h_{fe} I_b}{V_c} + h_{oe}$$

with $V_s = 0$

$$R_s I_b + h_{ie} I_b + h_{re} V_c = 0.$$

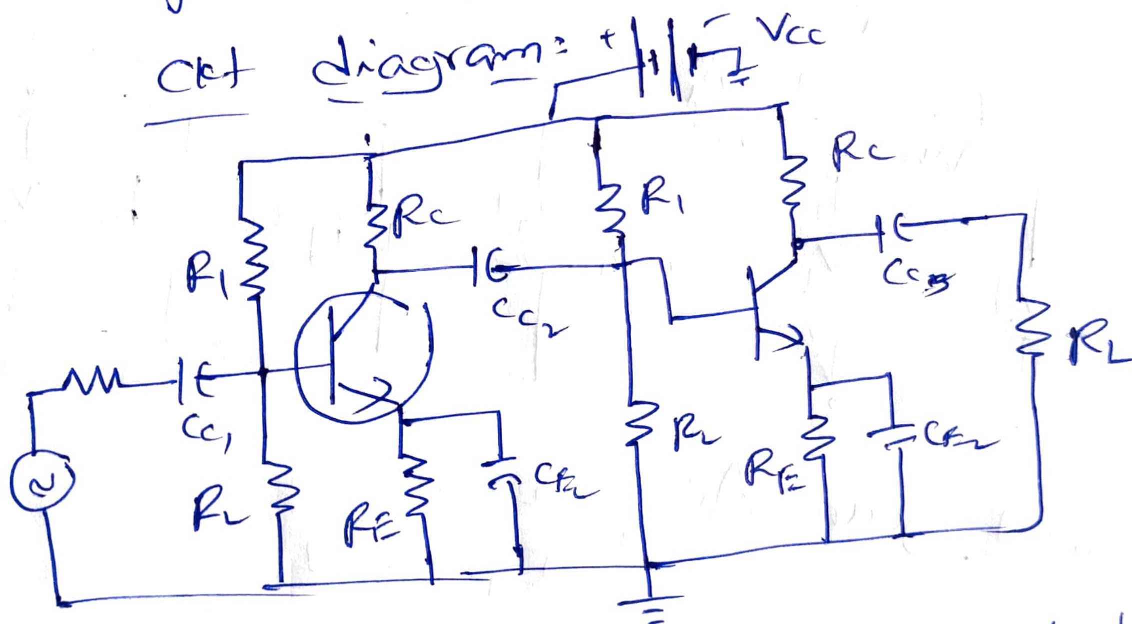
$$(R_s + h_{ie}) I_b = -h_{re} V_c \qquad \frac{I_b}{V_c} = \frac{-h_{re}}{R_s + h_{ie}}$$

Substituting value of $\frac{I_b}{V_c}$

$$Y_o = h_{oe} - \frac{h_{fe} h_{re}}{h_{ie} + R_s} \qquad R_o = \frac{1}{Y_o}$$

8a) Explain the working of a two stage RC coupled amplifier with circuit diagram.

Ckt diagram:



→ The o/p of stage 1 is coupled as an input to stage 2.

→ The signal is amplified further.

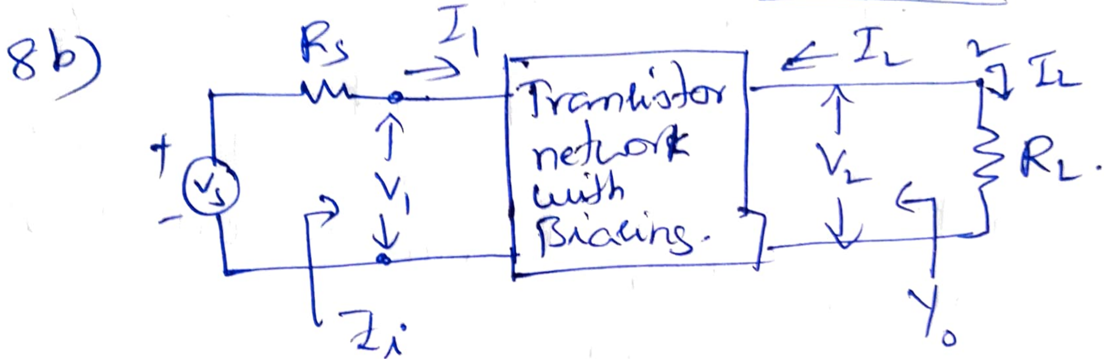
→ The first stage CE Amplifier is coupled to second stage CE Amplifier through collector Resistance Rc and.

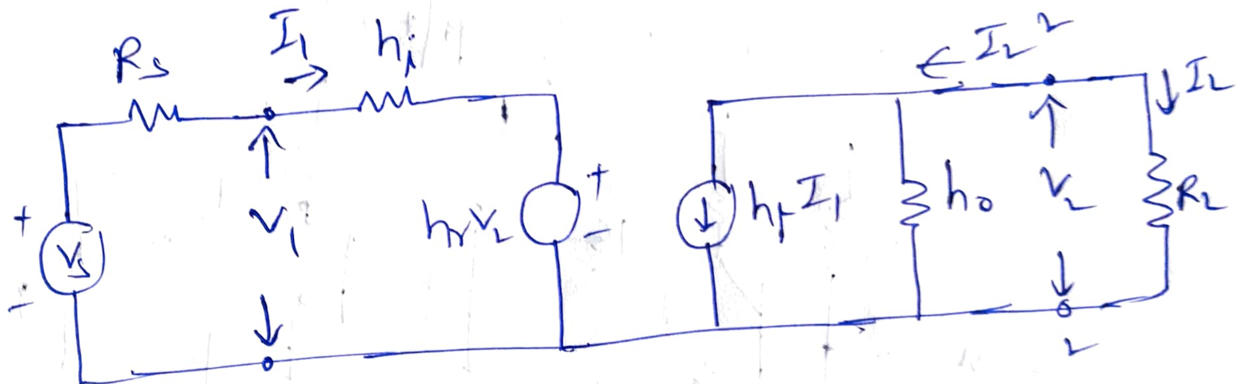
coupling capacitor C_c, The phase shift of 180° is avoided.

$$A_V = \frac{V_{o2}}{V_s} = \frac{V_{o2}}{V_{i2}} \times \frac{V_{o1}}{V_s}$$

$$= A_{V_2} \times A_{V_1}$$

8b)





current gain $A_i = \frac{I_L}{I_1} = -\frac{I_2}{I_1}$

$I_2 = h_f I_1 + h_o V_2 \qquad V_2 = -I_2 R_L$

$I_2 = h_f I_1 + h_o(-I_2 R_L)$

$I_2 + h_o I_2 R_L = h_f I_1$

$(1 + h_o R_L) I_2 = h_f I_1$

$$\boxed{\frac{I_2}{I_1} = \frac{h_f}{1 + h_o R_L}}$$

Current Gain (A_{is})

Input Impedance (Z_i) / (R_i)

$R_i = \frac{V_1}{I_1}$ $\quad V_1 = h_i I_1 + h_r V_2$

$\therefore R_i = h_i + h_r \frac{V_2}{V_1}$

$V_2 = -I_2 R_L = A_i I_1 R_L$

$R_i = h_i + \frac{h_r A_i I_1 R_L}{I_1} = h_i + h_r A_i R_L$

$A_i = \frac{-h_f}{1 + h_o R_L}$

Z_i or $R_i = h_i - \frac{h_f h_r R_L}{1 + h_o R_L}$

Voltage Gain (A_v)

$A_v = \frac{V_2}{V_1} = \frac{A_i I_1 R_L}{V_1} = \frac{A_i R_L}{Z_i}$

Output Admittance (Y_o)

$Y_o = \frac{I_2}{V_2}$ $\quad I_2 = h_f I_1 + h_o V_2$

$\frac{I_2}{V_2} = \frac{h_f I_1}{V_2} + h_o$

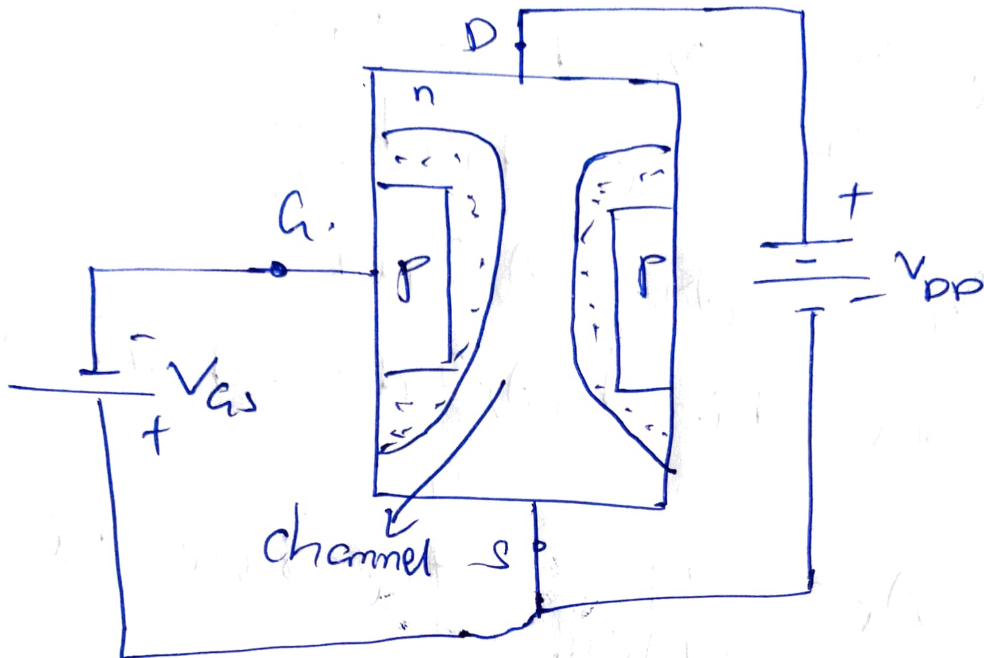
$Y_o = h_f \frac{I_1}{V_2} + h_o$, $R_s + I_1 + h_i I_1 + h_r V_2 = 0$

$\frac{I_1}{V_2} = \frac{-h_f}{R_s + h_i}$

$Y_o = h_o - \frac{h_f h_r}{h_i + R_s}$

9 a)

n-channel JFET



→ The biasing voltage V_{DS} is applied between Source and Drain.

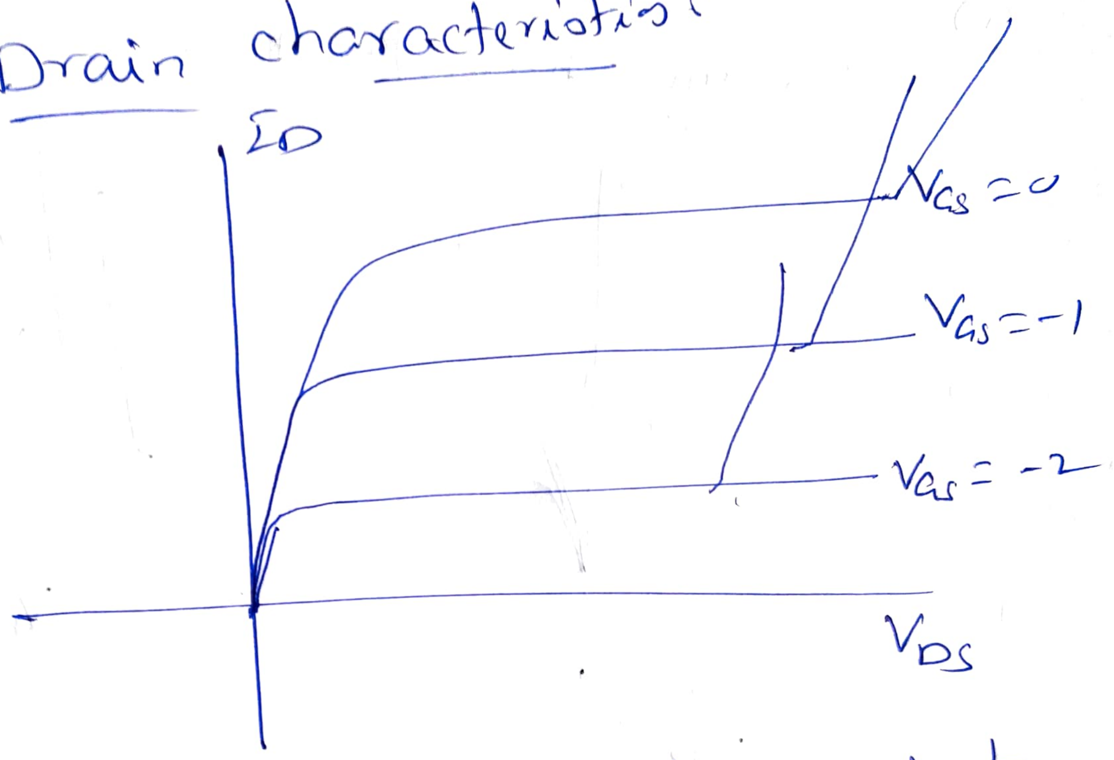
→ when V_{DS} is applied the electrons from metallic wire enters in to Source (S) and the electrons from the Source travel towards the Drain (D) as the Drain terminal is positive.

→ As the V_{DS} increases the flow of electrons from ~~chsm~~ source to Drain Increases and flow through the channel.

→ As the width of the channel is limited. the current is limited at

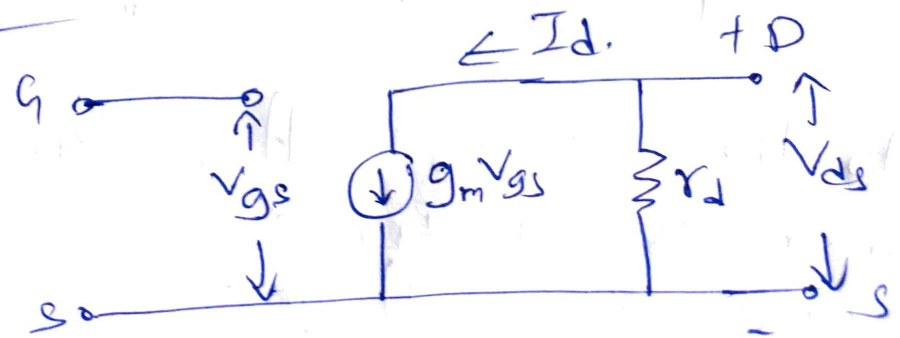
particular drain to source voltage V_{DS} the voltage at which the drain current I_D becomes constant is called "pinch off voltage V_P"

Drain characteristics:



→ if the reverse voltage across gate to source V_{GS} increases. the channel width is reduced due to increased in depletion region in the n type substrate.

9 b) Fixed bias method n channel JFET

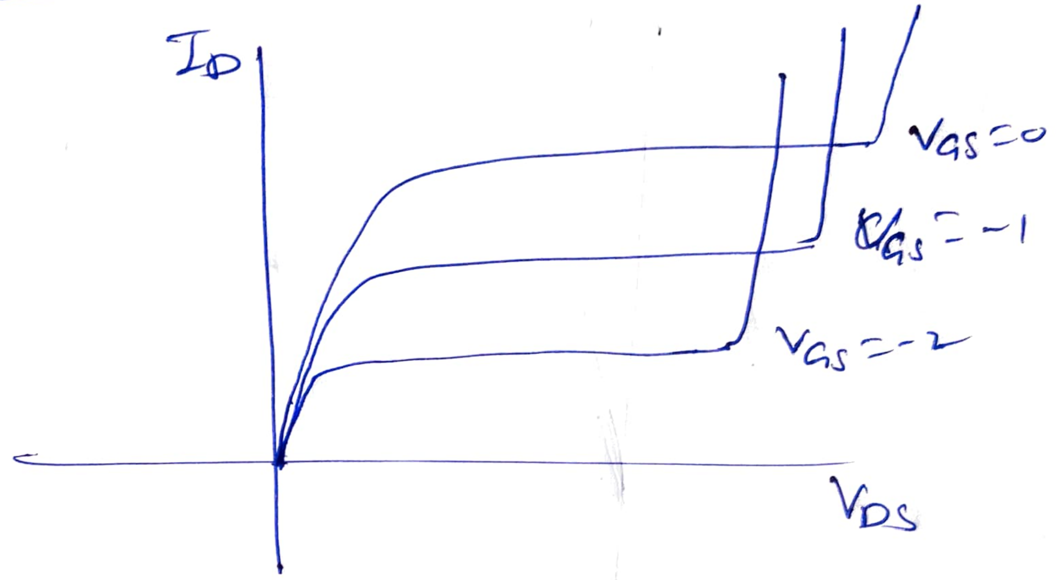


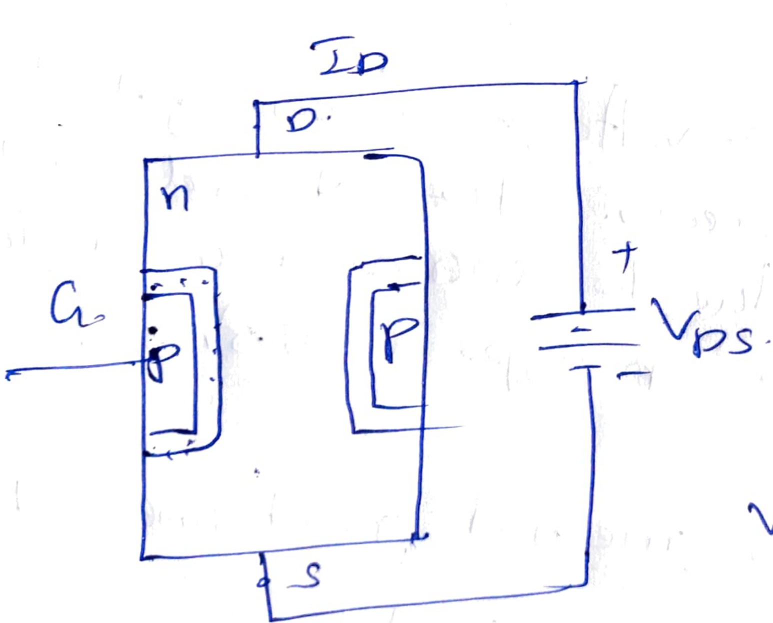
$$\Delta I_d = g_m \, \Delta V_{GS}$$

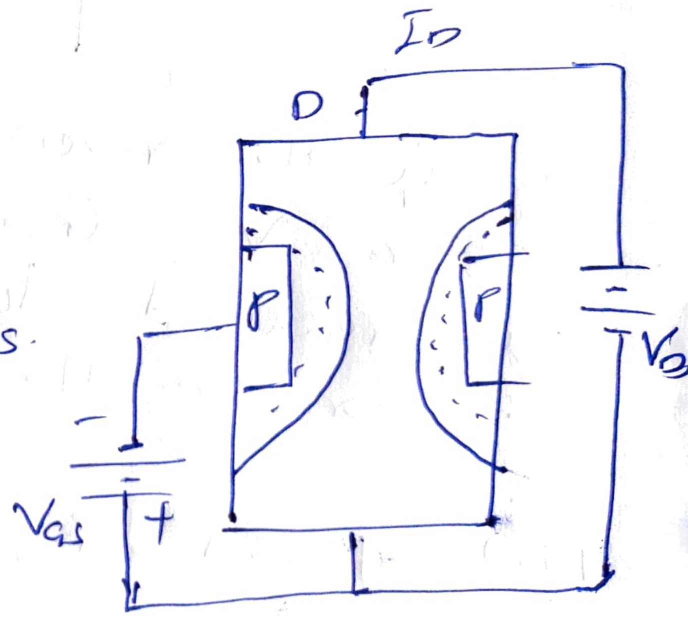
$$r_d = \left. \frac{\Delta V_{DS}}{\Delta I_D} \right|_{V_{GS} = \text{const.}}$$

10 a)

Drain characteristics.







→ As the biasing voltage V_{DS} increases the drain current I_D increases until the pinch off voltage.

if the gate to source voltage V_{GS} increases the negative bias at V_{GS} increases and hence the width of the depletion layer between p and n regions increases thus the channel width is reduced

→ Hence eventhough the drain to source voltage V_{DS} increases the drain current remains constant as the width of the channel is limited

10b) P-channel Enhancement MOSFET:

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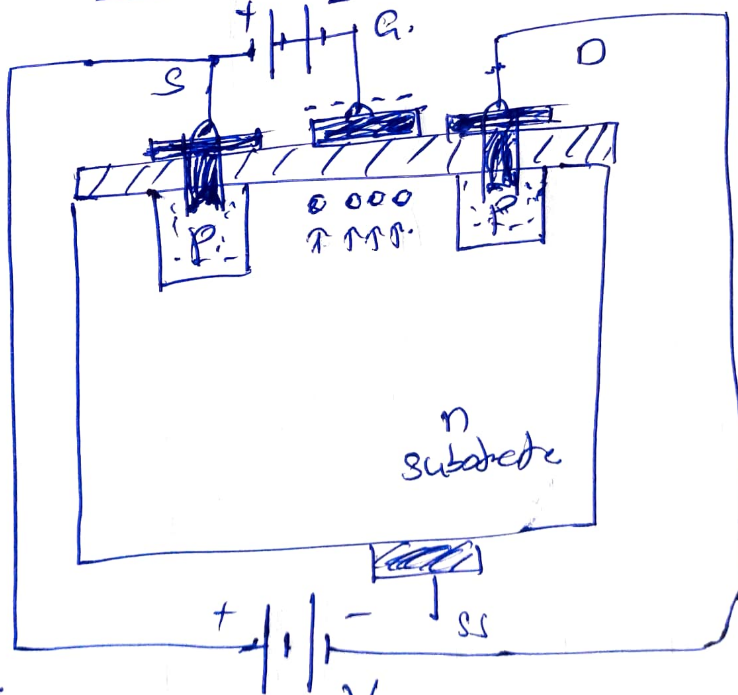
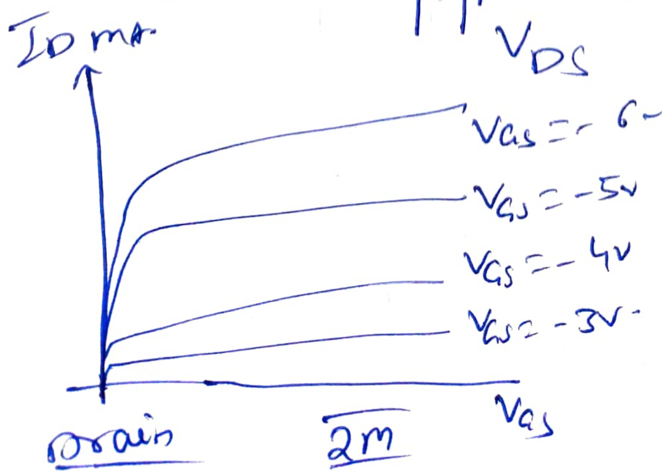
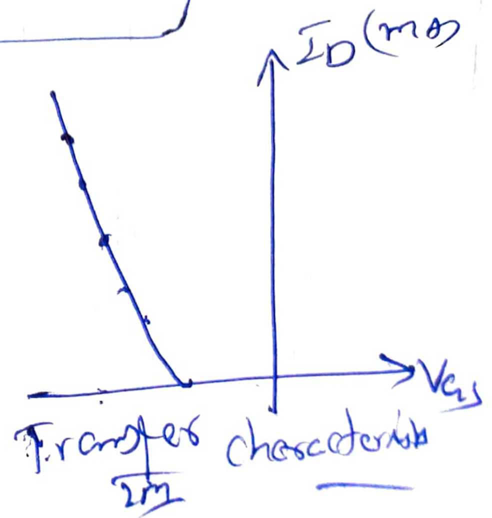


3m



Drain

2m



Transfer characteristics

2m