

UNIT - 1

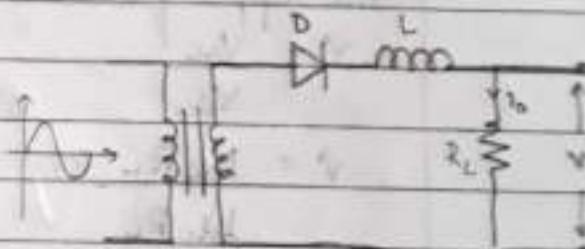
Diode Circuits and its Applications

* FILTERS:Types of filters:

1. Inductor filter (choke filter)
2. Capacitor filter
3. LC filter or L-section filter
4. CLL filter or Z-section filter

1. INDUCTOR FILTER:- HWR with inductor filter:

The analytical representation
of output current from Fourier
series.



$$i = I_m \left[\frac{1}{\pi} + \frac{1}{2} \sin \omega t - \frac{2}{\pi} \sum_{k=2,4,6}^{\infty} \frac{\cos k\omega t}{(k+1)(k-1)} \right] \quad (1)$$

$$i = \frac{I_m}{\pi} + \frac{I_m}{2} \sin \omega t - \frac{2I_m}{\pi} \left[\frac{\cos 2\omega t}{3} + \frac{\cos 4\omega t}{15} \right] \quad (2)$$

$$\text{at } \omega kt, I_{dc} = \frac{I_m}{\pi} = \frac{V_m}{\pi R_L} \quad (3)$$

The rms value of ac component is

$$I_{ac} = \frac{I_m}{2 \sqrt{2}} = \frac{I_m}{2\sqrt{2}}$$

$$\therefore I_{ac} = \frac{V_m}{2\sqrt{2}(R_L + j\omega L)}$$

At operating frequency: $\omega L \gg R_L$. Hence R_L can be neglected

$$I_{ac} = \frac{V_m}{2\sqrt{2}\omega L}$$

Here I_2 is the rms value of second harmonic

$$I_2 = \frac{2Vm}{3\pi} \times \frac{1}{\sqrt{2}} = \frac{2Vm}{3\sqrt{2}\pi}$$

$$\therefore I_2 = \frac{2Vm}{3\sqrt{\pi}(R_L + 2wL)}$$

At operating frequency, $wL \gg R_L$, hence neglecting R_L

$$I_2 = \frac{2Vm}{3\sqrt{2}\pi(2wL)}$$

$$I_2 = \frac{Vm}{3\sqrt{2}\pi wL}$$

The ac component is

$$I_{ac} = \sqrt{I_1^2 + I_2^2} \quad \text{--- (A)}$$

The ripple factor is given by

$$\gamma = \frac{V_{ac}}{V_{dc}}$$

$$\gamma = \frac{I_{ac} R_L}{I_{dc} R_L}$$

Substituting eq (3) and eq (4), I_1 and I_2

$$\gamma = \sqrt{\left(\frac{Vm}{2\sqrt{2}wL}\right)^2 + \left(\frac{Vm}{3\sqrt{2}\pi wL}\right)^2}$$

$$\frac{Vm}{\pi R_L}$$

$$\gamma = \frac{Vm}{wL} \sqrt{\left(\frac{1}{2\sqrt{2}}\right)^2 + \left(\frac{1}{3\sqrt{2}\pi}\right)^2}$$

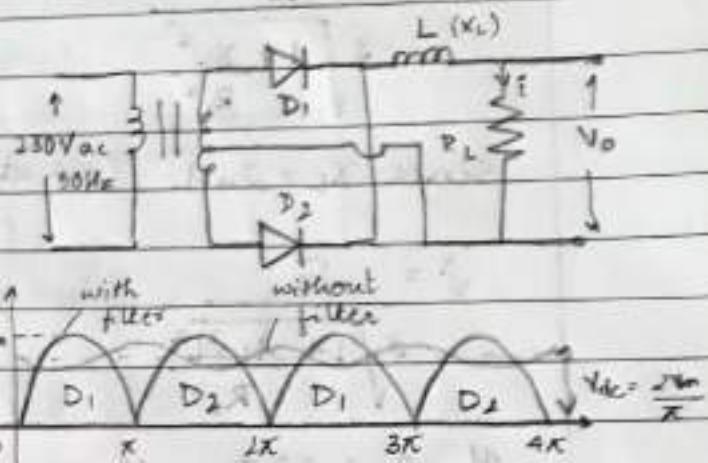
~~$\gamma = \frac{Vm}{\pi R_L}$~~

$$\gamma = \frac{\pi R_L}{wL} [0.36]$$

$$\gamma = \frac{1.13 R_L}{wL}$$

FWR with inductor filter:

The analytical representation of output current from Fourier Series is given by:



$$i = Im \left[\frac{2}{\pi} - \frac{4}{\pi} \sum_{k=2,4,6} \frac{\cos kwt}{(k+1)(k-1)} \right]$$

The analytical representation of rectified output voltage from Fourier Series is given by:

$$V_o = 2 \underbrace{\frac{Vm}{\pi}}_{\text{dc component}} - \underbrace{\frac{4}{\pi} Vm \cos 2wt}_{3} - \underbrace{\frac{4 Vm \cos 4wt}{15\pi}}_{\text{ac component}} \quad \text{--- (1)}$$

$$\text{wkt } V_{dc} = \frac{2Vm}{\pi} \quad \text{--- (2)}$$

The rms value of ac component

$$V_{ac} = \frac{4Vm}{3\pi} \times \frac{1}{\sqrt{2}} \times \frac{R_L}{\sqrt{R_L^2 + X_L^2}}$$

$$V_{ac} = \frac{2\sqrt{2}Vm R_L}{3\pi \sqrt{R_L^2 + X_L^2}}$$

The ripple factor is given by

$$\gamma = \frac{V_{ac}}{V_{dc}}$$

$$\gamma = \frac{2\sqrt{2}Vm R_L}{3\pi \sqrt{R_L^2 + X_L^2}}$$

$$\frac{2Vm}{\pi}$$

$$\gamma = \frac{\sqrt{2} R_L}{3 \sqrt{R_L^2 + X_L^2}}$$

$$V = \frac{\sqrt{2}}{\sqrt{1 + \frac{X_L^2}{R_L^2}}}$$

since $X_L = 2\omega L$ (ac at 2nd harmonic)

$$V = \frac{\sqrt{2}}{\sqrt{1 + \frac{4\omega^2 L^2}{R_L^2}}}$$

If $2\omega L \gg R_L$, then

$$V = \frac{\sqrt{2} R_L}{3(2\omega L)}$$

$$V = \frac{R_L}{3\sqrt{2}\omega L}$$

NOTE:

Demerits of inductive filter

- A drop across the inductor reduces the output voltage across load resistance
- Bulky and expensive.

Q1: A FWR with a load resistance of $15k\Omega$ uses an inductor filter of $15H$. The peak value of applied voltage $250V$ and the frequency is 50Hz . Calculate the dc load current, ripple factor, and dc output voltage.

Sol:

Given: $R_L = 15k\Omega$; $L = 15H$; $V_m = 250V$; $f = 50\text{Hz}$

$$V_{dc} = \frac{2V_m}{\pi} = \frac{2 \times 250}{3.14} = \underline{\underline{159.15V}}$$

$$I_{dc} = \frac{V_{dc}}{R_L} = \frac{159.15}{15 \times 10^3} = \underline{\underline{10.6mA}}$$

$$v_o = \frac{R_L}{3\sqrt{2} \cdot \omega L} \cdot \frac{15 \times 10^3}{3 \times \sqrt{2} \times 2\pi \times 50 \times 10^{-3}} = 0.75$$

$$i = Im \left[\frac{1}{\infty} - \frac{4}{\pi} \cos 2\pi t + \frac{4}{15\pi} \cos 4\pi t \right]$$

$$I_{ac} = \frac{4 V_m \times 1}{3\pi \sqrt{2}} \times \frac{1}{\sqrt{R_L^2 + 4\omega^2 L^2}}$$

$$I_{ac} = \frac{4 \times 250}{3 \times 3.14 \times \sqrt{2}} \times \frac{1}{\sqrt{(15k)^2 + 4 \times 314^2 \times 15^2}}$$

$$I_{ac} = 4.24mA$$

$$\sqrt{V} = \frac{I_{ac}}{I_{dc}} = \frac{4.24mA}{10.6mA} = 0.4$$

3. LC FILTER: (choke input filter)

Capacitor Filter

Advantage

- Ripple factor is not dependent on load resistance

$$HWR : \sqrt{V} = \frac{1}{2\sqrt{3} f C R_L}$$

$$FWR : \sqrt{V} = \frac{1}{4\sqrt{3} f C R_L}$$

Disadvantage

- Diode current increases due to which transistor heats up reducing efficiency.

Desired characteristics

C filter: voltage stability action

L filter: current smoothing action

Inductor Filter

- Ripple factor is dependent on load resistance.

$$HWR : \frac{1.13 R_L}{w_L L}$$

$$FWR : \frac{R_L}{3\sqrt{2} w_L L}$$

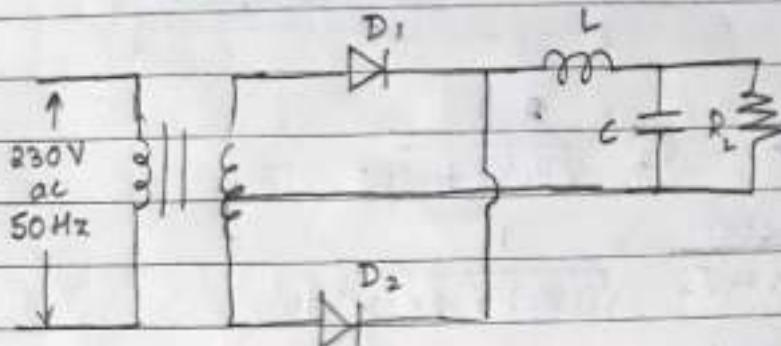
Advantage

- Any variation in current is smoothed out in case of inductor filter.

Disadvantage

- Reduces the output current and output voltage due to the drop across the inductor.

Ripple factor should be independent on R_L .
Diode current should be minimum.



Ripple Factor in an LC filter

Condition: $X_C \ll R_L$ and $X_L \gg X_C$ at $\omega = 4\pi f$ (at 2nd harmonic)
(To maintain the diode current to minimum)

$$\text{Wkt } V_{rms} = \frac{Vm}{\sqrt{2}}$$

$$v(t) = \underbrace{\frac{2Vm}{\pi}}_{\text{dc component}} - \underbrace{\frac{4Vm}{3\pi} \cos 2\omega t}_{\text{ac component}}$$

$$V_{dc} = \frac{2Vm}{\pi} \quad V_{ac} = \frac{4Vm}{3\pi}$$

$$\therefore V_{rms} = \frac{4Vm}{3\pi} \times \frac{1}{\sqrt{2}} \Rightarrow V_{rms} = \frac{2\sqrt{2}Vm}{3\pi} \quad \text{--- (1)}$$

$$I_{ac(rms)} = \frac{V_{ac(rms)}}{X_L} \quad (\text{Substituting eq (1)})$$

$$I_{ac(rms)} = \frac{2\sqrt{2}Vm}{3\pi X_L}$$

$$I_{ac(rms)} = \frac{\sqrt{2}}{3X_L} \times \frac{2Vm}{\pi}$$

$$I_{ac(rms)} = \frac{\sqrt{2}}{3X_L} V_{dc} \quad (\text{Substituting } V_{dc})$$

$$V_{ac(rms)} = I_{ac(rms)} X_L$$

$$V_{ac\text{ rms}} = I_{ac\text{ rms}} X_C$$

$$V_{ac\text{ rms}} = \frac{\sqrt{2}}{3} V_{dc} X_C \quad (\text{substituting } I_{ac})$$

$$\frac{V_{ac}}{V_{dc}} = \frac{\sqrt{2}}{3} \frac{X_C}{X_L}$$

$$\frac{V}{V_{dc}} = \frac{\sqrt{2}}{3} \frac{1/2 \omega C}{2 \omega L}$$

$$\boxed{\frac{V}{V_{dc}} = \frac{1}{6\sqrt{2} \omega^3 LC}}$$

Bleeder Resistor:

It helps to stabilize the inductance value which keeps varying from minimum to maximum.

It helps in discharging of capacitor after the removal of power supply.

Critical Inductance:

It is the maximum inductance value that is suitable for desired ripple factor. It should be selected in such a way that the diode current does not fall to zero.

Considering the Fourier series of output current

$$I_o = \frac{2V_m}{\pi R_L} - \frac{4V_m}{3\pi X_L} \cos 2wt$$

$$\frac{V_{dc}}{R_L} \geq \frac{4V_m}{3\pi X_L}$$

$$\frac{V_{dc}}{R_L} \geq \frac{2 \cdot 2V_m}{3 \pi} \frac{1}{X_L}$$

$$\frac{V_{dc}}{R_L} \geq \frac{2}{3} \frac{V_{dc}}{X_L}$$

$$X_L \geq \frac{2R_L}{3}$$

$$\omega_0 L = \frac{2R_L}{3}$$

$$L_{cr} = \frac{R_L}{3\omega}$$

Critical Inductance

Q1: A L section filter with $L = 2H$ and $C = 40\mu F$ is used in the output of full wave single phase rectifier that is fed from $10-0-40V$ peak transformer. The load current is $0.2A$. Calculate the ripple factor and output dc voltage assume that the rectifier diodes are ideal.

Sol: Given: $L = 2H$ $I_L = 0.2A$
 $C = 40\mu F$ $V_m = 40V$

DC output voltage

$$V_{dc} = 2V_m = \frac{2 \times 40}{\pi} = 25.46V$$

$$\underline{\underline{V_{dc} = 25.46V}}$$

Ripple factor

$$\underline{\underline{r^2 = \frac{1}{6\sqrt{2}\omega^2 LC} = \frac{1}{6\sqrt{2}(2\pi 50)^2 2(40 \times 10^{-6})}}}$$

$$\underline{\underline{r^2 = 0.0149}}$$

Q2: Design a full wave rectifier with LC filter to provide $10V$ dc at $100mA$ along with maximum ripple of 2% . The frequency of input voltage is $50Hz$. Determine the ripple factor of LC filter.

Sol: Given: $r^2 = 0.02$ $V_{dc} = 10V$
 $f = 50Hz$ $I_L = 100mA$

$$\frac{V^2}{R} = \frac{1}{6\sqrt{2}\omega^2 LC}$$

$$LC = \frac{1}{6\sqrt{2}\omega^2 V^2} = \frac{1}{6\sqrt{2}(2\pi 50)^2 0.02}$$

$$LC = 5.94 \times 10^{-5}$$

$$R_L = \frac{V_{dc}}{I_{dc}} = \frac{10}{100\text{mA}}$$

$$R_L = 100\Omega$$

$$L_{cr} = \frac{R_L}{3\omega} = \frac{100}{3 \times 2\pi \times 50}$$

$$L_{cr} = 0.106\text{H}$$

$$C = \frac{5.94 \times 10^{-5}}{0.106}$$

$$C = 5.63 \times 10^{-4}\text{F} = 0.563\mu\text{F}$$

Q3: A full wave rectifier is to supply 100mA at 350V with a ripple that must be less than 10V. Specify the elements of a rectifier using a single section filter that will provide the design results.

Sol: Given : $I_{dc} = 100\text{mA}$ $V_{ac} = 10\text{V}$

$$V_{dc} = 350\text{V}$$

$$\frac{V_R}{V_{dc}} = \frac{V_{ac}}{V_{dc}} = \frac{10}{350} \quad R_{f1} \quad \frac{V}{V_{dc}} = 0.028$$

$$R_L = \frac{V_{dc}}{I_{dc}} = \frac{350}{100\text{mA}} = 3.5\text{k}\Omega$$

$$L_{cr} = \frac{R_L}{3\omega} = \frac{3.5\text{k}}{3 \times 2\pi \times 50} = 3.41\text{H}$$

$$\sqrt{V} = \frac{1}{6\sqrt{2}\omega^2 LC}$$

$$LC = \frac{1}{6\sqrt{2}\omega^2 \sqrt{V}} = \frac{1}{6\sqrt{2}(2\pi 50)^2 (0.028)}$$

$$LC = \frac{1.26 \times 10^{-5}}{3.41} = 42.6 \mu$$

$$C = \frac{1.26 \times 10^{-5}}{3.41}$$

$$C = \frac{1.15 \times 10^{-5} F}{3.41} = 11.5 \mu F$$

Q.9: A full wave rectifier with LC type filter is to supply 100 mA at 30V with a ripple that must not exceed 1%. Calculate the suitable filter components assuming a supply frequency to be 50 Hz.

Sol: Given: $I_{dc} = 100 \text{ mA}$ $V_{ac} = 1 \text{ V}$

$$V_{dc} = 30 \text{ V}$$

$$\nabla R_L = \frac{V_{dc}}{I_{dc}} = \frac{30}{100 \text{ m}}$$

$$R_L = 300 \Omega$$

$$\sqrt{V} = \frac{V_{ac}}{V_{dc}} = \frac{1}{30}$$

$$\sqrt{V} = 0.033$$

$$\sqrt{V} = \frac{1}{6\sqrt{2}\omega^2 LC}$$

$$LC = \frac{1}{6\sqrt{2}\omega^2 \sqrt{V}} = \frac{1}{6\sqrt{2}(2\pi 50)^2 0.033}$$

$$LC = \frac{3.62 \times 10^{-5}}{3.41}$$

$$L_{CR} = \frac{R_L}{3\omega} = \frac{300}{3 \times (2\pi \cdot 50)}$$

$$\underline{L_{CR} = 318 \text{ mH}}$$

$$C = \frac{3.62 \times 10^{-5}}{318.3 \text{ m}}$$

$$\underline{C = 113.7 \mu\text{F}}$$

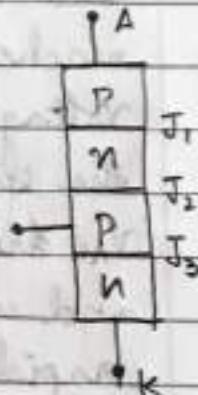
* POWER DEVICES:

1. Silicon Control Rectifier:

- current conduction: unidirectional
- It is a 4 layer, 3 terminal device
- It has 3 junctions.
- Used in switching devices

Biassing

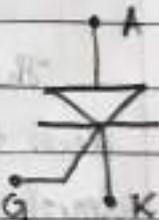
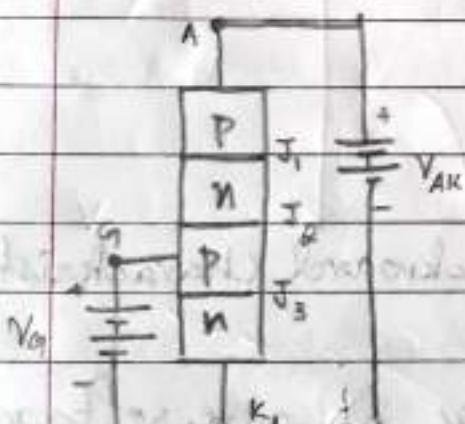
No Biassing



J_1 and J_3 are forward biased

J_2 is reverse biased

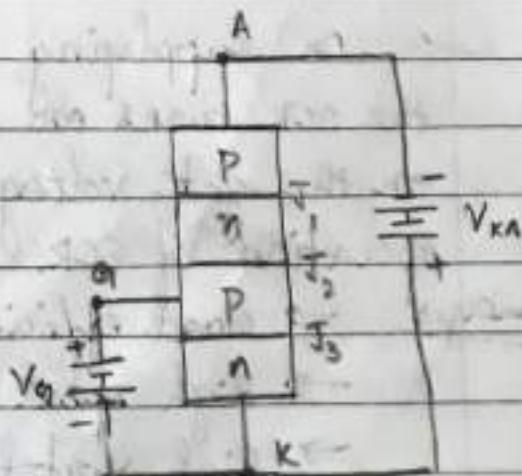
In this case the SCR does not conduct and lies in the cut off region.



J_1 and J_3 are reverse biased

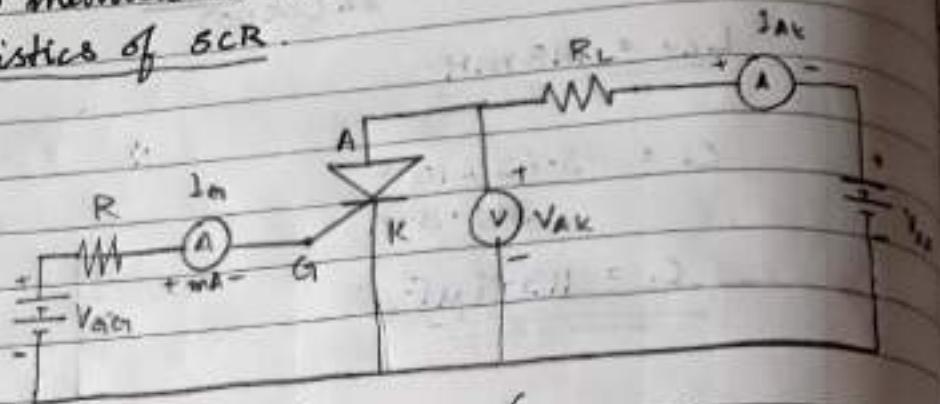
J_2 is forward biased.

In this case the SCR does not conduct and lies in the cut off region.

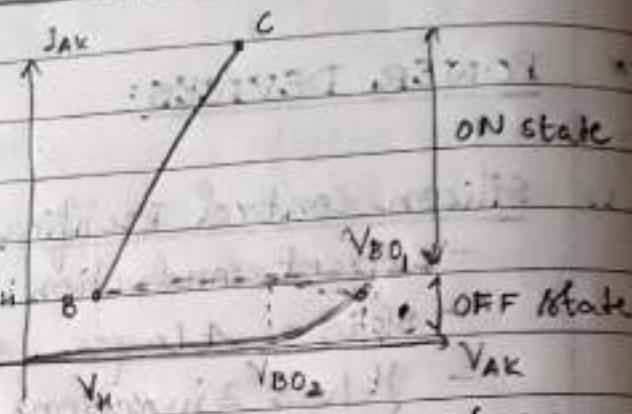


there are two methods to turn on a SCR.

v-1 characteristics of SCR.

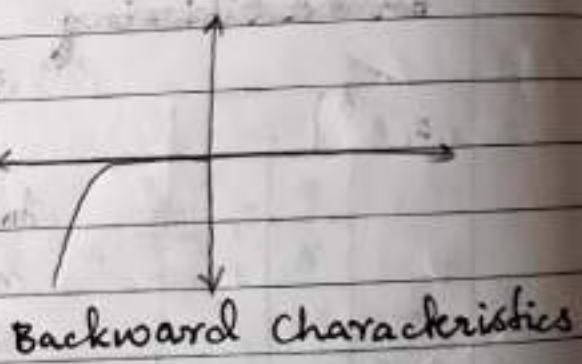


- The current remains zero until the supply V_{AK} reaches the Break over voltage. Once it reaches the break over voltage the V_{AK} drops to minimum and current increases rapidly.



Forward characteristics
 I_H - Holding current $V_{BO_1}, I_AK = 0$

The SCR breaks down due to avalanche breakdown when V_{AK} exceeds the break down voltage.



Backward characteristics

- On supplying a certain voltage at gate voltage the SCR turns on faster than usual. Once the SCR is on the gate voltage or gate current does not affect the operation of SCR.

Advantages

- good efficiency
- high speed current variation.
- High switching speed

Two-transistor Analogy of SCR:

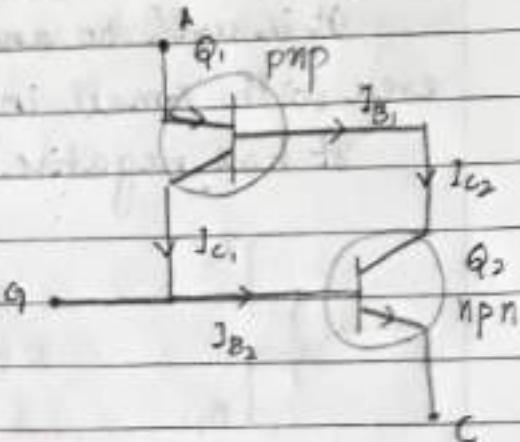
$$I_A = \frac{\alpha_2 I_g}{1 - (\alpha_1 + \alpha_2)}$$

I_A - anode current

I_g - gate current

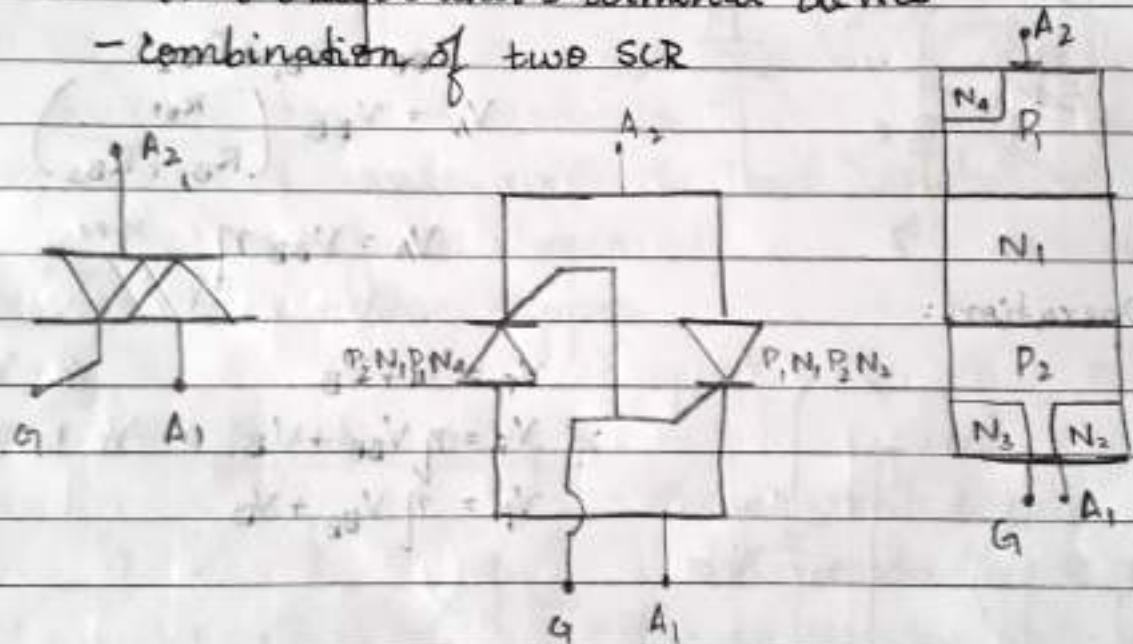
α_1 - current gain of Q_1

α_2 - current gain of Q_2 .

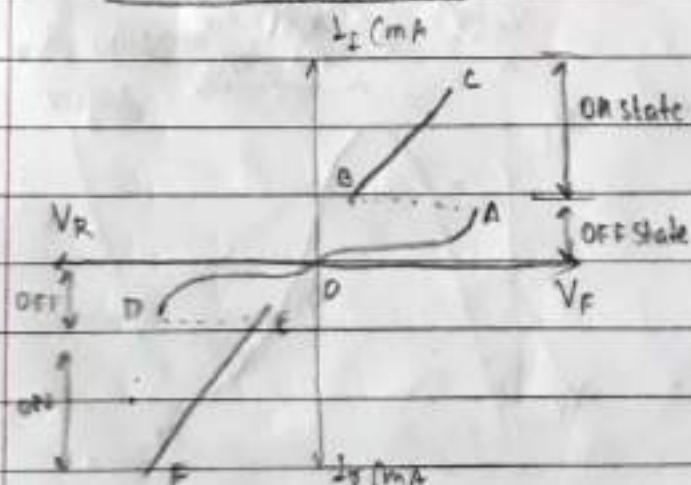


2. TRIAC:

- current conduction - bidirectional
- it is 5 layer and 3 terminal device
- combination of two SCR



VI characteristics



OA - Off state - less than break

ON state overvoltage hence small leakage current

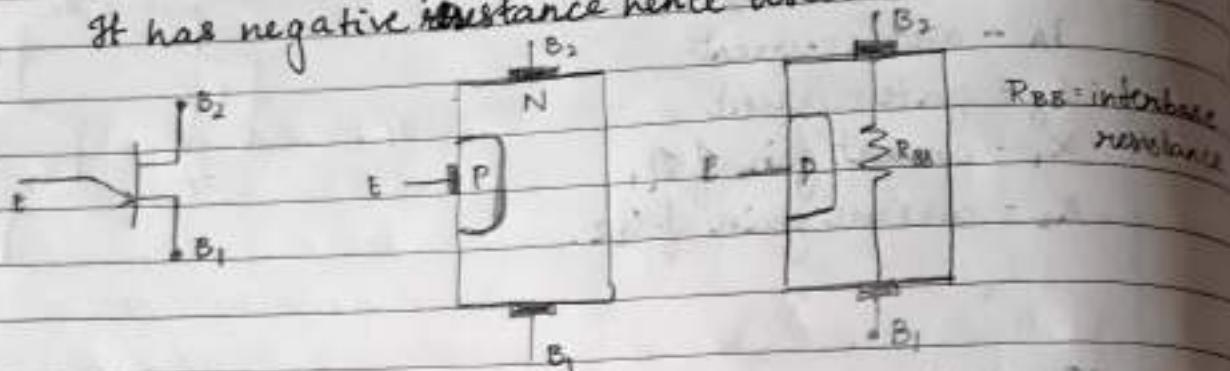
BC - On state - on positive voltage greater than break over voltage

→ light application

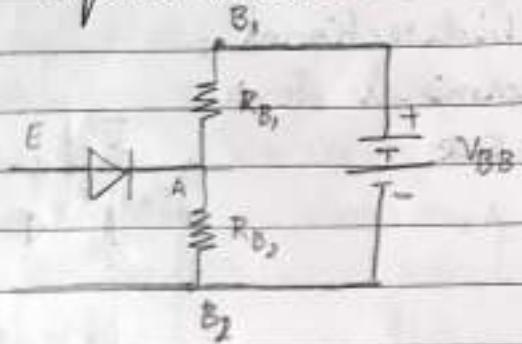
3. UJT : Uni Junction Transistor

It is used to analyse ac power delivered to the load even with small input.

It has negative resistance hence used in oscillators.



Equivalent circuit



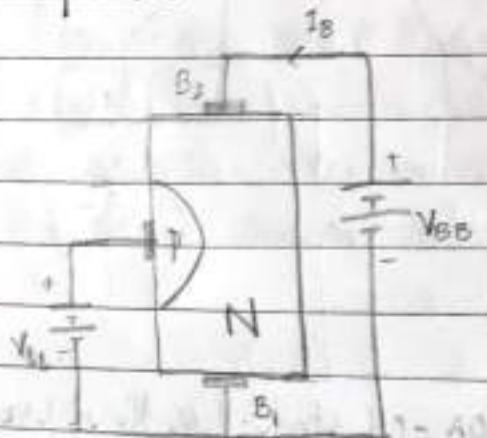
η - intrinsic stand off ratio

$$R_{BB} = R_{B1} + R_{B2}$$

$$V_A = V_{BB} \left(\frac{R_{B1}}{R_{B1} + R_{B2}} \right)$$

$$V_A = V_{BB} \eta$$

Operation:



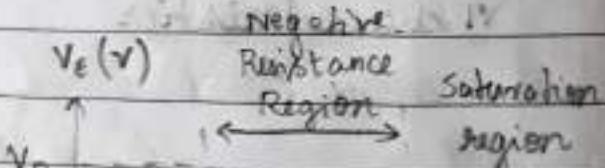
$$V_T = V_A + V_B$$

$$V_A = V_{BB} \eta$$

$$V_T = \eta V_{BB} + V_B$$

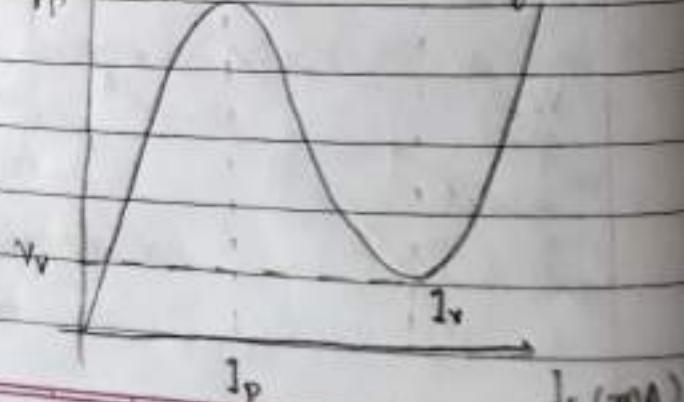
V_B - Barrier Voltage

$$V_P = \eta V_{BB} + V_B$$



As V_B decreases

I_c increases hence called as negative resistance region.



Application

- used in sawtooth wave generation, sine wave generation, pulse generation
- Triggering circuit
- voltage regulation.

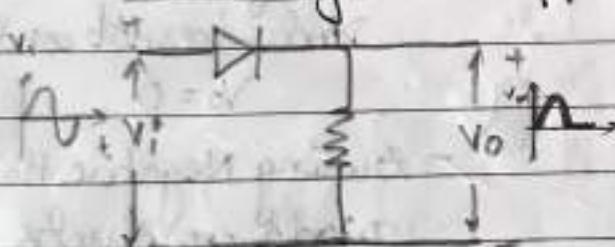
* CLIPPING CIRCUITS:

Part of the input wave is clipped off without any distortion in the signal.

Types:

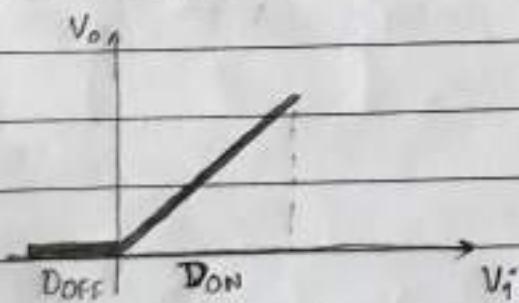
1. series clipper
2. Parallel clipper

- series clipper: A diode is connected in series with the load resistance.
 - series negative clipper
 - series positive clipper

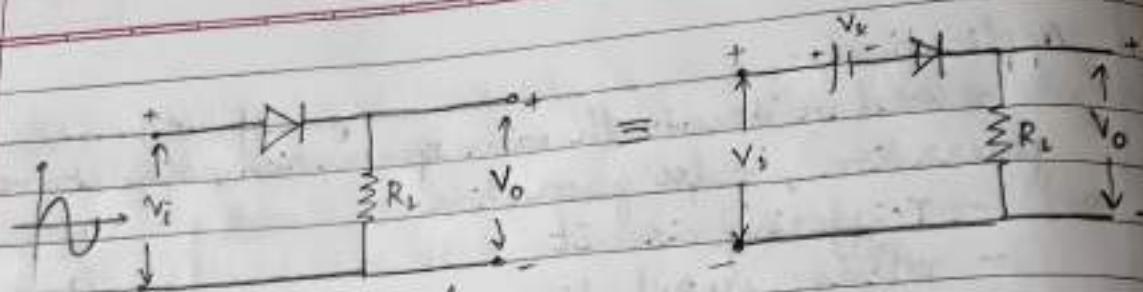
* Series Negative clipper

- During Positive cycle
Diode conducts $\rightarrow V_o = V_i = V_m$
- During Negative half cycle
Diode does not conduct $\rightarrow V_o = 0$

Ideal diode



Transfer characteristics



Practical diode.

only if $V_i > V_k$ only then
the diode conducts.

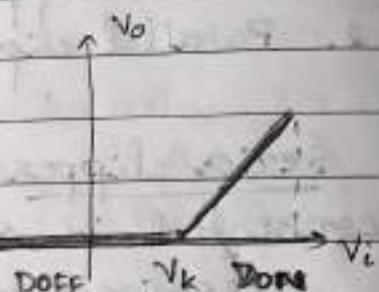
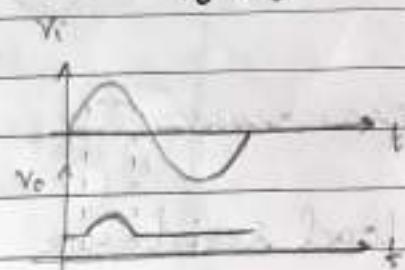
$$V_i - V_k - V_o = 0$$

$$V_o = V_i - V_k$$

if $V_i < V_k$ then the diode
does not conduct

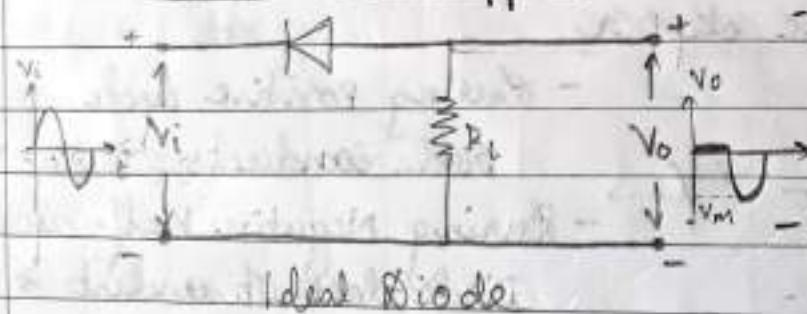
Positive Half cycle

$$V_o = 0$$



Transfer characteristics

* Series Positive Clipper:

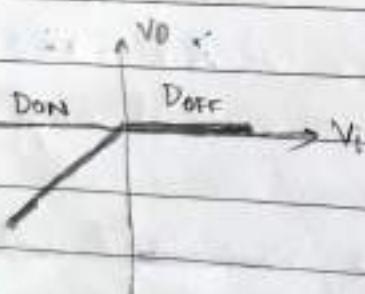


- During Positive Half cycle
Diode does not conduct

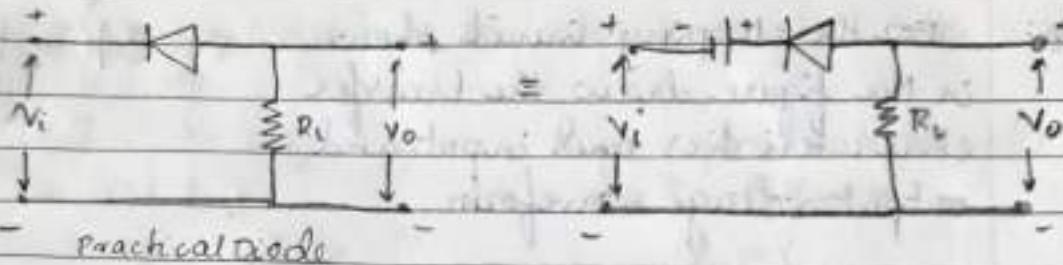
$$V_o = 0$$

- During Negative Half cycle
Diode conducts

$$V_o = -V_i = -V_m$$



Transfer characteristics



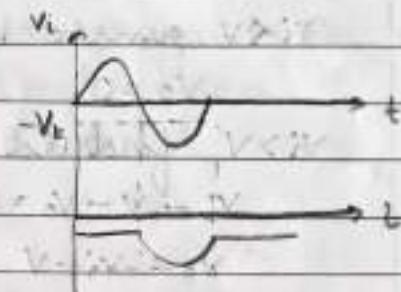
During positive Half cycle
the diode does not conduct

$$V_o = 0$$

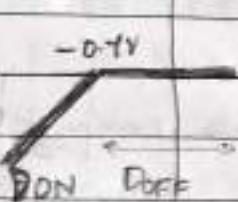
During negative Half cycle
the diode conducts

~~-ve retarding~~ $V_i + V_k = V_o$

~~reverse~~ $V_o = -V_m + V_k$

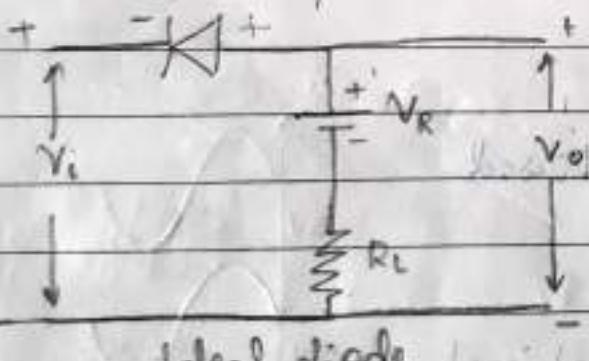


Transfer characteristics



Biased Clipper:

$$V_{\text{reference}} = 1 \text{ or } 2 \text{ V}$$



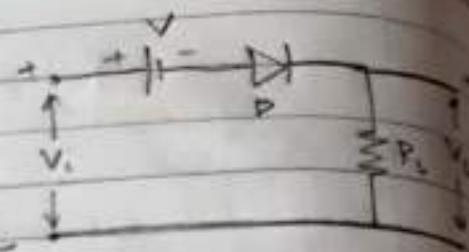
- During positive half cycle
 $V_i < V_R$ - forward biased
Hence diode conducts.

$$V_o = V_i + V_R$$

$V_i > V_R$ - reverse biased
Hence diode does not conduct

$$> V_o = V_R$$

Q1: For the clipping circuit shown in the figure draw the transfer characteristics and input and output voltage waveform.



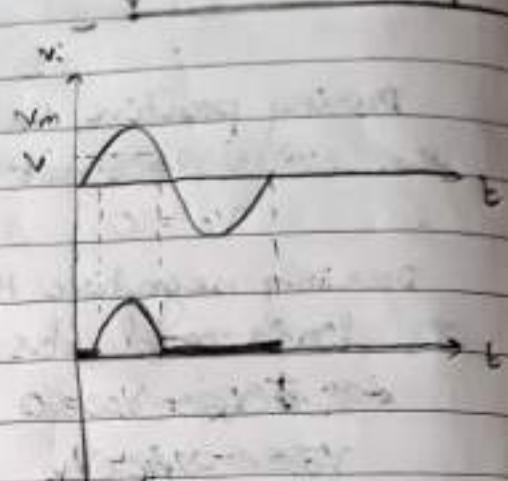
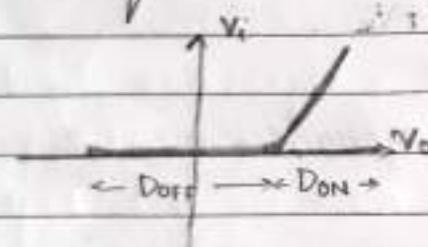
Sol: $v_i < v$ reverse biased
 $v_o = 0$

$v_i > v$ forward biased

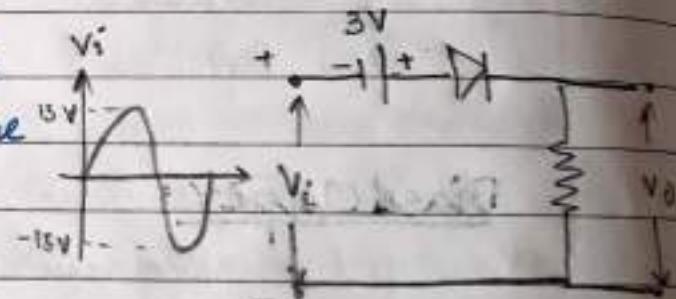
$$v_i - v - v_o = 0$$

$$v_o = v_i - v$$

Transfer characteristics



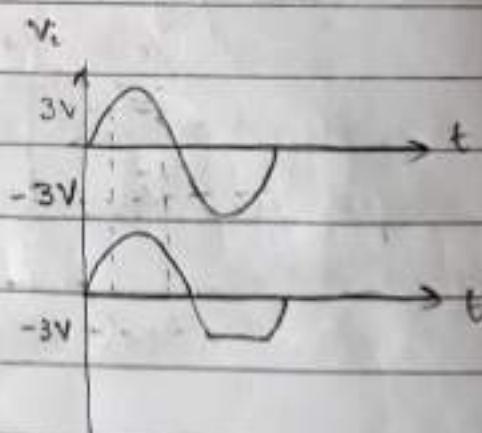
Q2: Show the output waveform for the network shown below if the peak value of ac input is 15V. Show all the voltage levels in the output.



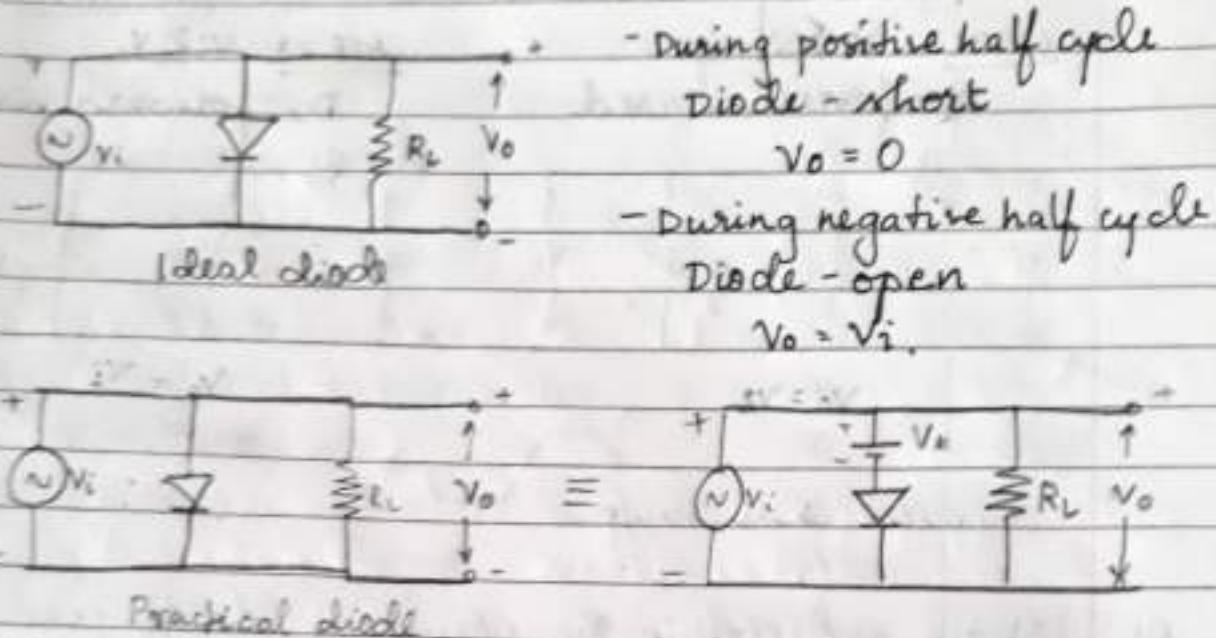
Sol: $v_i > 3V$ - forward biased
 $v_i + v_d - v_o = 0$

$$v_o = v_i + v_d$$

$v_i < 3V$ - reverse biased
 $v_o = 0$



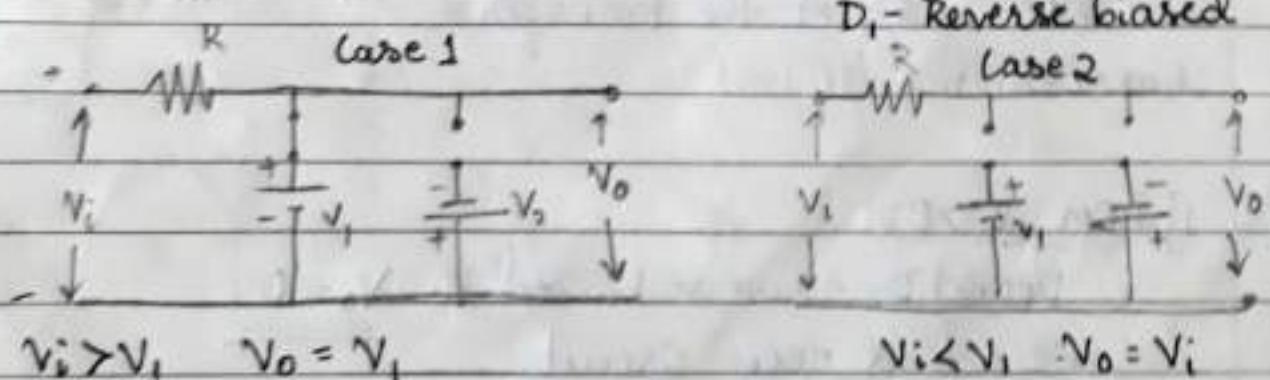
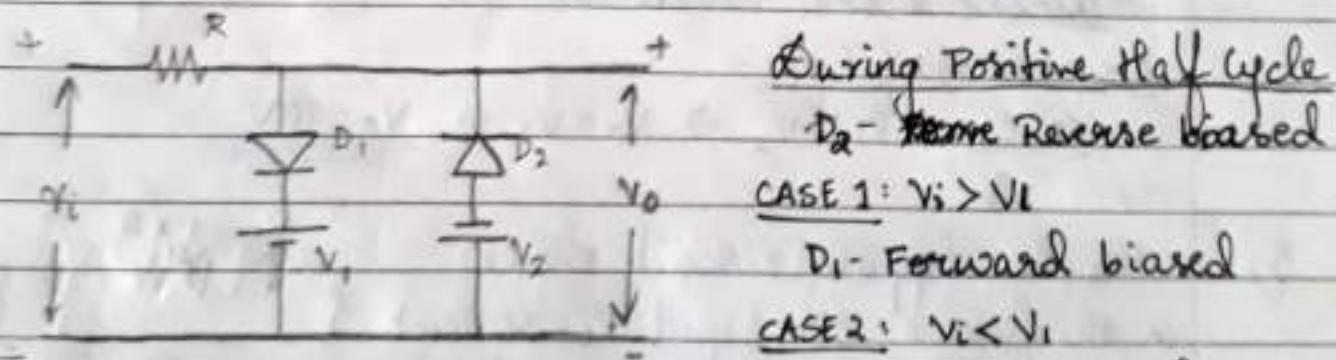
- Parallel clipper: A diode is connected in parallel with load.



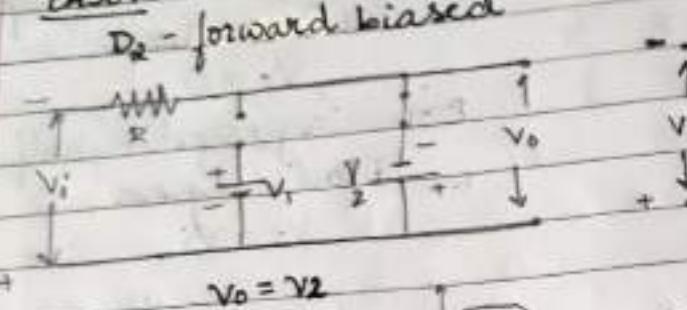
If $V_i > V_k$ - diode is forward biased and acts as short.
 $\Rightarrow V_o = V_k$

If $V_i < V_k$ - diode is reverse biased and acts as open circuit
 $\Rightarrow V_o = V_i$

- * Two way Parallel clipper / Double ended clipper:

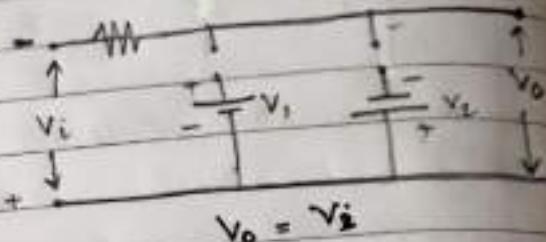


During negative half cycle
 D_1 - always reverse biased
CASE 1: $V_i < V_2$
 D_2 - forward biased



CASE 2: $V_i > V_2$

D_2 - reverse biased



Q1: Sketch and explain the circuit of double-ended clipper using ideal p-n junction diode which limits the output between 10V.

sol: $V_1 = 10V \quad V_2 = 10V$

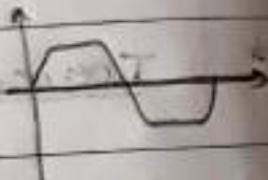
Positive Half Cycle:

CASE 1: $V_i > V_1 \rightarrow V_o = V_1 \Rightarrow \underline{\underline{V_o = 10V}}$

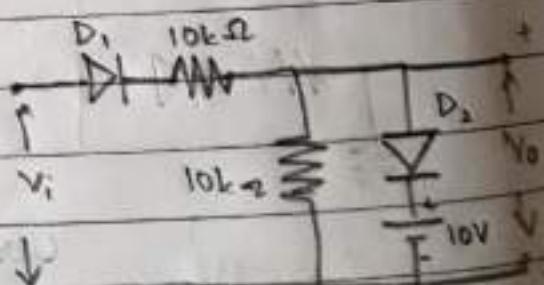
CASE 2: ~~reverse biased~~

Negative Half Cycle:

CASE 1: $V_i < V_2 \rightarrow V_o = V_2 \Rightarrow \underline{\underline{V_o = 10V}}$



Q2: For the clipping circuit shown in the figure, the input $V_i = 50\sin\omega t$ calculate and plot the transfer characteristics.



sol: 1] For $V_i > 0$:

D_1 and D_2 - reverse biased
and act as open circuit

$\underline{\underline{V_o = 0}}$

> ii) For $0 < V_i < 10V$:

D_1 - forward biased acts as short

D_2 - reverse biased acts as open circuit.

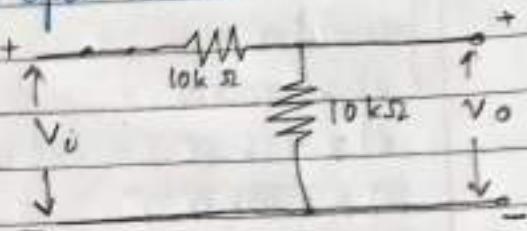
Applying KVL to input loop

$$V_i - 1(10k) - 1(10k) = 0$$

$$V_i = (20k)I$$

$$I = \frac{V_i}{20k\Omega} \quad \text{--- (1)}$$

$20k\Omega$



Applying KVL to output loop

$$V_o - 1(10k)I = 0$$

$$V_o = (10k)I$$

$$I = \frac{V_o}{10k\Omega} \quad \text{--- (2)}$$

V_i	$V_o = V_i/2$
0	0
1	0.5
2	1
3	1.5
4	2
10	5
20	10

Equating eq (1) and eq (2)

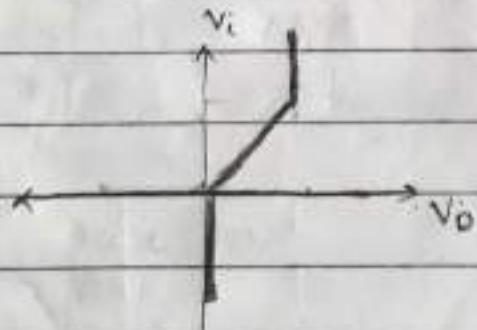
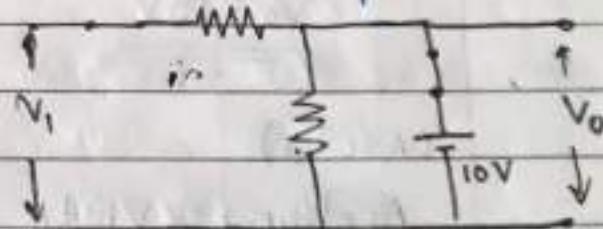
$$\frac{V_o}{10k\Omega} = \frac{V_i}{20k\Omega}$$

$$\Rightarrow \underline{\underline{V_o = V_i/2}}$$

iii) for $V_i > 10V$:

D_1 and D_2 are forward biased and act as ^{short} open circuit

$$\underline{\underline{V_o = 10V}}$$

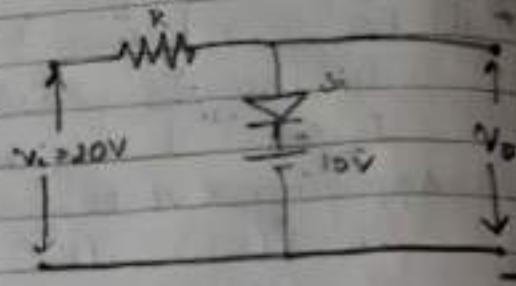


Transfer
Characteristics

Q3 For the diode clipping circuit shown in the figure, draw the input and output waveforms for

- $R = 100\Omega$
- $R = 1k\Omega$
- $R = 10k\Omega$

for $V_i = 20\sin \omega t$ and $V_R = 10V$. Assume $R_f = 100\Omega$ and $R_s = \infty$ and $V_T = 0$.



CASE i)

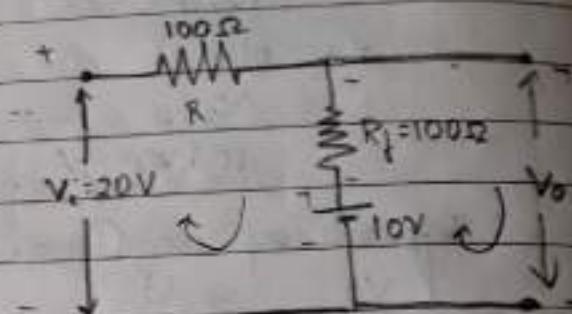
Sol Applying KVL to i/p

$$20 = 100(1) + 100(1) + 10$$

$$20 = 200I + 10$$

$$200I = 10$$

$$I = \frac{10}{200} = 0.05 \text{mA}$$



When $V_i > V_R \Rightarrow V_i > 10V$

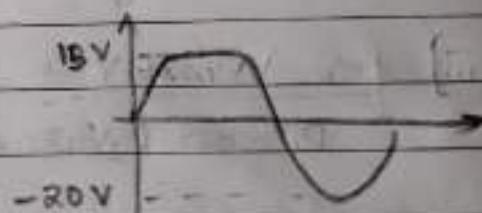
Applying KVL to o/p

$$V_o = 10 + I(100)$$

$$V_o = 10 + (0.05 \text{mA})(100)$$

$$V_o = 10 + 5$$

$$\underline{\underline{V_o = 15V}}$$



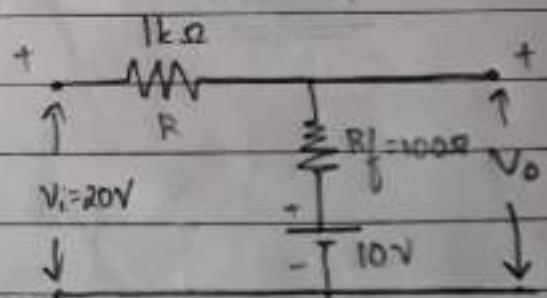
CASE ii)

Applying KVL to i/p

$$20 = 1k(1) + 100(1) + 10$$

$$10 = 1100(1)$$

$$I = \frac{10}{1100} = 9.09 \text{mA}$$



Applying KVL to o/p

$$V_o = 10 + (100)I$$

$$V_o = 10 + 9.09(100)$$

$$\underline{\underline{V_o = 10.9V}}$$



CASE iii)

Applying KVL to i/p

$$v_o = 10k(1) + 100(2) + 10$$

$$10 = 10k(1)$$

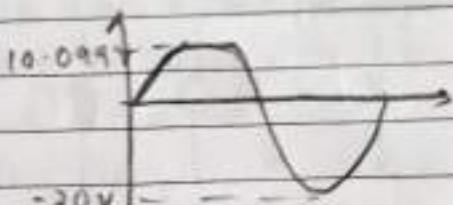
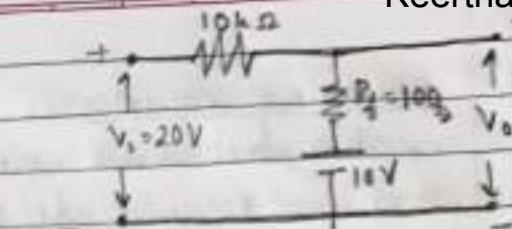
$$1 = \frac{10}{10k} = \underline{0.99 \text{ mA}}$$

Applying KVL to o/p

$$v_o = 10 + 100(1)$$

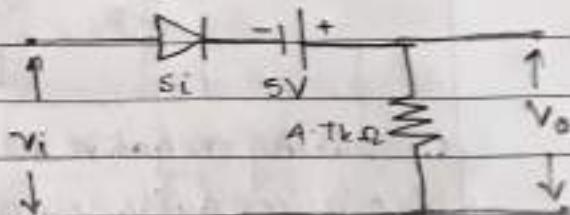
$$v_o = 10 + 100(0.99m)$$

$$\underline{v_o = 10.099 \text{ V}}$$

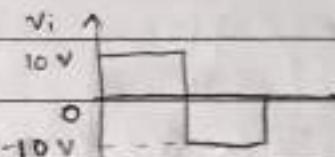
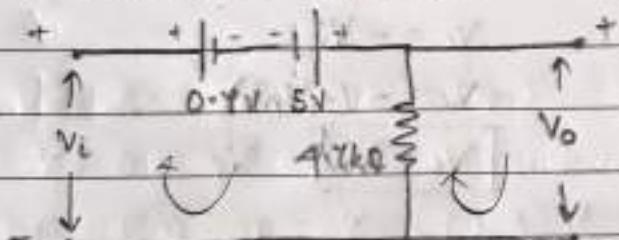


$$\text{if } v_i > 0 \quad v_o = v_i$$

Q2: Sketch the waveform of v_o for the given circuit.



Sol: During positive half cycle
The diode conducts



Applying KVL to i/p loop

$$v_i = 0.7 - 5 + 4.7k(1)$$

$$10 = -4.3 + 4.7k(1)$$

$$14.3 = 4.7k(1)$$

$$1 = \frac{14.3}{4.7k} = \underline{3.04 \text{ mA}}$$

$$\frac{1}{4.7k}$$

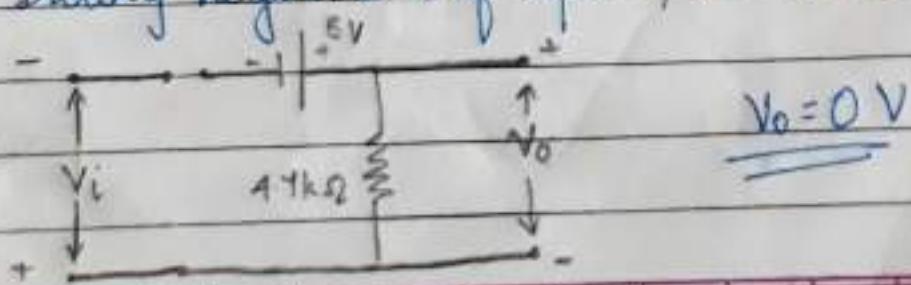
Applying KVL to o/p loop

$$v_o = 4.7k(1)$$

$$v_o = 4.7k(3.04m)$$

$$\underline{v_o = 14.3 \text{ V}}$$

During negative half cycle, the diode does not conduct

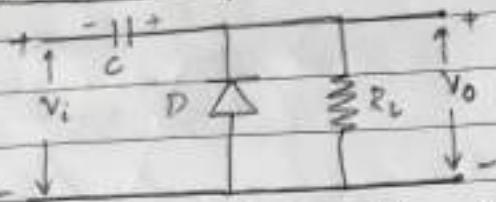


$$\underline{v_o = 0 \text{ V}}$$

* clamping circuits:

It is constructed using resistor, diode and capacitor.
It is used to add dc level to the input signal.

- positive clapper

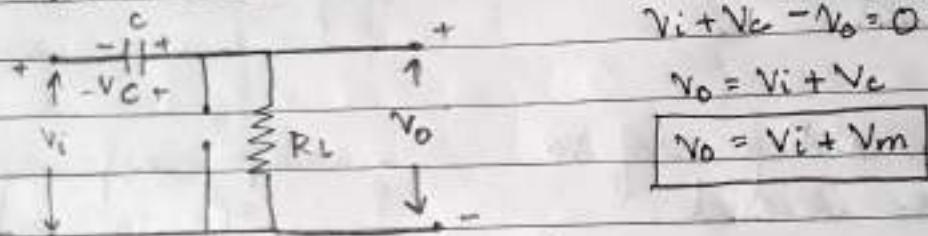


Procedure:

1. Find the capacitor voltage when the diode is conducting
2. Find the output voltage when the diode is not conducting

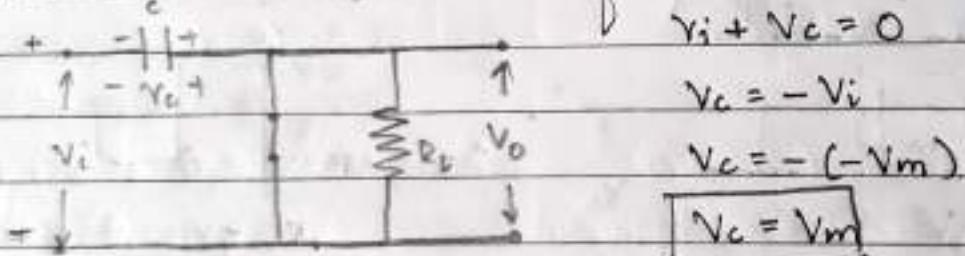
2. During positive half cycle

Diode ~~does not~~ does not conduct since it is reverse biased.

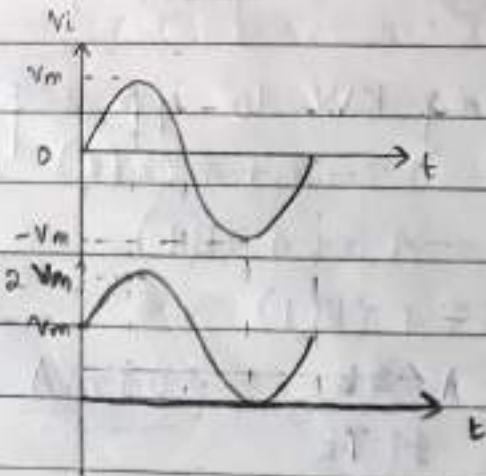


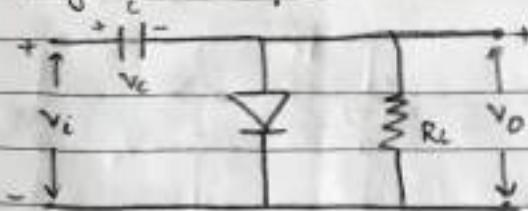
3. During negative half cycle

Diode conducts since it is forward biased



Vi	$Vo = Vi + Vm$
0	Vm
Vm	$2Vm$
$-Vm$	0

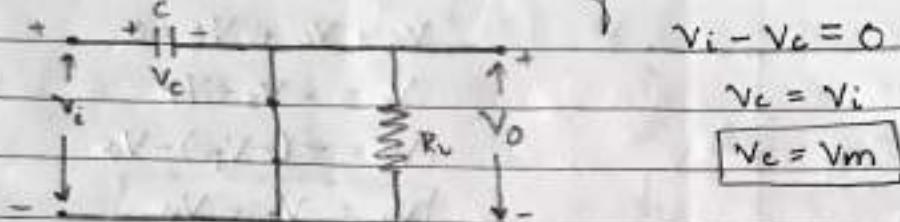


Negative ClamperProcedure:

1. Find the capacitor voltage when the diode is conducting.
2. Find the output voltage when the diode is not conducting.

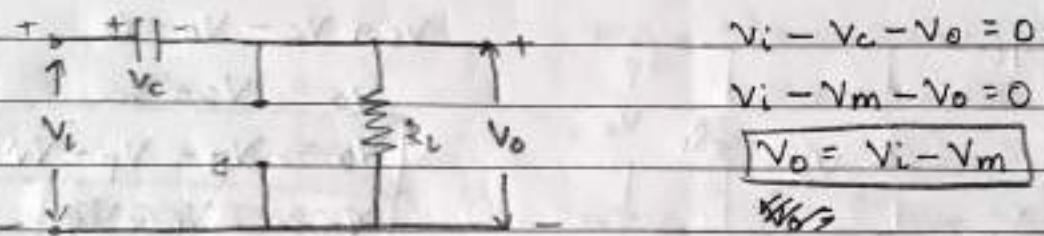
2. During positive half cycle:

Diode conducts since it is forward biased

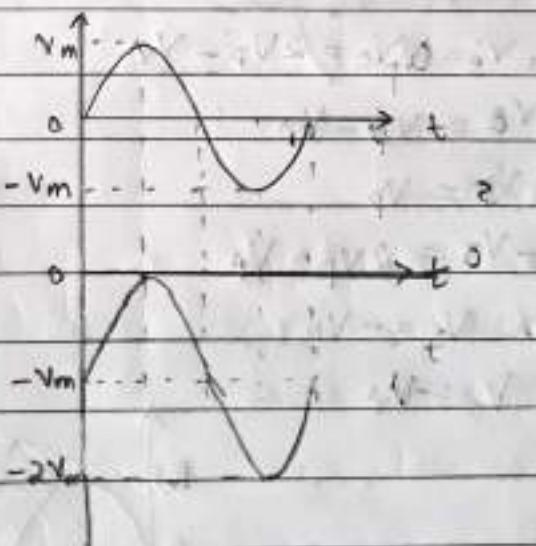


2. During negative half cycle:

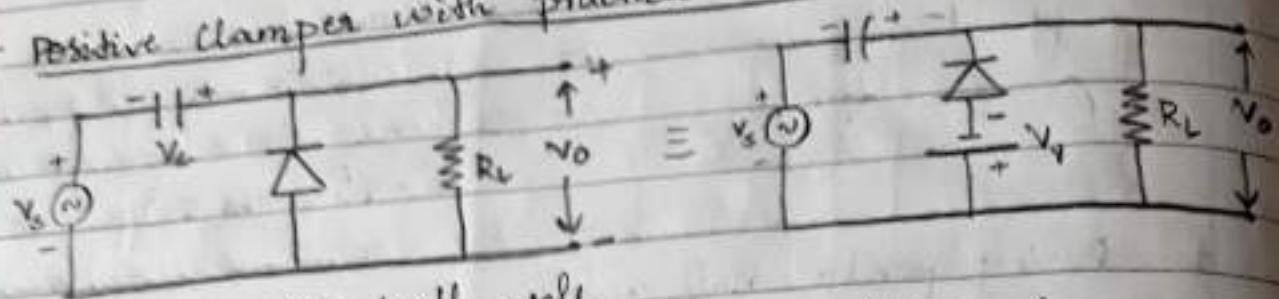
Diode does not conduct since it is reverse biased.



V_i	$V_o = V_i - V_m$
0	$-V_m$
$+V_m$	0
$-V_m$	$-2V_m$

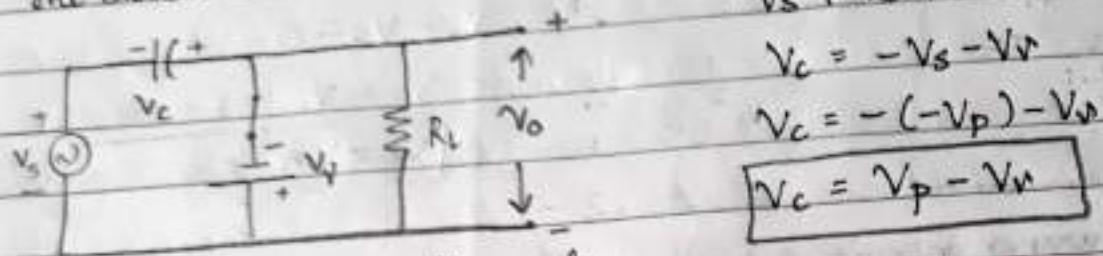


- Positive Clamper with practical diode:



During negative half cycle
The diode conducts since it is forward biased.

$$V_s + V_c + V_r = 0$$



$$V_c = -V_s - V_r$$

$$V_c = -(-V_p) - V_r$$

$$V_c = V_p - V_r$$

During positive half cycle
The diode does not conduct since it is reverse biased.

$$V_s + V_c - V_0 = 0$$

$$V_0 = V_s + V_c$$

$$V_0 = V_s + V_p - V_r$$

~~V0 = 2Vp - Vr~~

CASE 1: When $V_s = 0$

$$V_0 = V_p - V_r$$

considering $V_p = \pm 15V$

and $V_r = 0.7V$

CASE 2: When $V_s = V_p$

$$V_0 = 2V_p - V_r$$

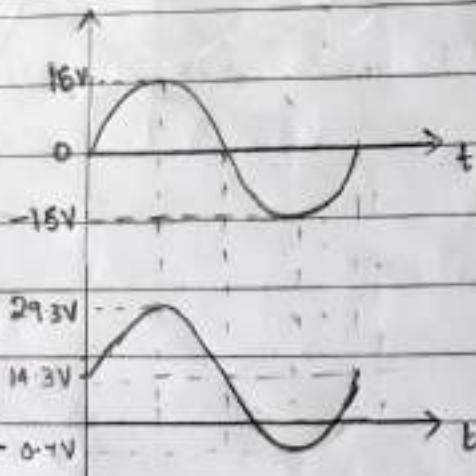
$$\text{CASE 1: } V_0 = 15 - 0.7 = 14.3V$$

CASE 3: When $V_s = -V_p$

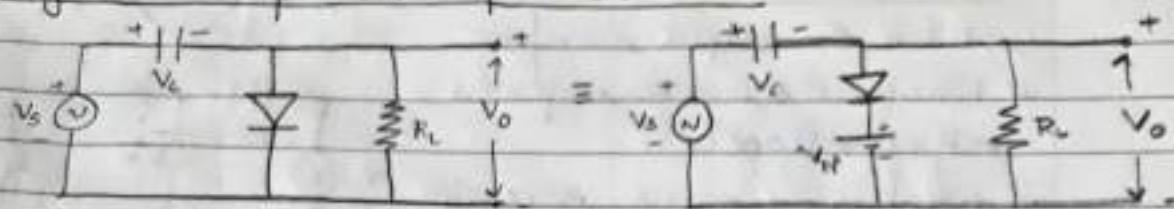
$$V_0 = -V_r$$

$$\text{CASE 2: } V_0 = 30 - 0.7 = 29.3V$$

$$\text{CASE 3: } V_0 = -0.7V$$

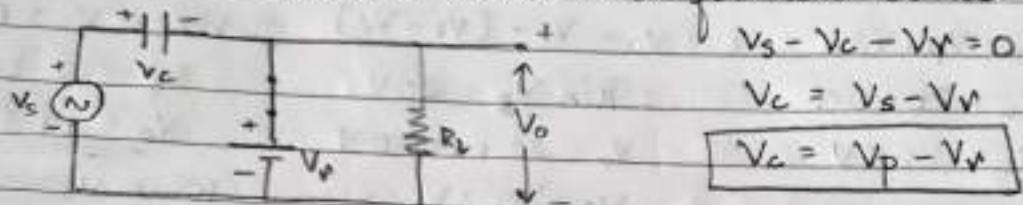


- Negative clapper with practical diode:



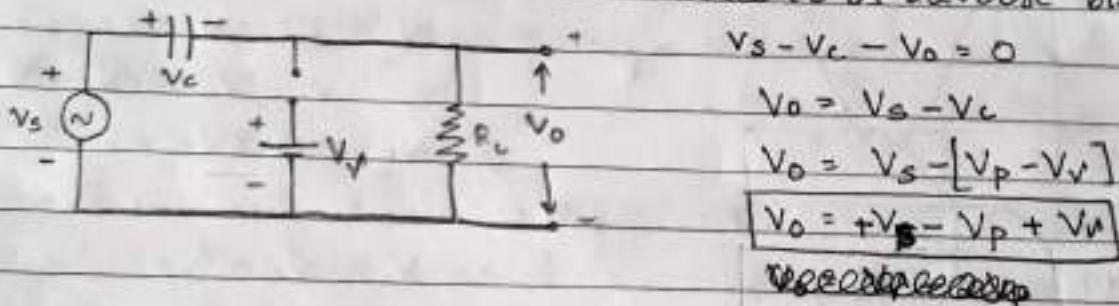
1. During positive half cycle

The diode conducts since it is forward biased



2. During negative half cycle

The diode does not conduct since it is reverse biased



CASE 1: When $V_s = 0$

$$V_0 = V_p - V_r$$

considering $V_p = \pm 15V$

and $V_r = 0.7V$

CASE 2:

When $V_s = V_p$

$$V_0 = V_r$$

$$\text{CASE 1: } V_0 = 0.7 - 15 = -14.3V$$

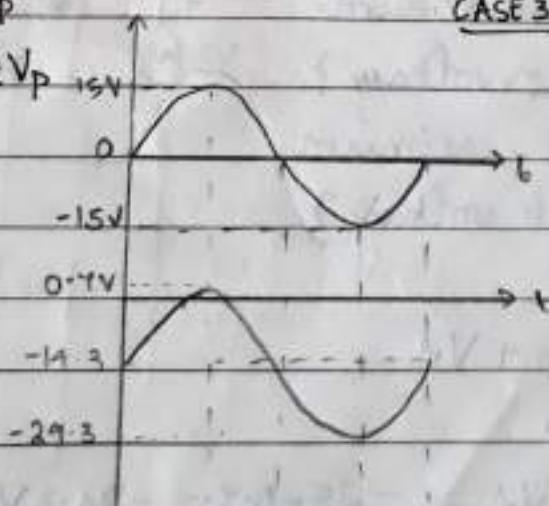
$$\text{CASE 2: } V_0 = 0.7V$$

CASE 3:

When $V_s = -V_p$

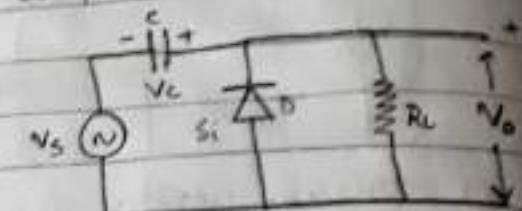
$$V_0 = V_r - 2V_p$$

$$\text{CASE 3: } V_0 = 0.7 - 30 = -29.3V$$



Q1: For the circuit shown

- sketch the output waveform
- What is the maximum positive output voltage?
- What is the maximum negative output voltage?



Sol:

$$V_C = V_P - V_N$$

$$V_C = 20 - 0.7$$

$$V_C = 19.3 \text{ V}$$

$$V_0 = V_S + [V_P - V_N]$$

$$\text{when } V_S = 20 \text{ V}$$

$$V_0 = 20 + 20 - 0.7$$

$$V_0 = 39.3 \text{ V}$$

$$\text{when } V_S = 0$$

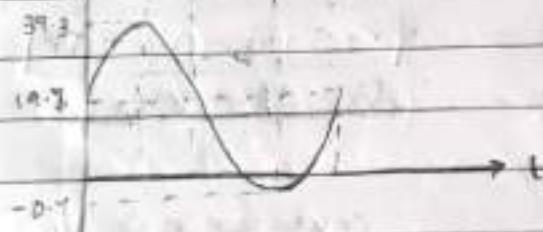
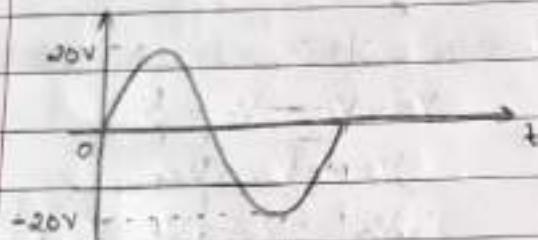
$$V_0 = 20 - 0.7$$

$$V_0 = 19.3 \text{ V}$$

$$\text{when } V_S = -20$$

$$V_0 = -20 + 20 - 0.7$$

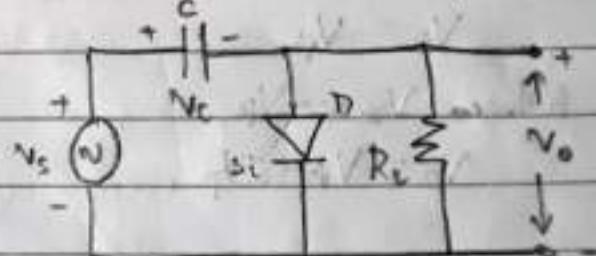
$$V_0 = -0.7 \text{ V}$$



Q2: For the circuit shown

- sketch the output waveform
- What is the maximum positive output voltage?
- What is the maximum negative output voltage?

Given: $V_P = 225 \text{ V}$, $V_N = 0.7 \text{ V}$



Sol:

$$V_0 = V_S - V_P + V_N$$

$$\text{when } V_S = 0$$

$$V_0 = -V_P + V_N = -225 + 0.7 = \underline{\underline{-224.3 \text{ V}}}$$

When $V_S = 25V$

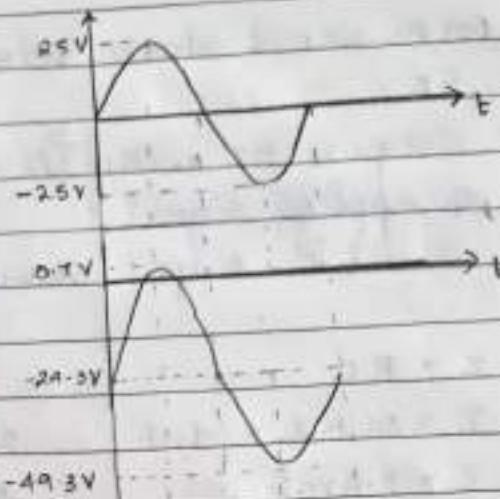
$$V_o = 25 - 25 + 0.7$$

$$V_o = 0.7V$$

When $V_S = -25V$

$$V_o = -25 - 25 + 0.7$$

$$V_o = -49.3V$$



* Capacitor in clamping:

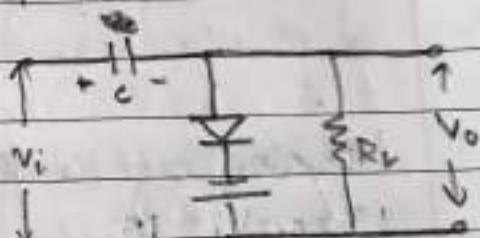
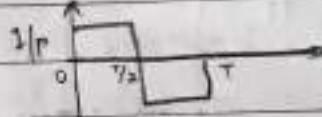
τ_f - charging time

$$\tau_f \approx T/2$$

τ_f is a very little less than the $T/2$.

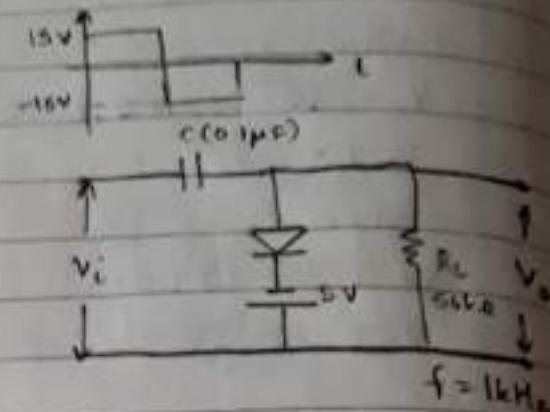
$\tau_f = \tau_f C$ during positive half cycle as the diode is forward biased.

$\tau = RC$ during negative half cycle as the diode is reverse biased.



$$5\tau \gg T/2$$

- Q1: For the circuit shown below
- $5Z$
 - Compare $5Z$ with $T/2$ of the applied signal.
 - Sketch the output waveform



Sol: i. $Z = RC$

$$Z = 56 \times 10^{-3} \times 0.1 \mu\text{F}$$

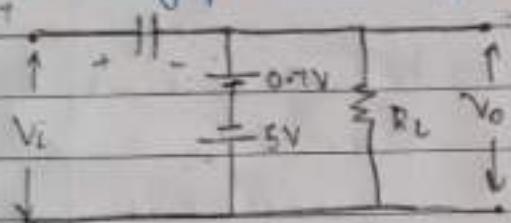
$$\underline{Z = 5.6\text{mS}}$$

ii. $T/2 = 0.5\text{ms}$

$$\underline{5Z = 28\text{ms}}$$

$$\therefore \underline{5Z \ll T/2}$$

During positive Half cycle



~~$V_C = V_i + 4.3$~~

~~$V_C = 19.3\text{V}$~~

~~$V_o = V_i - V_c$~~

~~$\underline{V_o = 19.3\text{V}}$~~

During negative half-cycle

When $V_i = 15$

$$V_o = 15 - 19.3$$

$$\underline{V_o = -4.3\text{V}}$$

When $V_i = -15$

$$V_o = -15 - 19.3$$

$$\underline{V_o = -34.3\text{V}}$$

When $V_i = 0$

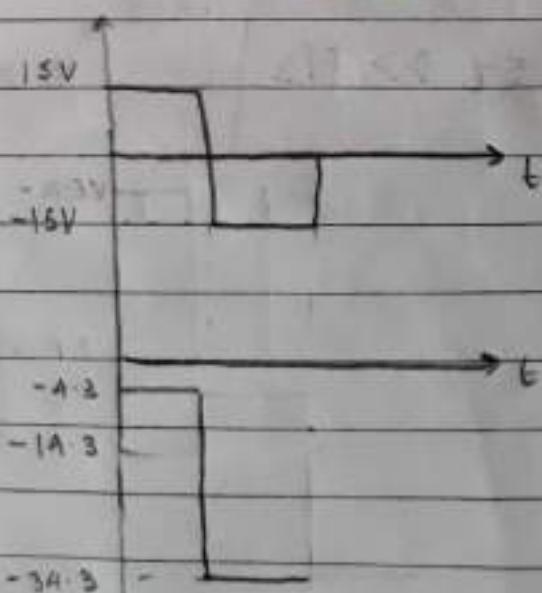
$$\underline{V_o = -19.3\text{V}}$$

~~$V_C = V_o$~~

~~$V_C = V_i$~~

~~$V_C = 19.3 - 15 = 4.3$~~

~~$\underline{V_o = 4.3\text{V}}$~~



UNIT - 4

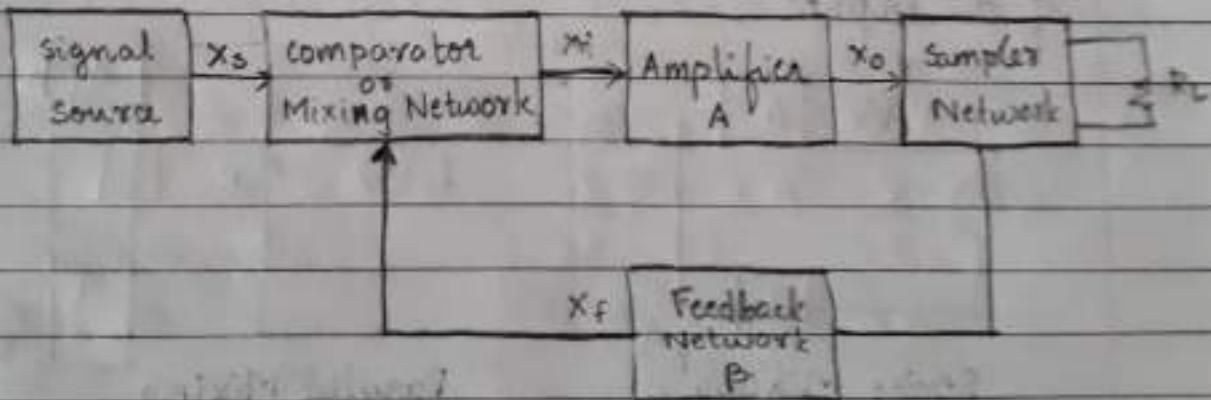
Feedback Amplifier* Negative feedback

- Increases bandwidth
- Increases gain
- Increases input impedance
- Decreases output impedance
- Decreases distortion

* Types of Amplifier

1. Voltage Amplifier
2. Current Amplifier
3. Transconductance Amplifier
4. Transresistance Amplifier

INPUT	OUTPUT	GAIN
V_i	V_o	$A_v = V_o/V_i$
I_i	I_o	$A_i = I_o/I_i$
V_g	I_o	$G_m = I_o/V_g$
I_i	V_o	$R_m = V_o/I_i$

* Block Diagram of Typical Feedback Amplifier:

$$X_i = X_s - X_f$$

$$X_o = A X_i$$

$$\beta = \frac{X_f}{X_o}$$

* Signal Source:

Keerthana Ashok

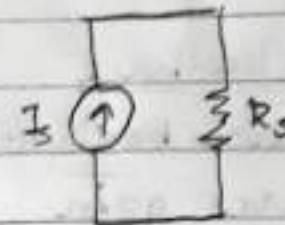
- Input can be voltage or current.

If voltage source

If current source



Thevenin's
Equivalent circuit

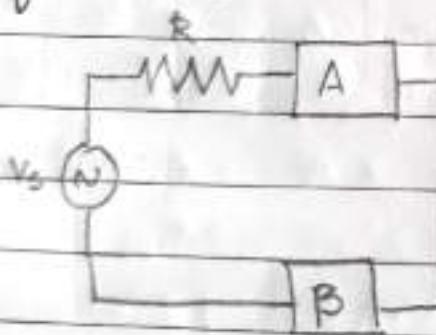


Norton's
Equivalent circuit

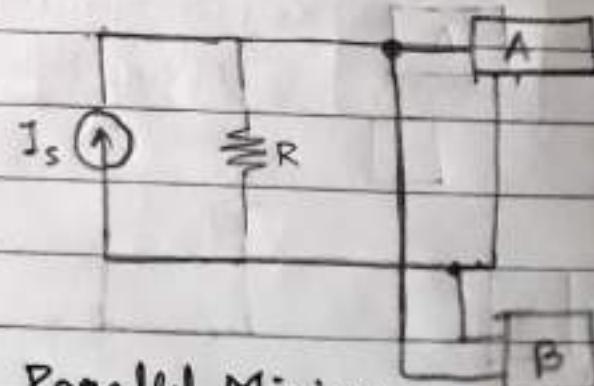
* comparator | Mixing Network:

- Series mixing: When input from source and feedback output is voltage.
- Shunt mixing: When input and feedback output is current.

In transconductance and transconductance the selection of mixing is based on the input.
The output of feedback should be converted in terms of the input!



Series Mixing



Parallel Mixing

Amplifier:

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

$$A_I = \frac{I_o}{I_i}$$

$$A_{Vf} = \frac{V_o}{V_s}$$

$$A_{If} = \frac{I_o}{I_s}$$

Voltage and current
Amplifier gain with and
without feedback.

$$G_m = \frac{I_o}{V_i}$$

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

Transconductance and transresistance gain

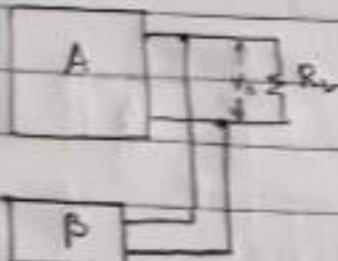
$$G_{mf} = \frac{I_o}{V_s}$$

$$R_{mf} = \frac{V_o}{I_s}$$

with and without feedback

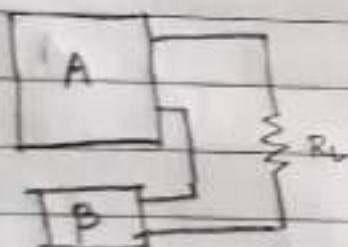
* Sampler Network:

- Voltage Sampler: Used when output of amplifier is in terms of voltage.



Here the feedback network is connected in parallel with the amplifier network

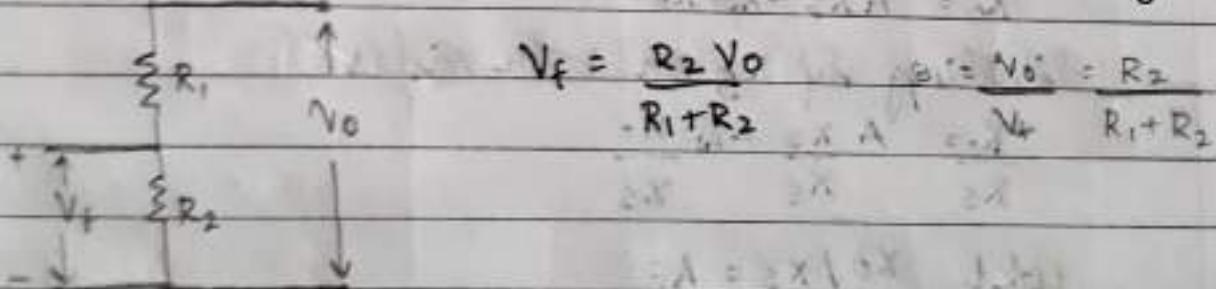
- Current Sampler: Used when output of amplifier is in terms of current.



Here the feedback network is connected in series with the amplifier network.

* Feedback Network:

The equivalent circuit for feedback network is given by



$$V_f = \frac{R_2 V_o}{R_1 + R_2}$$

$$\therefore A = \frac{V_o}{V_i} = \frac{R_2}{R_1 + R_2}$$

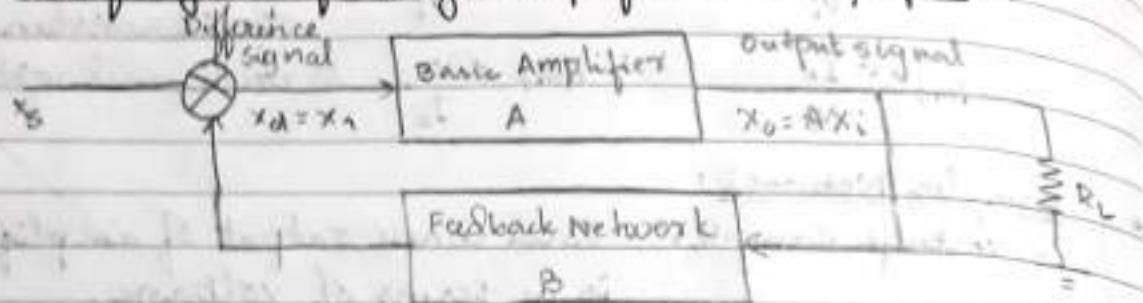
$$A = \frac{R_2}{R_1 + R_2}$$

$$A = -A$$

$$A = -A$$

$$A = -A$$

* Transfer gain of single loop feedback amplifier:



gain without feedback (open loop gain)

$$A = \frac{X_o}{X_i}$$

$$\Rightarrow X_o = AX_i \quad \text{--- (1)}$$

Gain with feedback (closed loop gain)

$$A_f = \frac{X_o}{X_s}$$

$$X_i = X_s - X_f \quad \text{--- (2)}$$

Substituting eq (2) in eq (1)

$$X_o = A(X_s - X_f)$$

$$\text{wkt } X_f = BX_o$$

$$X_o = A(X_s - BX_o)$$

$$X_o = AX_s - ABX_o$$

dividing by X_s on both sides

$$\frac{X_o}{X_s} = A - AB \frac{X_o}{X_s}$$

$$\text{wkt } \frac{X_o}{X_s} = A_f$$

$$A_f = A - AB A_f$$

$$AB(1+AB) = A$$

$$A_f = \frac{A}{1+AB}$$

for $1+AB < 1$

$A_f > A$

$$|A_f| = \frac{|A|}{|D|}$$

gain in dB

$$\text{where } D = 1 + AB \quad 20 \log |A_f| = 20 \log |A| - 20 \log |D|$$

* Effect of negative feedback on bandwidth of an amplifier:

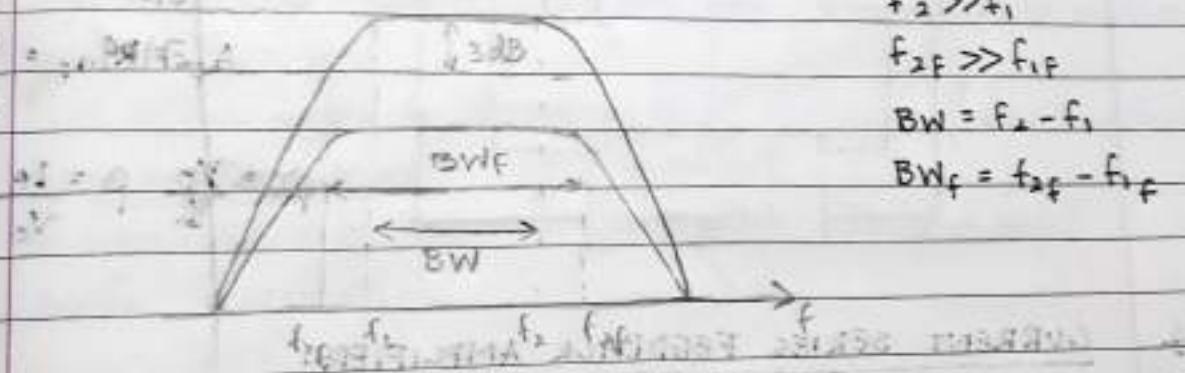
$$\frac{\text{Gain Bandwidth product with feedback}}{\text{Gain Bandwidth product without feedback}} = \frac{\text{Gain Bandwidth product with feedback}}{\text{Gain Bandwidth product without feedback}}$$

$$A_f(BW_f) = A(BW)$$

$$BW_f = \frac{A(BW)}{A_f}$$

$$\text{wkt } A_f = \frac{A}{1+AB} \Rightarrow \frac{A}{A_f} = 1+AB$$

$$BW_f = (1+AB)(BW)$$



$$f_2 \gg f_1$$

$$f_{2f} \gg f_{1f}$$

$$BW = f_2 - f_1$$

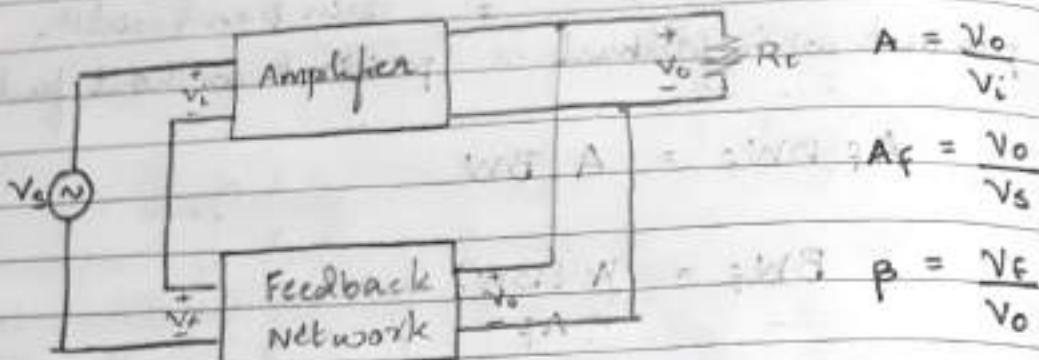
$$BW_f = f_{2f} - f_{1f}$$

* Feedback Topologies:

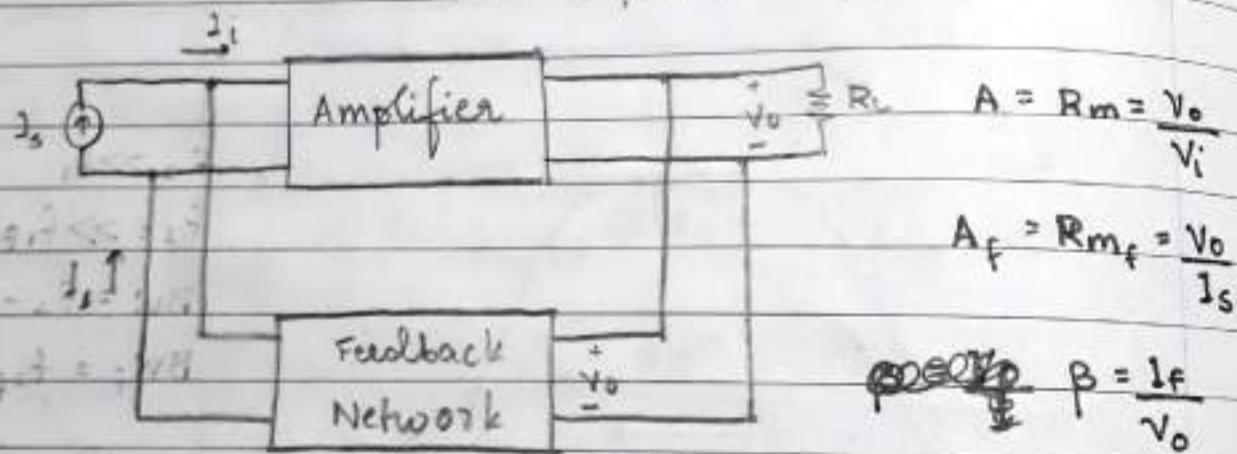
sample = Amixer

1. Voltage series feedback amplifier
2. Voltage shunt feedback amplifier
3. Current series feedback amplifier
4. Current shunt feedback amplifier

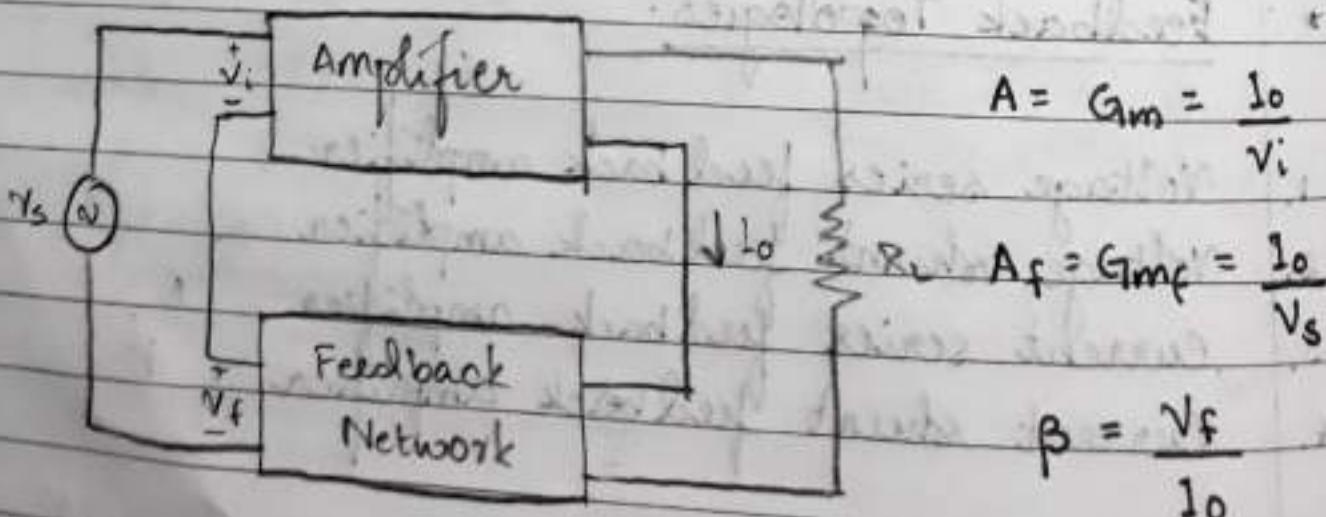
1. VOLTAGE SERIES FEEDBACK AMPLIFIER:



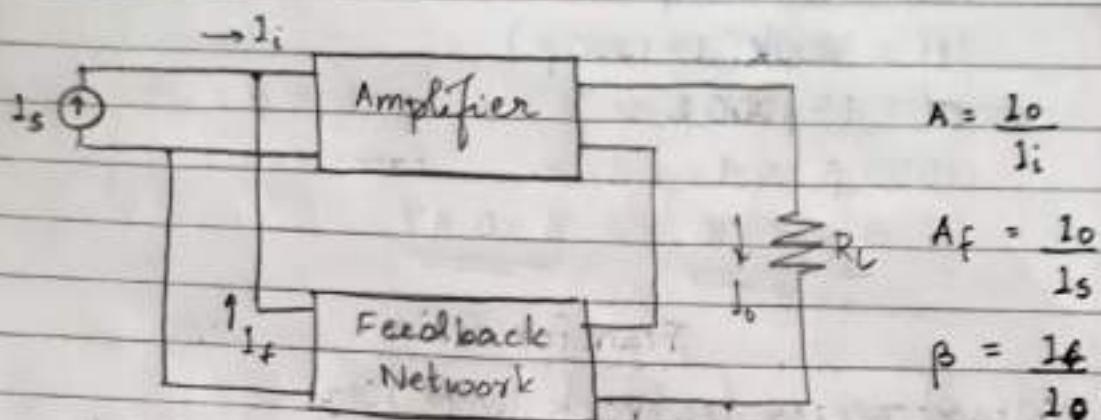
2. VOLTAGE SHUNT FEEDBACK AMPLIFIER:



3. CURRENT SERIES FEEDBACK AMPLIFIER:



4. CURRENT SHUNT FEEDBACK AMPLIFIER:



Q1: An amplifier has a bandwidth of 200 kHz and voltage gain of 1000.

i. What will be the new bandwidth and gain if 5% negative feedback is introduced?

ii. What is the gain bandwidth product with and without feedback?

iii. What should be the amount of feedback if the bandwidth required is 1 MHz?

Sol: Given: BW = 200 kHz

$$A_v = 1000$$

i. New bandwidth and gain

$$\beta = 0.05$$

$$BW_f = (1 + A\beta)(BW)$$

$$= (1 + 1000(0.05))(200 \text{ kHz})$$

$$= 10.2 \text{ MHz}$$

$$A_f = \frac{A_v}{1 + A\beta} = \frac{1000}{1 + (1000)(0.05)}$$

$$A_f = 19.6$$

$$ii. A(BW) = A_f(BW_f)$$

$$A(BW_f) = 19.6(10.2 \text{ MHz})$$

$$= 199.92 \text{ M}$$

$$\approx 2 \times 10^8$$

$$A(BW) = 1000(200 \text{ kHz})$$

$$= 2 \times 10^8$$

$$\text{iii. } \text{BW}_f = 1 \text{ MHz}$$

$$\text{BW}_f = \text{BW}(1 + A\beta)$$

$$1 \text{ MHz} = 200 \text{ kHz} (1 + 1000\beta)$$

$$5 = 1 + 1000\beta$$

$$1000\beta = 4$$

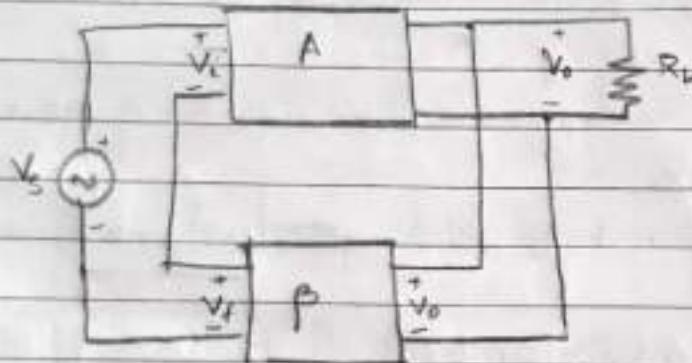
$$\underline{\underline{\beta = 4 \times 10^{-3}}}$$

$$\underline{\underline{\beta = 0.4}}$$

Transfer Gain

1. Voltage series feedback amplifier:

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



$$V_o = AV_i \quad \text{--- (1)}$$

KVL to the input

$$V_s - V_i - V_f = 0$$

$$V_i = V_s - V_f \quad \text{--- (2)}$$

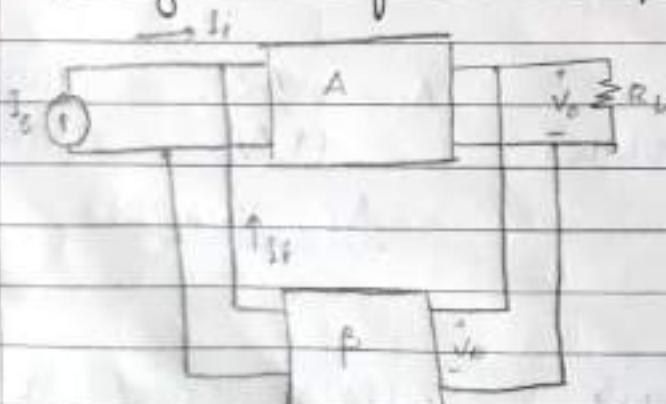
Substituting eq. (2)
in eq. (1)

$$V_o = A [V_s - V_f]$$

$$V_o = AV_s - A\beta V_o$$

$$A_F = \frac{V_o}{V_s} = \frac{Av}{1 + Av\beta}$$

2. Voltage shunt feedback amplifier:



$$A = \frac{V_o}{I_i}$$

$$A_F = \frac{V_o}{I_s}$$

$$V_o = A I_i \quad \text{--- (1)}$$

$$\beta = \frac{I_f}{V_o}$$

KCL to input

$$I_s - I_i - I_f = 0$$

$$I_i = I_s - I_f$$

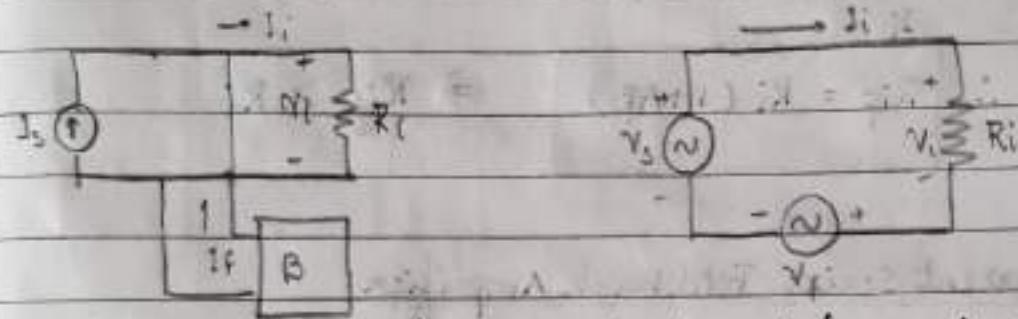
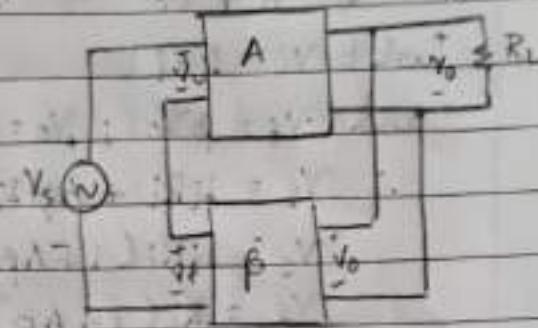
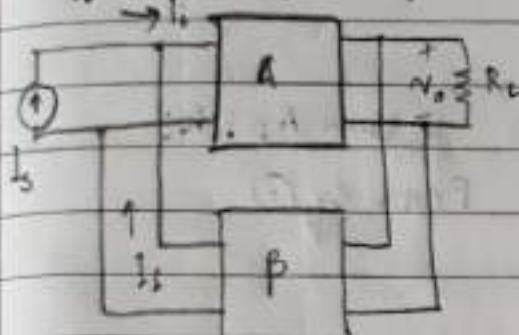
Substituting eq. (2) in eq. (1)

$$V_o = A [I_s - I_f]$$

$$V_o = A [I_s - A\beta V_o]$$

$$R_{mf} = \frac{R_m}{1 + R_m\beta}$$

* Effect of negative feedback on input resistance (dependent on type of mixer)

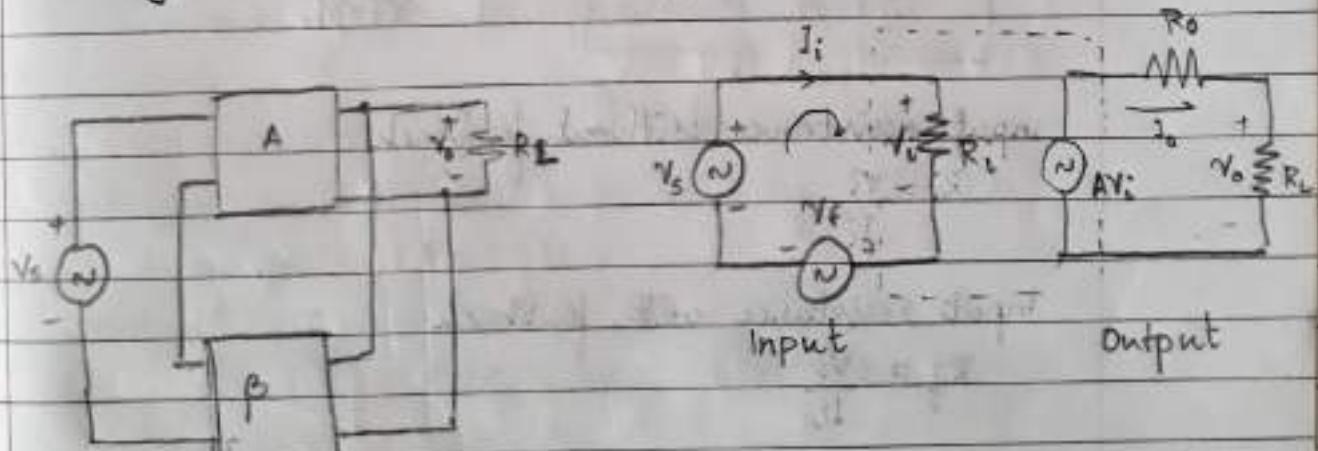


Input resistance decreases when shunt mixer is used
Input resistance increases when series mixer is used.

$$R_i > R_{if}$$

$$R_i < R_{if}$$

1. Voltage Series Feedback Amplifier:



Input resistance (without feedback)

$$R_i = \frac{V_i}{I_i}$$

Input resistance (with feedback)

$$R_{if} = \frac{V_s}{I_i}$$

KVL to input circuit

$$V_s = V_i + V_f \quad \text{--- } ①$$

$$\text{wkt } V_i = I_i R_i$$

$$\text{and } V_f = \beta V_o ; V_o = A V_i \Rightarrow V_f = A \beta I_i R_i$$

$$\therefore V_s = I_i R_i + A \beta I_i R_i$$

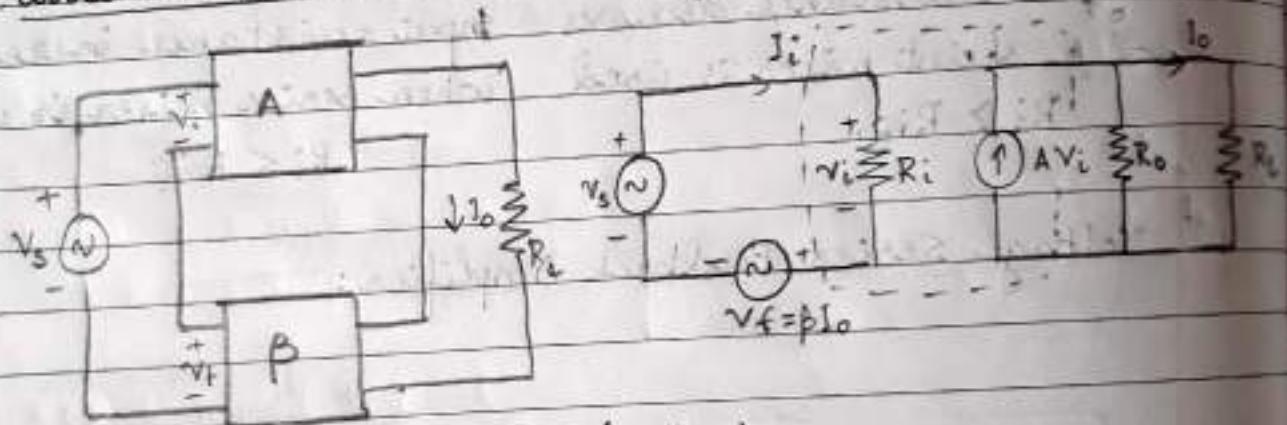
$$V_s = I_i R_i (1 + A\beta)$$

$$V_s = R_i (1 + A\beta)$$

I_i

$$\therefore R_{if} = R_i (1 + A\beta) \Rightarrow R_{if} > R_i$$

2. current series Feedback Amplifier:



Input resistance without feedback

$$R_i = \frac{V_i}{I_i}$$

Input resistance with feedback

$$R_{if} = \frac{V_s}{I_i}$$

KVL to input circuit

$$V_s = V_i + V_f \quad \text{--- } ①$$

$$\text{wkt } V_i = R_i I_i ; V_f = \beta I_o ; I_o = A V_i$$

$$\therefore V_f = A \beta V_i = A \beta I_i R_i$$

$$\therefore V_s = I_i R_i + A \beta I_i R_i$$

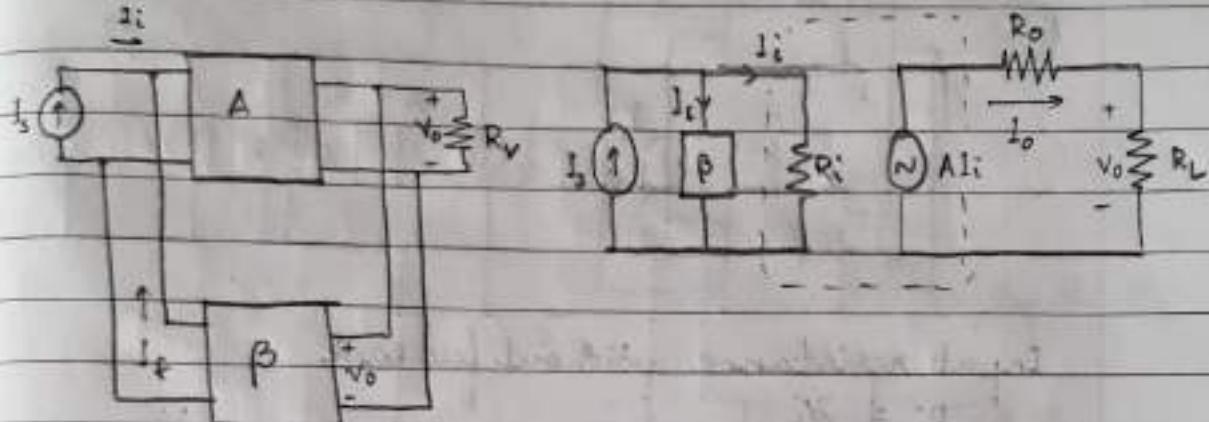
$$V_s = I_i R_i (1 + A\beta)$$

From eq, ①

$$\frac{V_s}{I_i} = R_i (1 + A\beta)$$

$$\therefore R_{if} = R_i (1 + A\beta) \quad \Rightarrow \quad R_{if} > R_i$$

Voltage Shunt Feedback Amplifier:



Input resistance without feedback

$$R_i = \frac{V_i}{I_i}$$

Input resistance with feedback

$$R_{if} = \frac{V_i}{I_s}$$

kG_L to input circuit

$$I_s = I_f + I_i \quad \text{--- (1)}$$

wk't $I_i = \frac{V_i}{R_i}$ and $I_f = \beta V_o$; $V_o = A I_i$
 $\Rightarrow I_f = A \beta I_i = A \beta \frac{V_i}{R_i}$

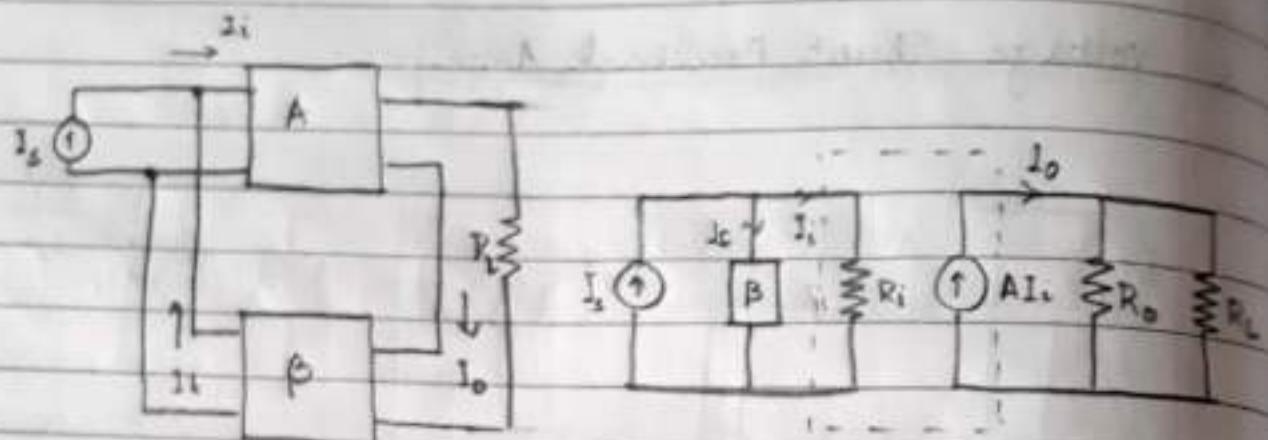
$$\therefore I_s = \frac{V_i}{R_i} + A \beta \frac{V_i}{R_i} \quad \text{From eq (1)}$$

$$I_s = \frac{V_i}{R_i} (1 + A\beta)$$

$$R_i = \frac{V_i}{I_s} (1 + A\beta)$$

$$\therefore R_{if} = \frac{R_i}{1 + A\beta} \quad \Rightarrow R_i > R_{if}$$

1. current shunt Feedback Amplifier:



Input resistance without feedback

$$R_i = \frac{V_i}{I_i}$$

Input resistance with feedback

$$R_{if} = \frac{V_i}{I_s}$$

KCL at input circuit

$$I_s = I_f + I_i \quad \text{--- (1)}$$

$$\text{wkt } I_i = \frac{V_i}{R_i} \quad I_f = \beta I_o ; \quad I_o = A I_i$$

$$\Rightarrow I_f = \beta A I_i = A \beta \frac{V_i}{R_i}$$

$$\therefore I_s = \frac{V_i}{R_i} + A \beta \frac{V_i}{R_i} \quad \text{from eq (1)}$$

$$I_s = \frac{V_i}{R_i} (1 + A\beta)$$

$$R_i = \frac{V_i}{I_s} (1 + A\beta)$$

$$R_{if} = \frac{R_i}{1 + A\beta} \quad \Rightarrow R_i > R_{if}$$

- * Effect of Negative Feedback on Output Resistance:
 (Dependent of type of sampler)
1. Replace voltage source or current source to zero.
 2. Remove R_L and connect voltage source 'V'.

Output resistance
decreases when voltage
sampler is used.

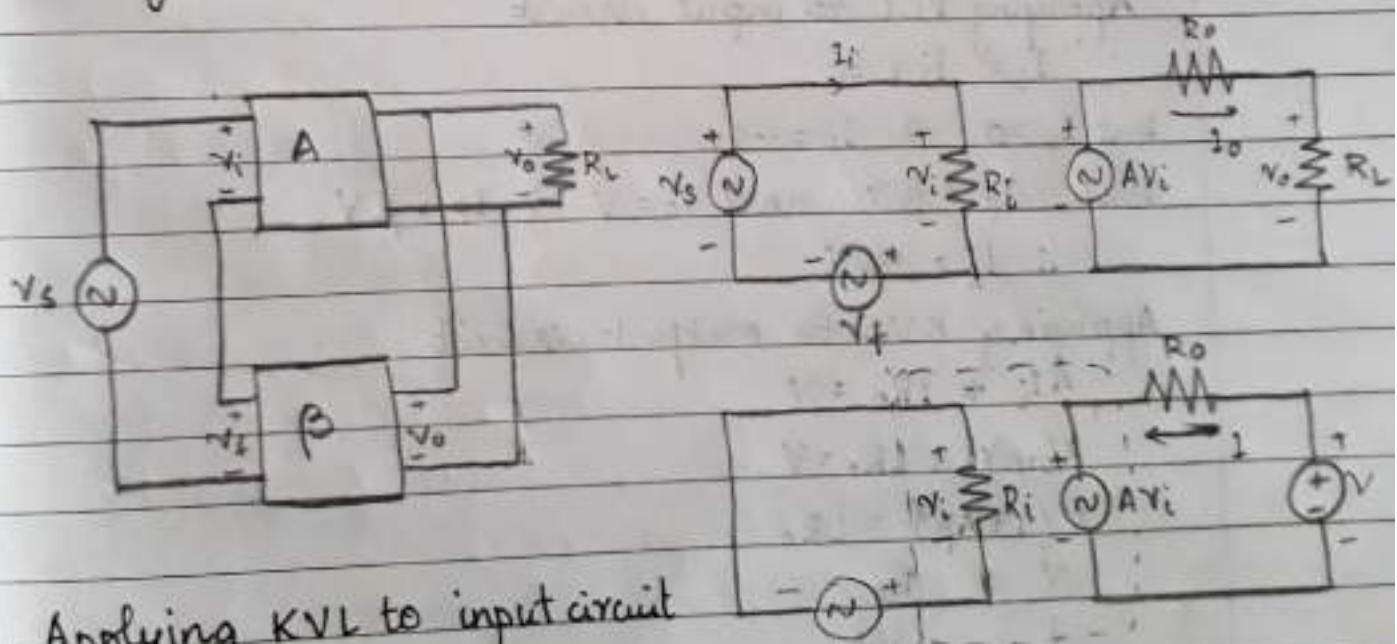
wkt

$$A_f = \frac{A}{1 + A\beta} \quad \text{when } A\beta \gg 1$$

$$\text{then } A_f = \frac{A}{A\beta} = \frac{1}{\beta} \Rightarrow R_{of} \approx 0 \text{ or } R_{of} \ll R_L$$

Output resistance
increases when current
sampler is used.

Voltage Series Feedback Amplifier:



Applying KVL to input circuit

$$\bullet V_i = -V_f$$

$$V_i = -\beta V_o \quad (\because V_f = \beta V_o)$$

$$V_i = -\beta V \quad (\because V_o = V)$$

Applying KVL to output circuit

$$AV_i = -IR_o + V$$

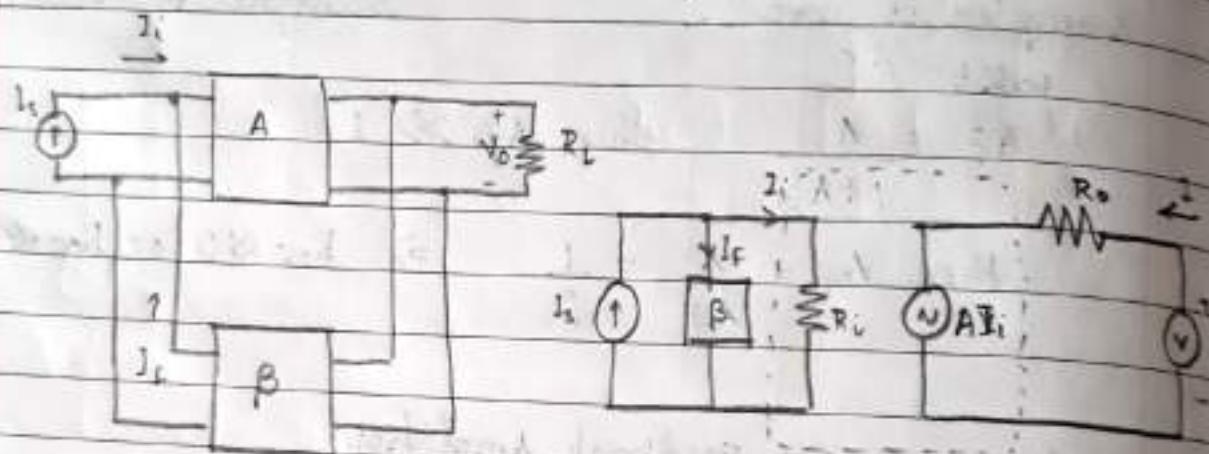
$$-A\beta V = -IR_o + V$$

$$(1 + A_B) V = - I_o R_o$$

$$\frac{V}{I} = \frac{R_o}{1 + A_B}$$

$$R_{of} = \frac{R_o}{1 + A_B} \Rightarrow R_{of} < R_o$$

2. Voltage Shunt Feedback Amplifier



Applying KCL to input circuit

$$I_s = I_i + I_f$$

$$\text{but } I_s = 0 \Rightarrow I_i = -I_f$$

$$\text{wkt } I_f = \beta V_o \text{ and } V_o = V \Rightarrow I_f = \beta V$$

$$\therefore I_i = -\beta V$$

Applying KVL to output circuit

$$A I_i + I R_o = V$$

$$A(-\beta V) + I R_o = V$$

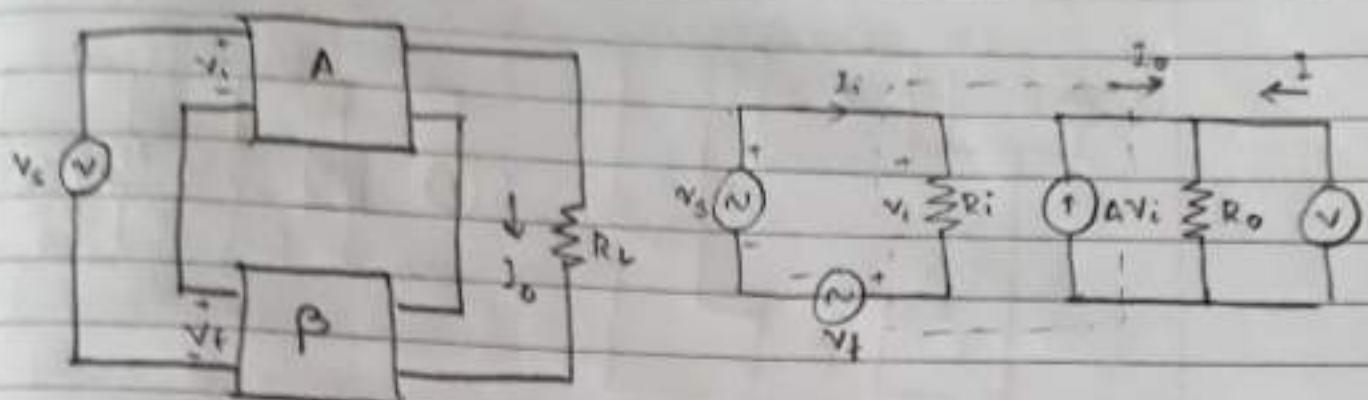
$$V(1 + A\beta) = I R_o$$

$$\frac{V}{I} = \frac{R_o}{1 + A\beta}$$

$$R_{of} = \frac{R_o}{1 + A\beta}$$

$$\Rightarrow R_{of} < R_o$$

3. Current Series Feedback Amplifier:



Applying KVL to input loop

$$v_s = v_i + v_f$$

$$\text{but } v_s = 0$$

$$v_i = -v_f$$

$$\text{wkt } v_f = \beta I_o$$

$$\therefore v_i = -\beta I_o$$

$$\text{but } I_o = -1$$

$$\therefore v_i = \beta 1$$

Applying KCL to output loop

$$A v_i + \frac{v}{R_o}$$

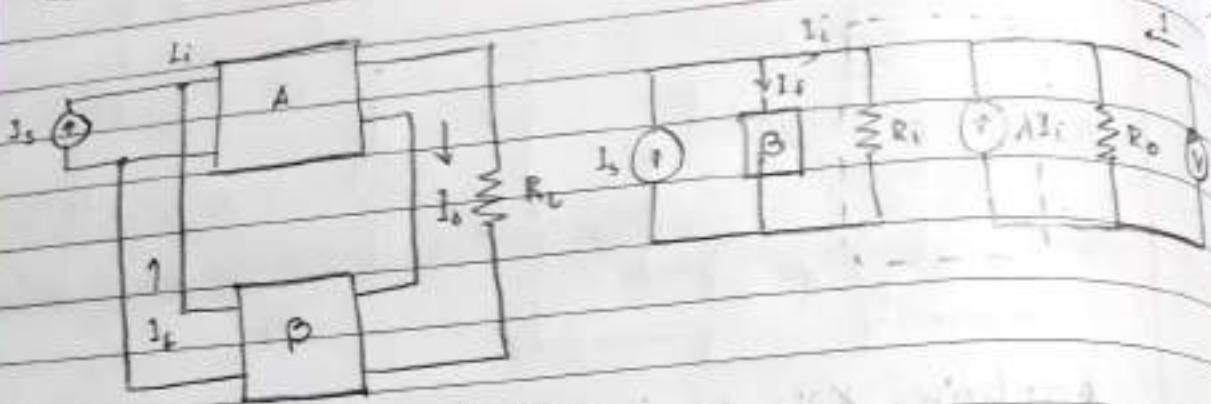
$$A \beta 1 + \frac{v}{R_o}$$

$$R_o(1+A\beta) = \frac{v}{1}$$

$$R_{of} = R_o(1+A\beta)$$

$$\Rightarrow R_{of} > R_o$$

1 Current Shunt Feedback Amplifier



Applying KCL to input loop

$$I_s = I_i + I_f$$

$$\text{but } I_s = 0$$

$$\Rightarrow I_i = -I_f$$

$$\text{wkt } I_f = \beta I_o$$

$$\therefore I_i = -\beta I_o$$

$$\text{but } I = -I_o$$

$$\therefore I_i = \beta I$$

Applying KCL to output loop

$$A\beta I + I = \frac{V}{R_o}$$

$$A\beta I + I = \frac{V}{R_o}$$

$$R_o(1+A\beta) = \frac{V}{I}$$

$$R_{of} = R_o(1+A\beta)$$

$$\Rightarrow R_{of} > R_o$$

UNIT - 5

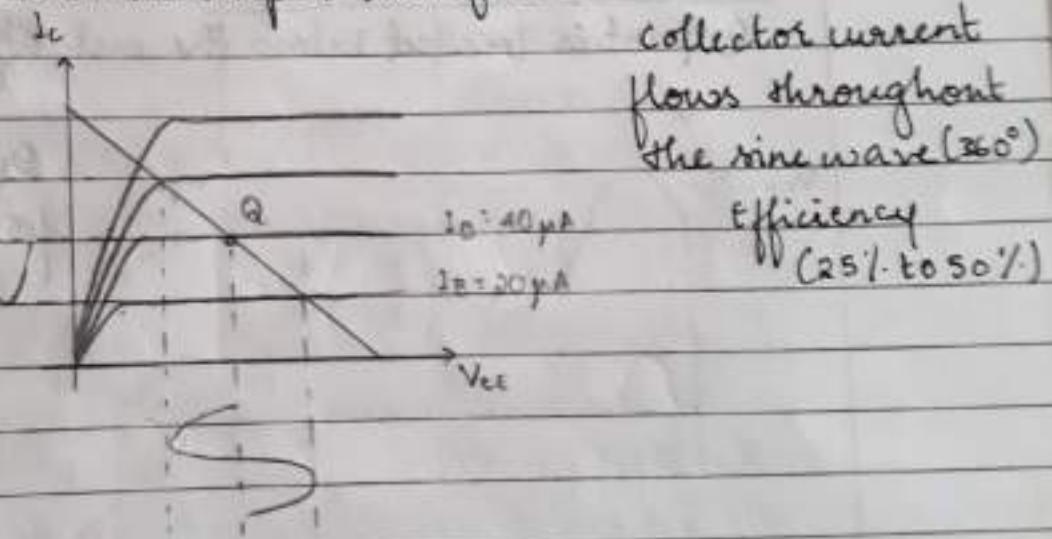
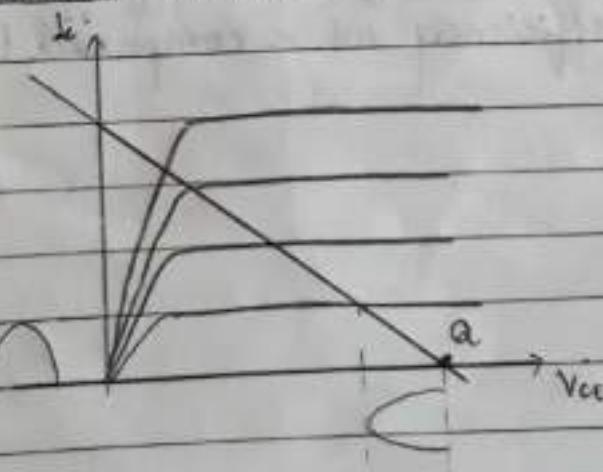
Power Amplifiers

* Classification:

1. Class A Power Amplifier
2. Class B Power Amplifier
3. Class AB Power Amplifier
4. Class C Power Amplifier
5. Class D Power Amplifier.

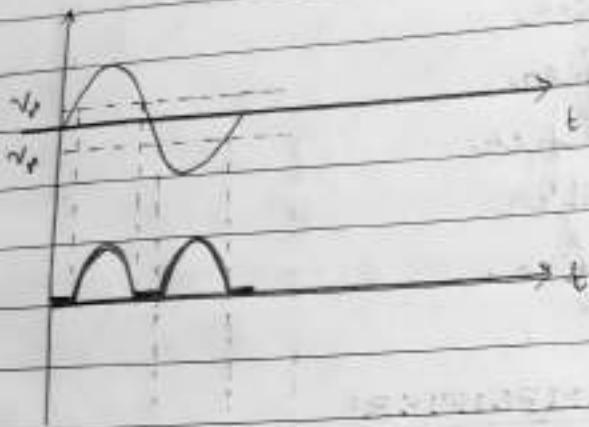
* CLASS A POWER AMPLIFIER:

- * Q point : It is situated at the center of the DC load line.
No distortion in the output waveform..

* CLASS B POWER AMPLIFIER:

* CLASS AB POWER AMPLIFIER:

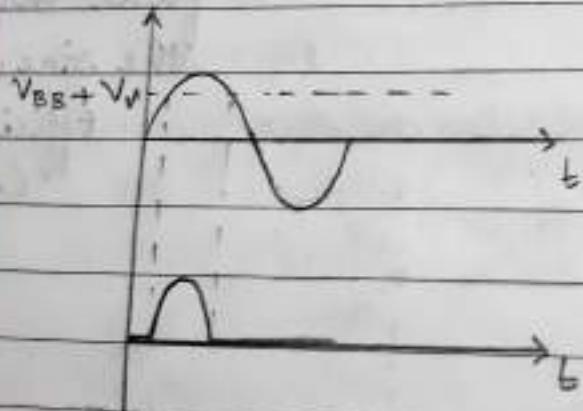
Q point is located at the cut off region in such a way that collector current flows 180° to 360° . In this case crossover distortion takes place.



When the input voltage is less than bias voltage then the output is zero this is called crossover distortion.
~~Efficiency~~
 class A < Class AB < Class B

* CLASS C POWER AMPLIFIER:

Q point is located below the cut off point.



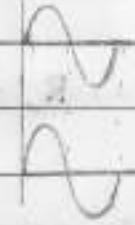
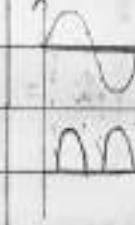
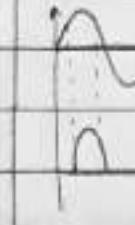
Output current flows for less than 180° .

* CLASS D POWER AMPLIFIER: (Digital)

Very high efficiency when compared to other amplifiers.

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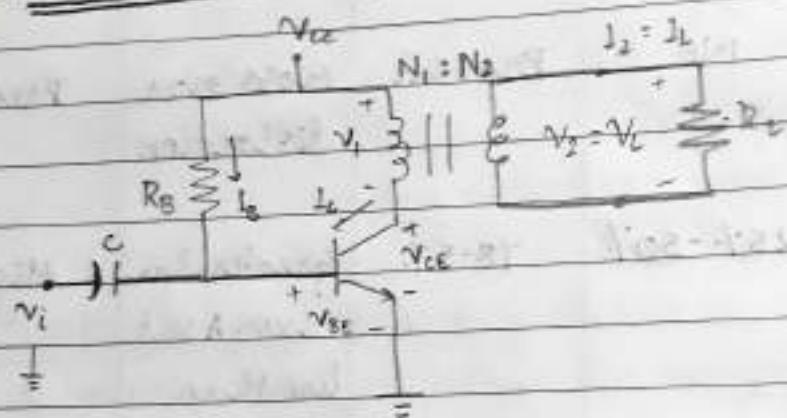
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<u>CLASS</u>	A	B	AB	C
1. Q Point	centre	cut off Region	cut off region with cut off region bias voltage	Below the bias voltage
2. Operating cycle	360°	180°	$180^\circ - 360^\circ$	less than 180°
3. Distortion	No	Present	Cross over distortion	Present
4. Efficiency	25% - 50%	78.5%	Greater than Class A but less than Class B	High
i. Input/Output waveform.				

* CLASS A POWER AMPLIFIER:

- series fed direct coupled class A Power Amplifier:
 - lesser efficiency
 - base biased
 - Simple circuit

2. Transformer coupled Class A Power Amplifier:



R_L' - reflected resistance across input.

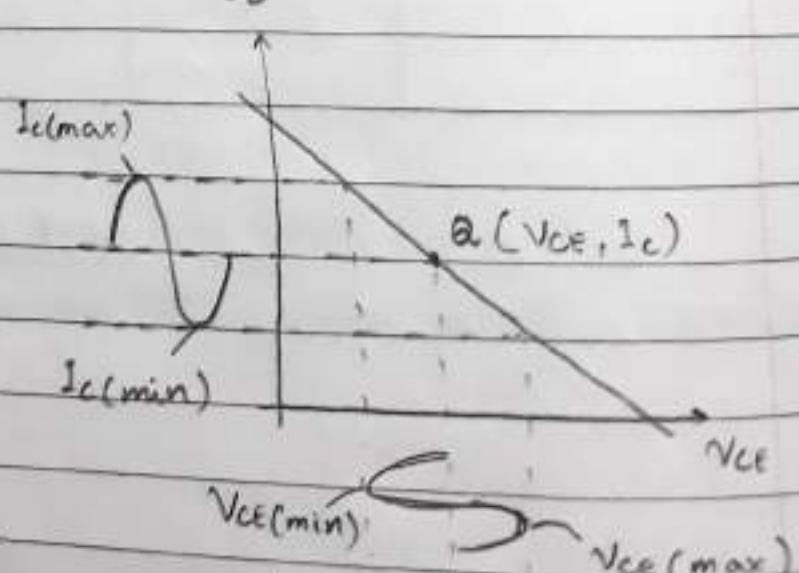
$$R_L' = \left(\frac{N_1}{N_2} \right)^2 R_L$$

$$R_L' = R_o$$

Now Applying KCL
 $V_{CC} + V_{CE} = 0$

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

ac power
 V_{im} - peak value of primary voltage
 I_{im} - peak value of primary current.



$$\text{ac power} : P_{ac} = \frac{V_{2m} \times I_{2m}}{2}$$

$$P_{ac} = \frac{V_{p-p}}{2} \times \frac{I_{p-p}}{2}$$

$$P_{ac} = \frac{(V_{ce\max} - V_{ce\min})}{2} \times \frac{(I_{c\max} - I_{c\min})}{2}$$

$$P_{ac} = \frac{(V_{ce\max} - V_{ce\min})}{8} (I_{c\max} - I_{c\min})$$

V_{2m} - peak value of secondary voltage

I_{2m} - peak value of secondary current

$$P_{ac} = \frac{V_{2m} \times I_{2m}}{2}$$

$$P_{ac} = \frac{V_{p-p}}{2} \times \frac{I_{p-p}}{2}$$

$$P_{ac} = \frac{(V_{ce\max} - V_{ce\min})(I_{c\max} - I_{c\min})}{8}$$

Hence ac power is same at primary winding and at secondary winding.

Efficiency

$$\eta = \frac{P_{ac}}{P_{dc}}$$

$$P_{dc} = V_{cc} I_{cq}$$

$$\eta = \frac{(V_{ce\max} - V_{ce\min})(I_{c\max} - I_{c\min})}{8} \Rightarrow P_{dc} = V_{cc} I_{cq}$$

$$V_{cc} I_{cq}$$

$$\eta = \frac{(2V_{cc})(2I_{cq})}{8}$$

$$V_{cc} I_{cq}$$

$$\boxed{\eta = 50\%}$$

$$V_{ce\min} = 0$$

$$I_{c\min} = 0$$

$$V_{ce\max} = 2V_{cc}$$

$$I_{c\max} = 2I_{cq}$$

Maximum output power $P_{ac(max)}$

$$P_{ac} = \frac{V_{im} \times I_{im}}{2}$$

$$P_{ac} = \frac{(V_{ce(max)} - V_{ce(min)}) (I_{c(max)} - I_{c(min)})}{8}$$

$$P_{ac} = \frac{2V_{cc} \times 2I_{cq}}{8}$$

$$P_{ac} = \frac{V_{cc} I_{cq}}{2}$$

$$P_{ac} = \frac{V_{cc}^2}{2R_L} \quad \text{or} \quad I_{cq} R_L \frac{V_{cc}}{2}$$

$$P_{ac} = \frac{V_{cc}^2}{2R_L'} \quad \text{or} \quad \frac{I_{cq}^2 R_L'}{2}$$

$P_{ac/2}$

Power dissipated

$$P_d = P_{ac} - P_{ac/2}$$

$$P_d = P_{ac}$$

$$P_d = V_{cc} I_{cq}$$

When input is high then maximum power is dropped across the load hence there will be less ~~power~~ dissipation.

Disadvantage

Frequency response is poor due to presence of inductive turnings of the transformer

Efficiency is affected by the number of turnings

Q1:

- A Class A transformer coupled audio power amplifier is required to deliver a maximum of 1W into a loud speaker of 10Ω resistance. If the output resistance of the amplifier is 1000Ω calculate:
- Turns ratio of transformer.
 - Calculate the power supply voltage.

~~address~~ ~~Reference~~

Assume an ideal transformer (100% efficiency)

Q1: Given: $P_{AC\max} = 1W$

$$R_L = 10\Omega$$

$$R_o = R_L' = 1000\Omega$$

i) $R_L' = \left(\frac{N_1}{N_2}\right)^2 R_L$

$$1000 = \left(\frac{N_1}{N_2}\right)^2 10$$

$\frac{N_1}{N_2} = 10:1$ // Step down transformer

ii) $V_{CC} = ?$

$$P_{AC\max} = \frac{V_{CC}^2}{2R_L'}$$

$$1 = \frac{V_{CC}^2}{2(1000)}$$

$$V_{CC}^2 = 2000$$

$$\underline{V_{CC} = 44.72V \approx 45V}$$

Q2: A transformer coupled class A amplifier drives ~~to~~ 16Ω load through 4:1 transformer with $V_{CC} = 36V$ and the circuit delivers $2W$ to the load. Find:

i. Power across transformer primary

ii. Rms voltage across load.

iii. Find rms voltage across transformer primary.

iv. Rms value of load current and primary current

v. Conversion efficiency if dc collector current is 150mA

Sol:Reqd.

$$\text{Given: } N_1 : N_2 = 4 : 1$$

$$V_{cc} = 36 \text{ V}$$

$$R_L = 16 \Omega$$

$$P_{ac\max} = 2 \text{ W}$$

$$I_{CQ} = 150 \text{ mA}$$

$$V_2 = V_L$$

$$\frac{V_1}{V_L} = \frac{N_1}{N_2} = \frac{I_L}{I_C}$$

$$\text{i) } R_L' = \frac{N_1 R_L}{A_B}$$

$$R_L' = \frac{4 \times 16}{4} = 64 \Omega$$

$$P_{ac} = \frac{V_{cc}^2}{2R_L'} = \frac{(36)^2}{2 \times 64} = 10.125 \text{ W}$$

$$\text{i) } P_{pri} = P_{ac} = P_L = 2 \text{ W}$$

ii) rms voltage across load

$$P_L = \frac{V_L^2 \text{ (rms)}}{R_L}$$

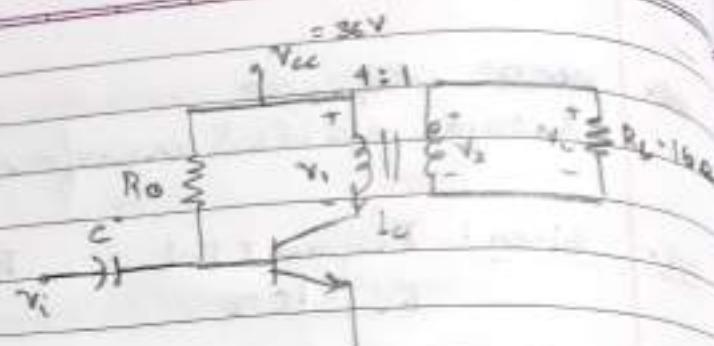
$$V_L \text{ (rms)} = \sqrt{P_L R_L} = \sqrt{2 \times 16}$$

$$V_L \text{ (rms)} = 5.65 \text{ V}$$

$$\text{iii) } \frac{V_L \text{ (rms)}}{V_{L \text{ (rms)}}} = \frac{N_1}{N_2}$$

$$V_L \text{ (rms)} = \frac{4 \times 5.65}{1}$$

$$V_L \text{ (rms)} = 22.6 \text{ V}$$



$$\text{iv) } P_L = I_L^2 R_L$$

$$I_{L(\text{rms})} = \sqrt{\frac{P_L}{R_L}} = \sqrt{\frac{2}{6}}$$

$$I_{L(\text{rms})} = 0.353 \text{ A}$$

$$\frac{I_{L(\text{rms})}}{I_{C(\text{rms})}} = \frac{N_1}{N_2}$$

$$I_{C(\text{rms})} = \frac{4}{4} \times 0.353$$

$$I_{C(\text{rms})} = 88.25 \text{ mA}$$

$$\text{v) } \eta = \frac{P_{ac}}{P_{dc}} = \frac{P_{ac}}{V_{cc} I_{ca}}$$

$$= \frac{2}{36 \times 150 \text{ m}}$$

$$\eta_b = 34.03\%$$

Q3: Find the turns ratio of the transformer required for four parallel 16Ω loudspeakers so that they appear as an $8k\Omega$ effective load.

Sol:

$$R_L' = 8k\Omega$$

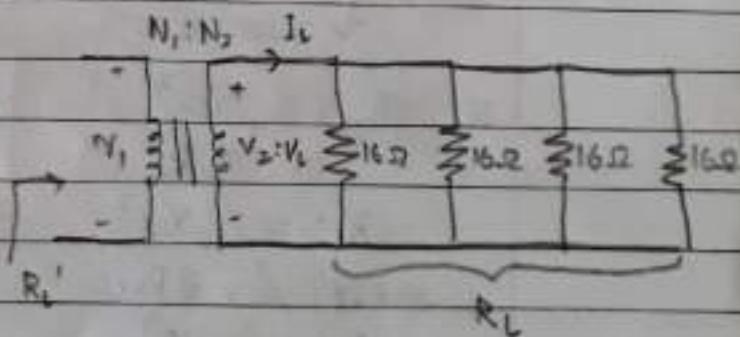
$$R_L = 16\Omega || 16\Omega || 16\Omega || 16\Omega$$

$$R_L = \frac{16}{4}$$

$$R_L = 4\Omega$$

$$R_L' = \left(\frac{N_1}{N_2}\right)^2 R_L$$

$$\frac{N_1}{N_2} = \sqrt{\frac{R_L'}{R_L}} = \sqrt{\frac{8k}{4}} = 44.72$$



a4: The following data is available for class A transformer coupled power amplifier.

$$V_{CE(\max)} = 18.5V$$

$$I_{CE(\max)} = 250mA$$

$$V_{CE(\min)} = 1.5V$$

$$I_{CE(\min)} = 25mA$$

$$V_{CC} = 10V$$

$$I_{CQ} = 140mA$$

$$R_L = 8\Omega$$

Find:

- ac power delivered to the load
- conversion efficiency
- transformer turns ratio

Sol: i. $P_{AC} = \frac{(V_{CE(\max)} - V_{CE(\min)})(I_{CE(\max)} - I_{CE(\min)})}{8} = \frac{V_P I_P}{2}$

$$P_{AC} = \frac{(18.5 - 1.5)(250m - 25m)}{8}$$

$$\underline{P_{AC} = 0.478W = 478.125mW}$$

ii. $\eta = \frac{P_{AC}}{P_{DC}} = \frac{P_{AC}}{V_{CC} I_{CQ}}$

$$\eta = \frac{0.478.125m}{10(140m)} \times 100$$

$$\underline{\eta = 34.15\%}$$

$$\text{iii. } V_{CE(p)} = I_{C(p)} R_L'$$

$$R_L' = \frac{V_{CE(\text{max})} - V_{CE(\text{min})}}{I_{C(\text{max})} - I_{C(\text{min})}}$$

$$R_L' = \frac{18.5 - 1.5}{250 \text{ m} - 25 \text{ m}}$$

$$R_L' = 75.5 \Omega$$

$$\therefore \frac{N_1}{N_2} = \sqrt{\frac{R_L'}{R_L}}$$

$$\frac{N_1}{N_2} = \sqrt{\frac{75.5}{8}}$$

$$\frac{N_1}{N_2} = 3.07$$

$$R_L' = \left(\frac{N_1}{N_2} \right)^2 R_L$$

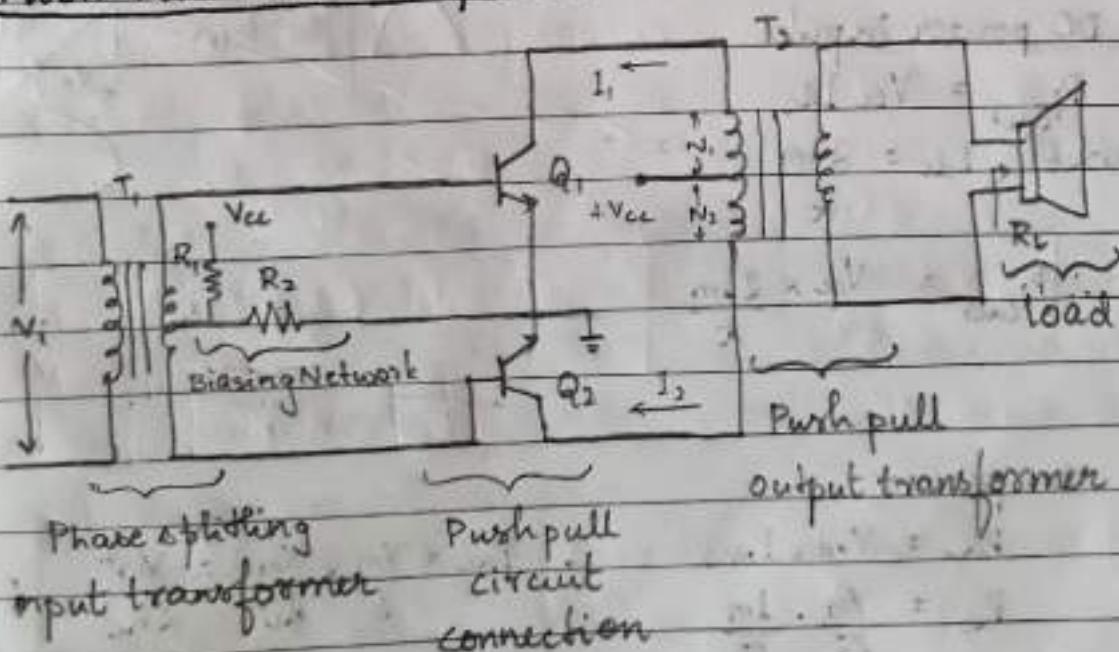
* CLASS B POWER AMPLIFIER:

In class B only one half of the cycle is the output. Hence by using two transistors we get both the half cycles as output.

Based on the transistors used it is classified as:

- Push Pull Power Amplifier (n-p-n or p-n-p)
- Complementary Symmetry Power Amplifier (n-p-n & p-n-p)

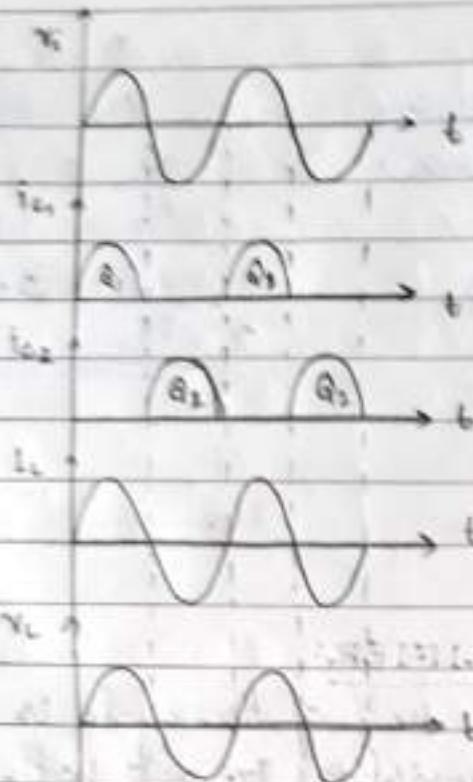
1. Push Pull Power Amplifier:



Phase splitting
input transformer

Push pull
circuit
connection

Push pull
output transformer



disadvantages

- bulky, costly
- poor frequency response

Advantages

- High efficiency

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

DC operation of class B push pull power amplifier

$$V_{CEQ} = V_{cc} \quad \beta_{eq} = 0$$

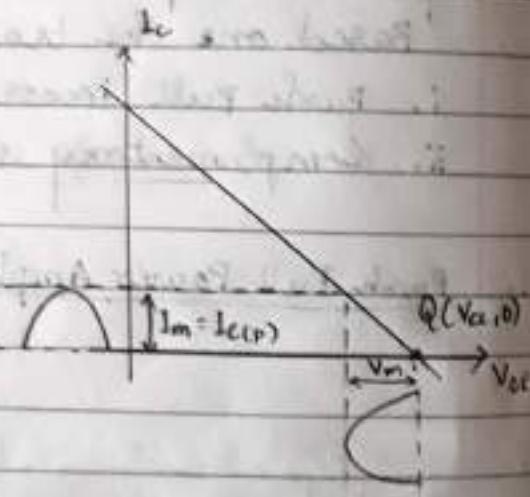
$$Q(V_{cc}, 0)$$

DC power input

$$P_{i(dc)} = V_{cc} I_{dc}$$

$$\text{wkt } I_{dc} = \frac{2V_m}{\pi}$$

$$\therefore P_{i(dc)} = V_{cc} \times \frac{2V_m}{\pi}$$



ac power

$$P_{ac} = V_{rms} I_{rms}$$

$$P_{ac} = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}}$$

$$P_{ac} = \frac{V_m I_m}{2}$$

$$P_{ac} = \frac{V_m \times V_m}{2 R_L'} = \frac{V_m^2}{2 R_L'}$$

$$P_{ac} = \frac{I_m \times I_m R_L'}{2} = \frac{I_m^2 R_L'}{2}$$

Efficiency

$$\eta \% = \frac{P_{dc} \times 100}{P_{ac}} = \frac{V_m I_m / 2}{2 V_{cc} I_m / \pi}$$

$$\boxed{\eta \% = \frac{V_m \pi}{4 V_{cc}}}$$

Max efficiency

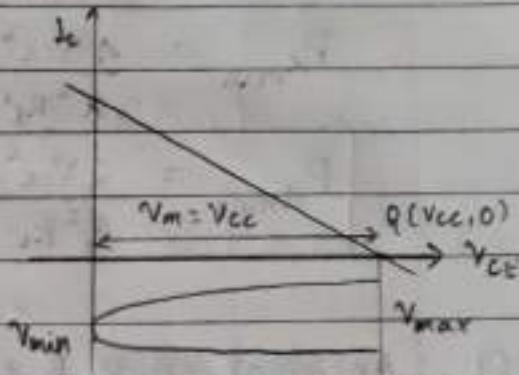
$$\eta \% = \frac{V_m \pi}{4 V_{cc}} \times 100$$

$$V_m = V_{cc}$$

$$\eta \% = \frac{V_{cc} R}{4 V_{cc}} \times 100$$

$$\eta \% = \frac{\pi}{4} \times 100$$

$$\boxed{\eta \% = 78.5\%}$$

Power dissipation

$$P_d = P_{dc} - P_{ac}$$

$$P_d = \frac{2 V_{cc} I_m}{\pi} - \frac{V_m I_m}{2}$$

$$\text{wkt } I_m = \frac{V_m}{R_L'}$$

$$\therefore P_d = \frac{2 V_{cc} V_m}{\pi R_L'} - \frac{V_m^2}{2 R_L'}$$

$$\boxed{P_d = \frac{2 V_{cc} V_m}{\pi R_L'} - \frac{V_m^2}{2 R_L'}}$$

If the input is minimum
then the power dissipated
is zero ($\because V_m \approx 0$)

Max Power dissipation.

differentiating eq ① wrt V_m and equate it to zero.

$$\frac{dP_d}{dV_m} = \frac{2 V_{cc}}{\pi R_L'} - \frac{2 V_m}{2 R_L'} = 0$$

$$\frac{2 V_{cc}}{\pi R_L'} = \frac{V_m}{R_L'}$$

$$\Rightarrow \boxed{V_m = \frac{2 V_{cc}}{\pi}} \quad \text{--- (2)}$$

Substituting eq ② in eq ①

$$P_d = \frac{2V_{cc}}{\pi R_L} \left(\frac{2V_{cc}}{\pi} \right) - \left(\frac{2V_{cc}}{\pi} \right)^2 \frac{1}{2R_L}$$

$$P_{d\max} = \frac{4V_{cc}^2}{\pi^2 R_L} - \frac{4V_{cc}^2}{2\pi^2 R_L}$$

$$P_{d\max} = \frac{4V_{cc}^2}{\pi^2 R_L} - \frac{2V_{cc}^2}{\pi^2 R_L}$$

$$P_{d\max} = \frac{2V_{cc}^2}{\pi^2 R_L}$$

Q1: An ideal class B push pull power amplifier with input and output transformers has $V_{cc} = 20V$ and $N_2 = 2N_1$, and $R_L = 20\Omega$, the transistors have $h_{FE} = 20$, let the input be sinusoidal for the maximum output signal at V_{ce} peak = V_{cc} . Determine:

- i. Output signal power
- ii. The collector dissipation in each transistor
- iii. conversion efficiency.

Sol:

$$\text{Given: } R_L = 20\Omega \quad N_2 = 2N_1$$

$$V_{cc} = 20V = V_{ce(p)} \quad h_{FE} = 20$$

$$i) P_{ac} = \frac{V_{cc}^2}{2R_L}$$

$$R_L' = \left(\frac{N_1}{N_2} \right)^2 R_L$$

$$P_{ac} = \frac{(20)^2}{2(5)}$$

$$R_L' = \left(\frac{1}{2} \right)^2 (20)$$

$$P_{ac} = \underline{40W}$$

$$\underline{R_L' = 5\Omega}$$

$$iii) P_{dc} = \frac{2V_{cc} I_m}{\pi} = \frac{2V_{cc} V_{ce(p)}}{\pi R_L} = \frac{2V_{cc}^2}{\pi R_L}$$

$$P_{dc} = \frac{2(20)^2}{\pi 50} = \underline{50.93W}$$

$$\text{Efficiency } \eta = \frac{P_{ac}}{P_{dc}} \times 100 = \frac{40}{50.93} \times 100 = 78.5\%$$

ii) $P_d = P_{dc} - P_{ac}$ Power dissipation in each

$$P_d = 50.93 - 40$$

$$P_d = 10.93 \text{ W}$$

$$\frac{P_d}{2} = \frac{10.93}{2} = 5.49 \text{ W}$$

Q2: A class B push pull amplifier operating with $V_{cc} = 25V$ provides a $22V$ peak signal to a 8Ω load. Find i. rms and peak load output currents

ii. rms and peak collector current

iii. dc current drawn from the supply

iv. input power

v. output power

vi. circuit efficiency

vii. power dissipation in each transistors

Sol:

Given: $V_{cc} = 25V$

$V_L(p) = 22V = V_{CE}(p)$ (transformer info not given hence considered)

$$\text{i. } I_{L(p)} = \frac{V_{CE(p)}}{R_L} = \frac{22}{8} = 2.75A \Rightarrow R_L = R'_L = 8\Omega$$

$$\text{ii. Rms Load current} = \frac{I_{L(p)}}{\sqrt{2}} = \frac{2.75}{\sqrt{2}} = 1.945A$$

$$\text{iii. } I_{C(rms)} = I_{L(rms)} \quad \because V_L(p) = V_{CE(p)} \text{ & } R_L = R'_L$$

$$I_{C(rms)} = 1.945A \quad I_{C(p)} = I_{L(p)} = 2.75A$$

$$\text{iv. } I_{dc} = \frac{2I_m}{\pi} = \frac{2(2.75)}{\pi} = 1.75A \quad \text{each transistor: } \frac{1.75}{2} = 0.875A$$

$$\text{v. } P_{dc} = V_{cc} I_{dc} = 25 \times 1.75 = 43.75 \text{ W}$$

$$\text{vi. } P_{ac} = \frac{V_m I_m}{2} = \frac{22 \times 2.75}{2} = 30.25 \text{ W}$$

$$\text{vi. } \eta = \frac{\pi V_m}{4 V_{cc}} = \frac{\pi (22)}{4 (25)} = \underline{\underline{69.11\%}}$$

$$\text{vii. } P_d = \frac{2 V_{cc} V_m}{\pi R_L} - \frac{V_m^2}{2 R_L} \quad \text{or} \quad P_d = P_{ac} - P_{dc}$$

$$P_d = \frac{2(25)(22)}{\pi(8)} - \frac{(22)^2}{2(8)}$$

$$P_d = 13.52 \text{ W}$$

$$\text{Each transistor } P_d = \frac{13.52}{2} = \underline{\underline{6.76 \text{ W}}}$$

- Q3: For a class B push pull power amplifier with $V_{cc} = 25 \text{ V}$ driving an 8Ω load find:
- maximum input power.
 - maximum output power.
 - maximum circuit efficiency.
 - maximum collector dissipation.
 - maximum collector dissipation in each transistor.

Q5:

Sol:

Sol:

$$\text{i. } P_{d(max)} = \frac{2 V_m^2 = 2 \times 22^2 = 2(25)}{\pi^2 R_L \pi R_L \pi^2 (8)} = \underline{\underline{49.74 \text{ W}}}$$

$$\text{ii. } P_{o(max)} = \frac{V_m^2}{2 R_L} = \frac{V_{cc}^2}{2 R_L} = \frac{25^2}{2(8)} = \underline{\underline{39.06 \text{ W}}}$$

$$\text{iii. } \eta_{(max)} = \frac{P_{o(max)}}{P_{d(max)}} \times 100 = \frac{39.06}{49.74} \times 100 = \underline{\underline{78.51\%}}$$

$$\text{iv. } P_{d(max)} = \frac{2 V_{cc}^2}{\pi^2 R_L} = \frac{2(25)^2}{\pi^2 (8)} = \underline{\underline{15.83 \text{ W}}}$$

$$\text{v. Each transistor } P_d_{(max)} = \frac{15.83}{2} = \underline{\underline{7.91 \text{ W}}}$$

Q4:

- Calculate the efficiency of class B push pull power amplifier for a supply voltage of $V_{cc} = 22 \text{ V}$ driving a 4Ω load with peak voltage of
- $V_{pp} = 22 \text{ V}$
 - $V_{L(pp)} = 20 \text{ V}$
 - $V_{L(pp)} = 4 \text{ V}$
- Compare and comment on the result.

$$\eta = \frac{\pi}{4} \frac{V_m}{V_{cc}} \times 100 \rightarrow \eta = \frac{\pi}{4} \frac{V_{CE(p)} \times 100}{V_{cc}}$$

Given: $V_{cc} = 22V$ $R_L = R_{CE(p)} \times 100$

a. $V_{CE(p)} = 22V = V_{CE(p)}$

$$\eta = \frac{\pi}{4} \times \frac{22}{22} \times 100 = 43.5\%$$

b. $V_{CE(p)} = 20V = V_{CE(p)}$

$$\eta = \frac{\pi}{4} \times \frac{20}{22} \times 100 = 71.39\%$$

c. $V_{CE(p)} = 4V = V_{CE(p)}$

$$\eta = \frac{\pi}{4} \times \frac{4}{22} \times 100 = 14.28\%$$

As $V_{CE(p)}$ decreases
efficiency decreases
When $V_{CE(p)} = V_{CE(p)}$
efficiency is max.

Q5:

In a class B power amplifier $V_{CE(min)} = 1V$ and $V_{cc} = 18V$, calculate the collector circuit efficiency.

Sol:

Given: $V_{CE(min)} = 1V$, $V_{cc} = 18V$

$$V_{CEF(p)} = V_{CE(max)} - V_{CE(min)} = V_{cc} - V_{CE(min)}$$

$$V_{CE(p)} = 18 - 1 = 17V$$

$$\eta = \frac{\pi}{4} \frac{V_m \times 100}{V_{cc}} = \frac{\pi}{4} \frac{V_{CE(p)} \times 100}{V_{cc}} = \frac{\pi}{4} \frac{17 \times 100}{18} = 44.17\%$$

* Distortion in Amplifiers:

1. Frequency distortion

2. Amplitude distortion

3. Phase shift distortion

4. Harmonic distortion.

A. Fundamental freq

% Harmonic distortion = $\frac{|A_m| \times 100}{|A_f|}$ where $A_m = n^{\text{th}}$ harmonic

Total Harmonic

$$\text{distortion (THD)} = \sqrt{D_2^2 + D_3^2 + D_4^2 + \dots D_n^2} \times 100$$

In class B and class AB, second harmonic component causes harmonic distortion.

collector current waveform

Basic equation

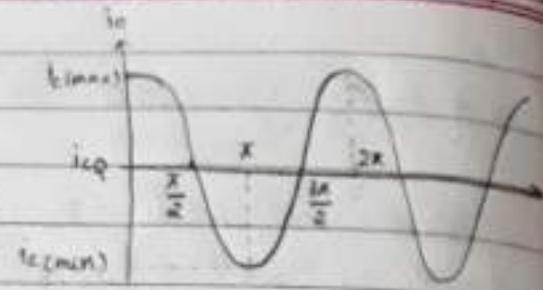
$$i_c = i_{cq} + I_0 \cos \omega t + I_1 \cos 2\omega t$$

\downarrow
Collector current at Q point

\downarrow
fundamental ac signal

decomponent

Second harmonic component



- At $\omega t = 0$

$$i_{c(max)} = i_{cq} + I_0 + I_1 + I_2 \quad \text{--- (1)}$$

- At $\omega t = \pi/2$

$$i_{cq} = i_{cq} + I_0 - I_2 \quad \text{--- (2)}$$

- At $\omega t = \pi$

$$i_{c(min)} = i_{cq} + I_0 - I_1 + I_2 \quad \text{--- (3)}$$

From eq (2) : $I_0 = I_2$

i.e. From eq (1) : $i_{c(max)} = i_{cq} + 2I_0 + I_1 \quad \text{--- (4)}$

i.e. From eq (3) : $i_{c(min)} = i_{cq} + 2I_0 - I_1 \quad \text{--- (5)}$

Adding eq (4) and eq (5)

$$i_{c(max)} + i_{c(min)} = 2i_{cq} + 4I_0$$

$$\Rightarrow I_0 = I_2 = \frac{i_{c(max)} + i_{c(min)} - 2i_{cq}}{4}$$

Subtracting eq (4) and eq (5)

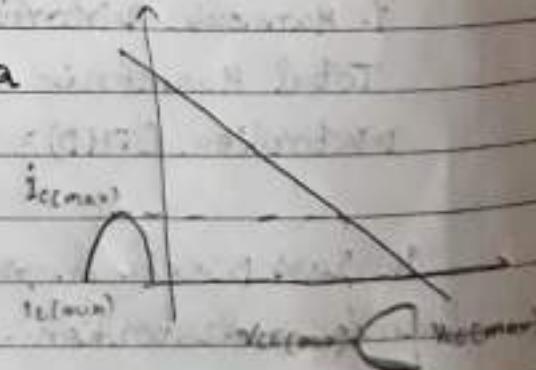
$$i_{c(max)} - i_{c(min)} = 2I_1$$

$$\Rightarrow I_1 = \frac{i_{c(max)} - i_{c(min)}}{2}$$

In terms of voltage

$$V_0 = V_2 = \underline{V_{CE(max)} + V_{CE(min)} - 2V_{CEQ}}$$

$$V_1 = \frac{V_{CE(max)} - V_{CE(min)}}{2}$$



NOTES

Q1: Calculate the second harmonic distortion for an output waveform using measured values of $V_{CE(\min)} = 2.4V$, $V_{CE(\max)} = 20V$ and $V_{CEQ} = 10V$

$$\text{Sol: } A_1 = I_1 = \frac{i_{c(\max)} - i_{c(\min)}}{2}$$

$$A_2 = I_2 = I_3 = \frac{i_{c(\max)} + i_{c(\min)} - 2I_{cQ}}{4}$$

$$\text{HD}\% = \frac{|A_2|}{|A_1|} \times 100 = \frac{\frac{i_c(\max) + i_c(\min) - 2I_{cQ}}{4}}{\frac{i_c(\max) - i_c(\min)}{2}} \times 100$$

$$\text{HD}\% = \frac{\frac{1}{2}(i_{c(\max)} + i_{c(\min)}) - I_{cQ}}{i_{c(\max)} - i_{c(\min)}} \times 100$$

$$\text{HD}\% = \frac{\frac{1}{2}(V_{CE(\max)} + V_{CE(\min)}) - V_{CEQ}}{V_{CE(\max)} - V_{CE(\min)}} \times 100$$

$$\text{HD}\% = \frac{\frac{1}{2}(20 + 2.4) - 10}{20 - 2.4} \times 100 = \underline{\underline{6.82\%}}$$

Q2: The following readings are available for power amplifier. calculate the 2nd harmonic distortion in each case:

i. $V_{CEQ} = 10V$, $V_{CE(\max)} = 18V$, $V_{CE(\min)} = 1V$

ii. $V_{CEQ} = 10V$, $V_{CE(\max)} = 19V$, $V_{CE(\min)} = 1V$

$$\text{Sol: } \text{HD}\% = \frac{\frac{1}{2}(V_{CE(\max)} + V_{CE(\min)}) - V_{CEQ}}{V_{CE(\max)} - V_{CE(\min)}} \times 100$$

$$= \frac{\frac{1}{2}(18 + 1) - 10}{18 - 1} \times 100 = \underline{\underline{2.94\%}}$$

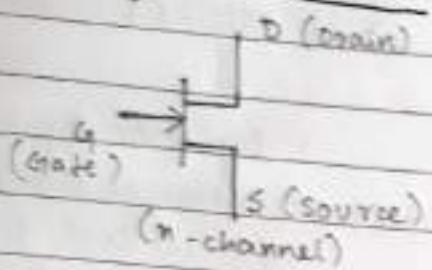
$$\text{HD}\% = \frac{\frac{1}{2}(V_{CE(\max)} + V_{CE(\min)}) - V_{CEQ}}{V_{CE(\max)} - V_{CE(\min)}} \times 100$$

$$= \frac{\frac{1}{2}(19 + 1) - 10}{19 - 1} \times 100 = \underline{\underline{0\%}}$$

UNIT - 6

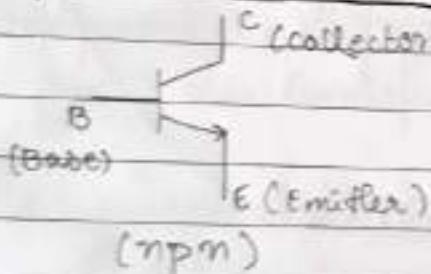
Field Effect Transistors Amplifiers (FET)

- * Field Effect Transistor:



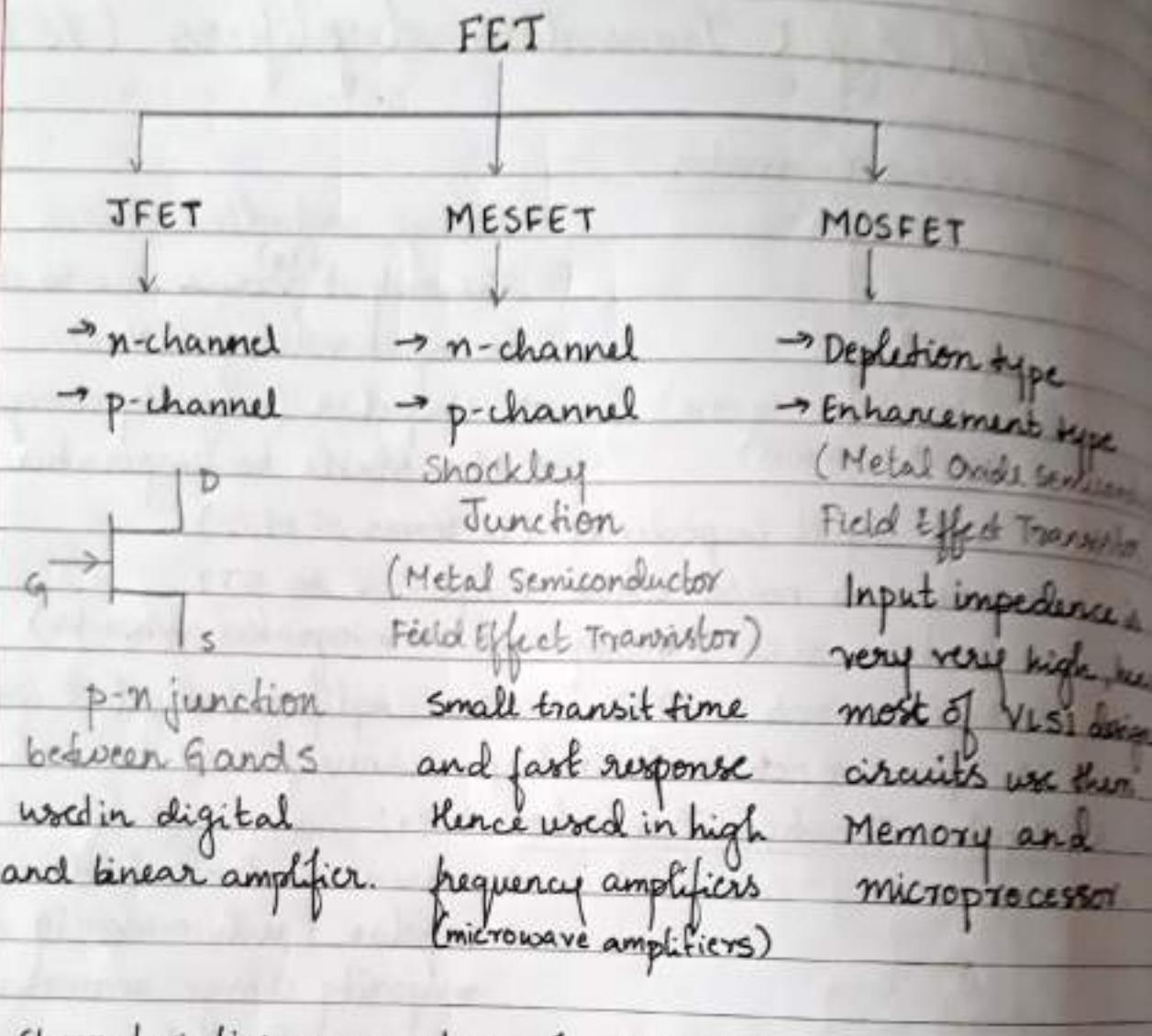
- voltage controlled device
- The output varies due to change in input voltage (V_{GS}).
- Unipolar (majority charge carriers)
- More stable to temperature variation
- High input impedance (in terms of MΩ)
- Very less noise when compared to BJT.
- Smaller size (widely used in integrated circuits)
- Applications: JFET - linear amplifier / digital circuits.
- Types: n-channel and p-channel.

- * Bipolar Junction Transistor: (I_C controls I_E)



- current controlled device
- bipolar (both minority and majority charge carriers contribute)
- less stable to temperature variation (thermal run away)
- Input impedance is less than that of FET.
- More noise when compared to FET.
- Larger in size when compared to FET.
- Types: npn and pnp.
- Configuration: common base, common collector and common emitter. where as in FET the configurations are common gate, common drain, common emitter.
- Sensitivity Thermal stability is less where as more in FET.
- Gain Bandwidth product is more than that of FET.

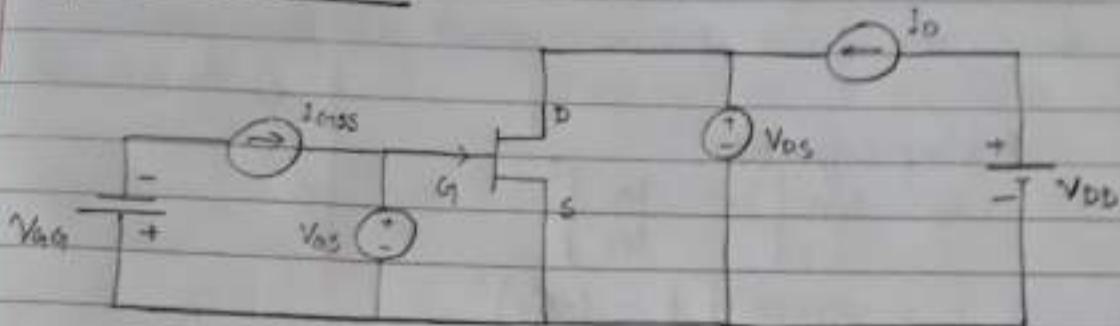
* Different types of FET's



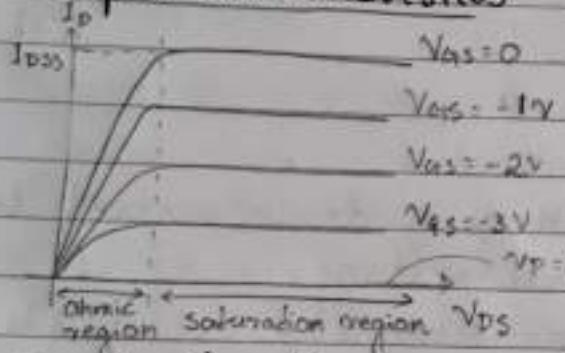
* Characteristics parameters of JFET's:

1. Transconductance: (g_m)
 2. Input resistance: (R_{in})
 3. Drain to Source Resistance (r_d)
 4. Amplification factor (μ)
 5. Power dissipation (P_o)

* Operation of FET:



Output characteristics



It is plotted as I_D versus V_{DS} keeping input voltage V_{GS} constant because it is a voltage controlled device.

Pinch off voltage: It is the voltage (V_{GS}) below which the FET is off (i.e., $I_D = 0$).

I_{DSS} - maximum drain current. when $V_{GS} = 0$.

FET current Equation

Shockley Equation

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

I_D - Drain current

I_{DSS} - Maximum drain current

V_{GS} - Gate to source voltage

V_P - Pinch off voltage.

when $V_{GS} = 0$ then $I_D = I_{DSS}$

When $V_{GS} = V_P$ then $I_D = 0$

Q: For a JFET if $I_{DSS} = 20\text{mA}$ and $V_{GS(\text{off})} = -5\text{V}$ and $V_{GS} = -4\text{V}$ find drain current at this point

Sol: Shockley Equation

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

$$= 20 \times 10^{-3} \left[1 - \frac{(-4)}{(-5)} \right]^2$$

$$\underline{I_D = 0.8\text{mA}}$$

* TRANSCONDUCTANCE:

It is a ratio of change in drain current to change in gate to source voltage.

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}} \quad (\text{millisiemens})$$

(slope of transfer characteristics)

By Shockley's Equation

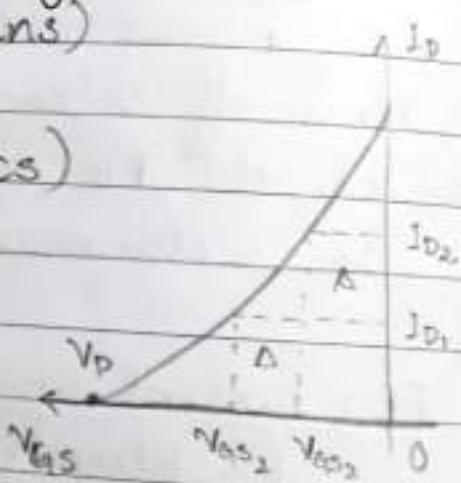
$$I_D = I_{DSS} \left[1 - \frac{V_{GS}}{V_P} \right]^2$$

diff wrt to V_{GS}

$$\frac{\Delta I_D}{\Delta V_{GS}} = -\frac{2I_{DSS}}{V_P} \left[1 - \frac{V_{GS}}{V_P} \right]$$

$$g_m = -\frac{2I_{DSS}}{V_P} \left[1 - \frac{V_{GS}}{V_P} \right]$$

$$g_m = g_{m0} \left[1 - \frac{V_{GS}}{V_P} \right]$$



where $g_{m0} = \left[-\frac{2I_{DSS}}{V_P} \right]$

Q: For a JFET if $I_{DSS} = 20\text{mA}$ and $V_{GSOFF} = -5\text{V}$ and $g_{m0} = 4\text{m siemens}$. Determine the transconductance for $V_{GS} = -4\text{V}$.

Sol:

$$g_m = g_{m0} \left[1 - \frac{V_{GS}}{V_p} \right]$$

$$= 4 \times 10^{-3} \left[1 - \frac{(-4)}{(-5)} \right]$$

$$\underline{g_m = 0.8\text{mS}}$$

* INPUT RESISTANCE:

Input resistance is the ratio of gate to source voltage and reverse gate current

$$R_{in} = \left| \frac{V_{GS}}{I_{GSS}} \right|$$

Q: Given $I_{GSS} = 10\text{nA}$ for $V_{GS} = 10\text{V}$ at 25°C . Find the input resistance.

Sol:

$$R_{in} = \left| \frac{V_{GS}}{I_{GSS}} \right| = \frac{10}{10 \times 10^{-9}} = \underline{\underline{1000\text{M}\Omega}}$$

Q: Given $I_{GSS} = 1\text{mA}$ for $V_{GS} = 10\text{V}$ at 100°C . Find the input resistance and compare with previous case.

Sol:

$$R_{in} = \left| \frac{V_{GS}}{I_{GSS}} \right| = \frac{10}{10^{-6}} = \underline{\underline{10\text{M}\Omega}}$$

With increase in temperature, current increases hence the input resistance decreases.

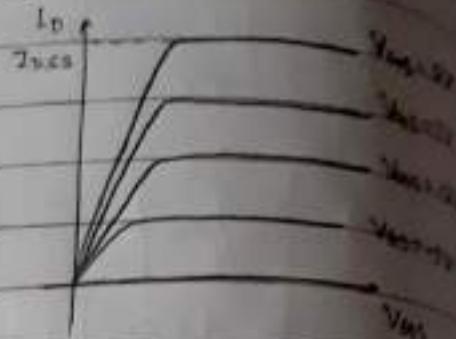
* DRAIN TO SOURCE RESISTANCE:

Drain to source resistance is defined as the ratio of change in V_{DS} to change in drain current in an output characteristics.

$$\gamma_d = \frac{\Delta V_{DS}}{\Delta I_D}$$

impedance

γ_d (50 k Ω to few hundred k Ω)



Admittance : $Y_{DS} = \frac{1}{\gamma_d}$

* AMPLIFICATION FACTOR:

It is the ratio of change in drain to source voltage to change in gate to source voltage.

$$\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}}$$

In terms of g_m and γ_d

Multiplying and dividing by ΔI_D

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

but wkt $\frac{\Delta V_{DS}}{\Delta I_D} = \gamma_d$ and $\frac{\Delta I_D}{\Delta V_{GS}} = g_m$

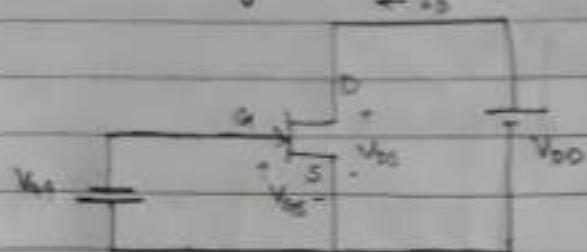
$$\therefore \mu = \gamma_d \times g_m$$

* POWER DISSIPATION:

Power dissipation is the product of output current to output voltage

$$P_D = I_D V_{DS}$$

* small signal ac model



$\rightarrow I_D \propto V_{DS}$
(voltage controlled device)

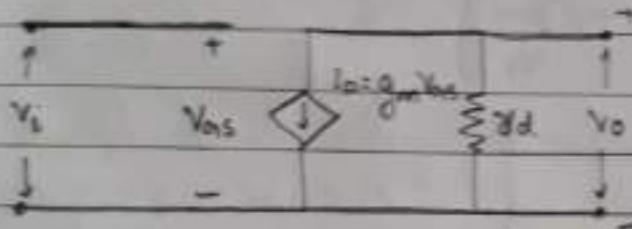
$$I_D = g_m V_{DS}$$

$g_m = Y_{fs}$ (forward transfer admittance)

Given circuit

$$\rightarrow V_{DS} \propto I_D$$

$$I_D = \frac{1}{Y_d} V_{DS}$$



$$Y_d = \frac{1}{V_{DS}} \text{ (output admittance)}$$

Small signal ac model

Q: A FET has $Y_{fs} = 4mS$ and $Y_{os} = 33.33\mu S$. Find

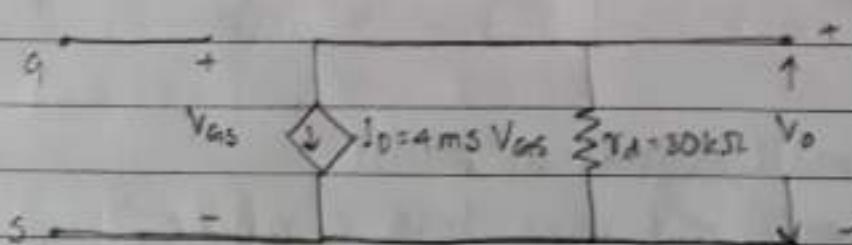
a. g_m and Y_d

b. sketch the small signal ac model of FET.

Sol: a. $g_m = Y_{fs} = \underline{\underline{4mS}}$

$$Y_d = \frac{1}{Y_{os}} = \frac{1}{33.33 \times 10^{-6}} = \underline{\underline{30k\Omega}}$$

b.



* Relationship between I_D and g_m .

From Shockley's equation

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

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

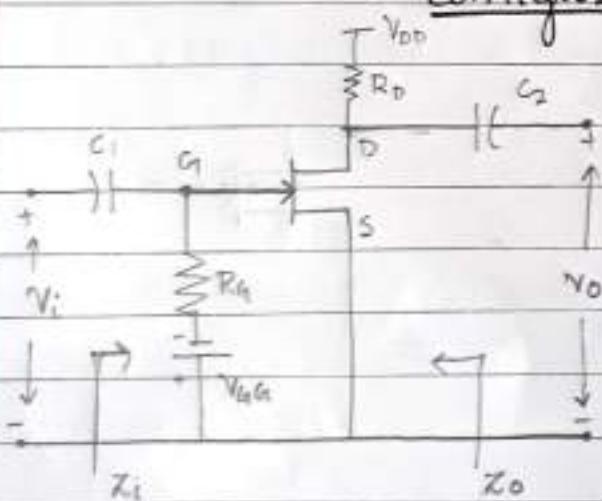
$$\sqrt{\frac{I_D}{I_{DSS}}} = 1 - \frac{V_{GS}}{V_P} \quad \text{--- (1)}$$

$$\text{wkt } g_m = g_{m0} \left(1 - \frac{V_{GS}}{V_P} \right)$$

From eq (1)

$$g_m = g_{m0} \sqrt{\frac{I_D}{I_{DSS}}}$$

* JFET Common Source Amplifier using Fixed Bias Configuration:



R_D and R_G are connected to avoid damage to the JFET due to large current from source.

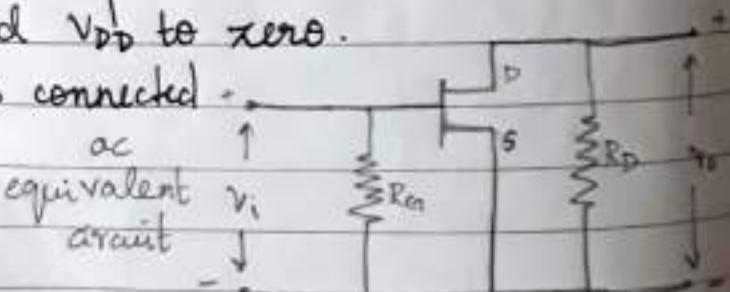
C_1 and C_2 are the coupling capacitors.

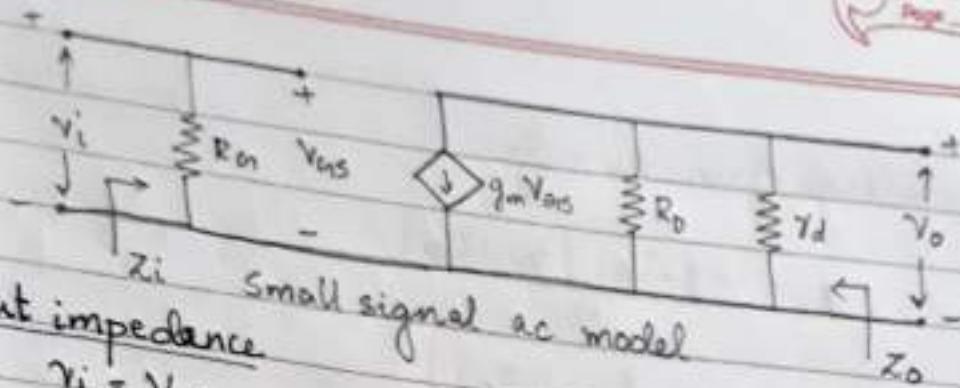
To get small signal ac model

1. short circuit the capacitors C_1 and C_2
2. Reduce V_{GS} and V_{DD} to zero.

(i.e., V_{GS} and V_{DD} is connected to ground)

ac equivalent circuit



 $Z_i = V_{ds}$

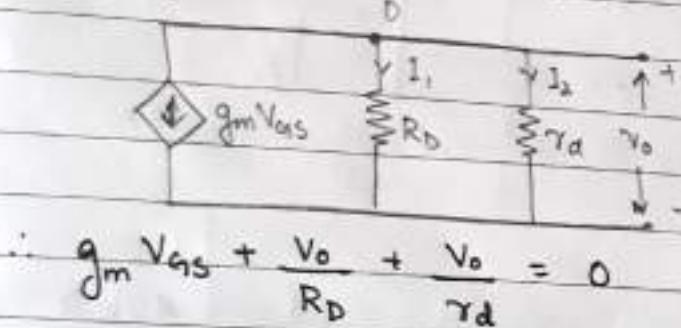
Open circuit the gate and source terminal to find the input impedance.

$$\Rightarrow Z_i = R_d$$

Output impedance

Reduce input voltage to zero to find the output impedance.

$$\Rightarrow V_i = V_{ds} = 0$$

Voltage gain

Applying KCL to nodes
 $g_m V_{ds} + I_1 + I_2 = 0$
 but $I_1 = \frac{V_o}{R_d}$, $I_2 = \frac{V_o}{\gamma_d}$

$$\therefore g_m V_{ds} + \frac{V_o}{R_d} + \frac{V_o}{\gamma_d} = 0$$

$$g_m V_{ds} = -V_o \left(\frac{1}{R_d} + \frac{1}{\gamma_d} \right)$$

$$g_m V_{ds} = -V_o \left(\frac{R_d + \gamma_d}{R_d \gamma_d} \right)$$

$$V_o = -g_m V_{ds} \left(\frac{R_d \gamma_d}{R_d + \gamma_d} \right)$$

$$V_o = -g_m V_{ds} [\gamma_d \parallel R_d]$$

$$\text{voltage gain } A_v = \frac{V_o}{V_i}$$

$$\therefore A_v = -g_m V_{o\text{ss}} [\tau_d || R_D]$$

$$A_v = -g_m [\tau_d || R_D]$$

There is 180° phase shift between the input and output
When $\tau_d \gg 10R_D$

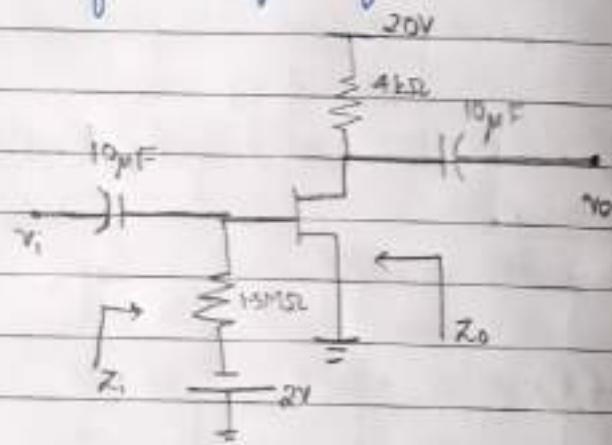
$$\Rightarrow Z_0 \approx R_D \Rightarrow A_v = -g_m R_D$$

Q: For JFET amplifier shown below calculate Z_i and Z_o , A_v , given:

$$I_{DSS} = 15 \text{ mA}$$

$$V_P = -6 \text{ V}$$

$$Y_{OS} = 25 \mu\text{S}$$



$$Z_i = R_G = 1.5 \text{ M}\Omega /$$

$$Z_o = \tau_d || R_D$$

$$= 40 \text{ k} \parallel 4 \text{ k}$$

$$= \frac{40 \text{ k} \times 4 \text{ k}}{44 \text{ k}}$$

$$\tau_d = \frac{1}{Y_{OS}} = \frac{1}{25 \times 10^{-6}} = 40 \text{ k}\Omega$$

$$A_v = -g_m [\tau_d || R_D]$$

$$Z_o = 3.63 \text{ k}\Omega /$$

$$g_m = g_{m0} \left[1 - \frac{V_{GS}}{V_P} \right]^2$$

$$g_m = 5 \text{ m} \left[1 - \frac{(-2)}{(-6)} \right]^2$$

$$g_m = 3.33 \text{ mS}$$

$$g_{m0} = \frac{-2 \times 10^{-5}}{-6} = -2(15 \text{ m})$$

$$g_{m0} = 5 \text{ mS}$$

$$A_v = -g_m [\frac{1}{R_d} + \frac{1}{R_s}]$$

$$= -3.33 \times 10^{-5} \left[\frac{4k \times 4k}{4k} \right]$$

$$A_v = -12.11$$

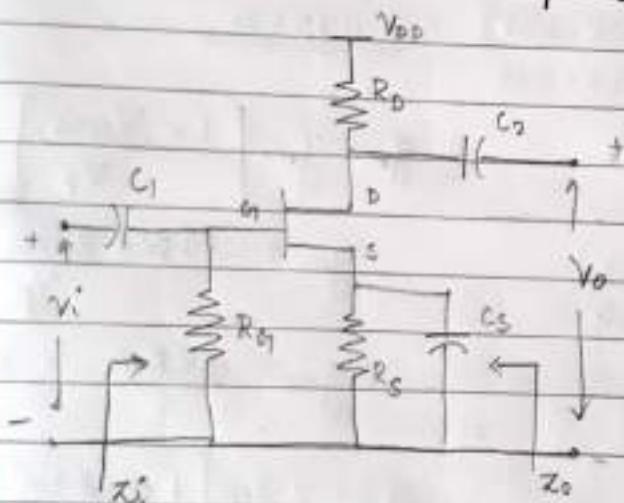
Neglecting the effect of γ_d

$$Z_i = R_G = 1.5M\Omega$$

$$Z_o \approx R_D = 4k\Omega$$

$$A_v \approx -g_m R_D = -(3.33 \times 4k) = -13.32$$

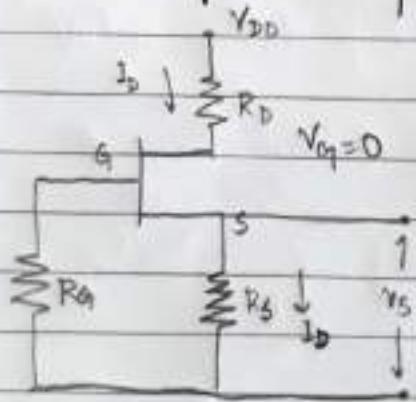
* JFET Common Source Amplifier using Self bias Configuration



C_1 and C_2 are the coupling capacitors.
 C_B - bypass capacitor is used to increase gain as it blocks ac - ve feedback to the resistor.

For ac component capacitor acts as short, the ac equivalent circuit is same as that of fixed bias configuration.

For dc component capacitor acts as open circuit.



$$V_{ASQ} = V_{G1} - V_S$$

$$V_{ASQ} = 0 - I_D Q R_S$$

$$V_{ASQ} = -I_D Q R_S$$

$$\text{Hence } Z_i = R_G \quad \left. \begin{array}{l} (\text{ac equivalent circuit}) \\ Z_o = R_D \| R_S \end{array} \right\}$$

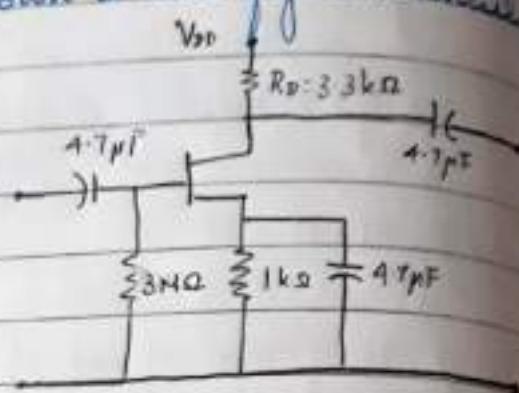
$$A_v = -g_m (R_D \| R_S)$$

- Q: For a JFET amplifier shown in the figure, calculate
 i. Z_i and Z_o
 ii. A_v
 iii. V_o if $V_i = 10mV$ (p-p)
 iv. Z_i , Z_o , A_v and V_o
 neglecting the effect of R_d .

Given:

$$I_{DSS} = 8mA \quad V_p = -5V$$

$$I_{DSQ} = 2.5mA \quad Y_{OS} = 20\mu S.$$



Sol: i. $Z_i = R_g = \underline{3M\Omega}$ $\tau_d = \frac{1}{Y_{OS}} = \frac{1}{20 \times 10^{-6}} = \underline{50k\Omega}$

$$Z_o = (\tau_d || R_D) = \frac{(50k \times 3.3k)}{50k + 3.3k} = \underline{3.095k\Omega}$$

ii. $A_v = -g_m (\tau_d || R_D)$

$$g_m = g_{m0} \left[1 - \frac{V_{GSQ}}{V_p} \right]$$

$$A_v = -1.6m \left(\frac{50k \times 3.3k}{50k + 3.3k} \right)$$

$$g_{m0} = \frac{20 \times 8m}{V_p} = 2.5mS$$

$$\underline{A_v = -4.95}$$

$$g_{m0} = \frac{2 \times 8m}{5} = 3.2mS$$

$$g_m = 3.2m \left[1 - \frac{(2.5m)(12)}{5} \right]$$

$$g_m = \underline{1.6mS} \quad V_{GSQ} = 10mV$$

iii. V_o when $V_i = 10mV$ (p-p)

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

$$V_o = A_v V_i$$

$$V_o = -4.95 (10mV)$$

$$\underline{V_o = -49.5mV}$$
 (p-p)

$$\text{iv. } Z_i = R_{in} = \underline{3\text{ M}\Omega}$$

$$A_v = -g_m R_D = -1.6 \text{ m} \times 3.3 \text{ k}$$

$$A_v = \underline{-5.28}$$

$$Z_o = R_D = \underline{3.3 \text{ k}\Omega}$$

$$V_o = A_v V_i = (-5.28)(10 \text{ m})$$

$$V_o = \underline{-52.8 \text{ mV (p-p)}}$$

Q: For a JFET amplifier shown in the figure calculate:

i. Z_i and Z_o .

ii. A_v

iii. calculate V_o if $V_i = 50 \text{ mV (p-p)}$

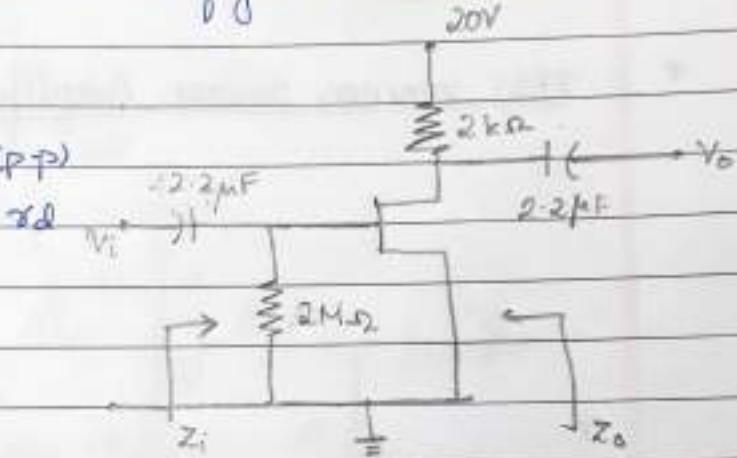
iv. Z_i , Z_o , A_v , V_o neglecting r_d

Given:

$$I_{DSS} = 5 \text{ mA}$$

$$V_p = -6 \text{ V}$$

$$Y_{OS} = 40 \mu\text{s}$$



Sol: i. $Z_i = R_{in} = \underline{2\text{ M}\Omega}$

$$Y_d = \frac{1}{Y_{OS}} = \frac{1}{40 \times 10^{-6}} = \underline{25\text{ k}\Omega}$$

$$Z_o = (Y_d || R_D) = \frac{(25\text{ k}\Omega \times 2\text{k})}{25\text{k}+2\text{k}} = \underline{1.85 \text{ k}\Omega}$$

ii. $A_v = -g_m (Y_d || R_D)$

$$g_{mo} = \frac{2 I_{DSS}}{V_p} = \frac{2(5\text{m})}{6} = \underline{1.67 \text{ mS}}$$

$$A_v = -1.67 \text{ m} \left(\frac{25\text{k} \times 2\text{k}}{25\text{k}+2\text{k}} \right)$$

$$g_m = g_{mo} \left[1 - \frac{V_{GSQ}}{V_p} \right]^2$$

$$A_v = \underline{-3.09}$$

$$R_s = 0 \Rightarrow V_{GSQ} = 0$$

$$\therefore g_m = g_{mo} = 1.67 \text{ mS}$$

iii. V_o when $V_i = 50 \text{ mV (p-p)}$

$$A_v = V_o / V_i$$

$$V_o = A_v V_i = -3.09(50 \text{ m}) = \underline{-154.5 \text{ mV (p-p)}}$$

$$\text{iv. } Z_i = R_g = \underline{\underline{2M\Omega}}$$

$$V_o = AvV_i$$

$$V_o = (-3.34)(50m)$$

$$Z_o = R_D = \underline{\underline{2k\Omega}}$$

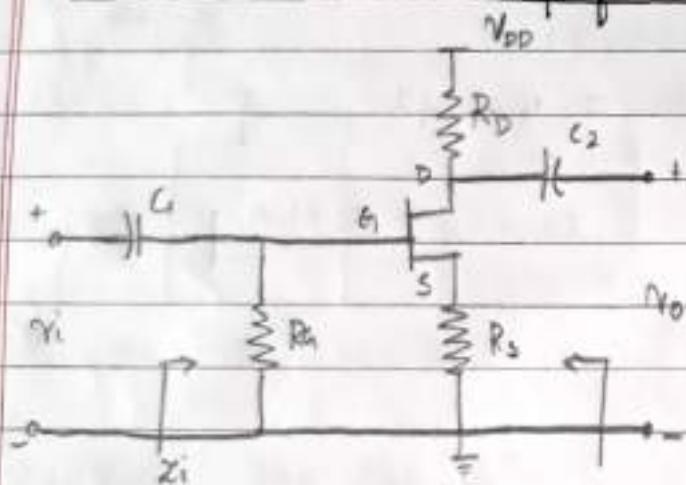
$$V_o = \underline{\underline{16.1mV (p-p)}}$$

$$A_v = -g_m R_D \approx$$

$$A_v = -\underline{\underline{3.34}}(2k)$$

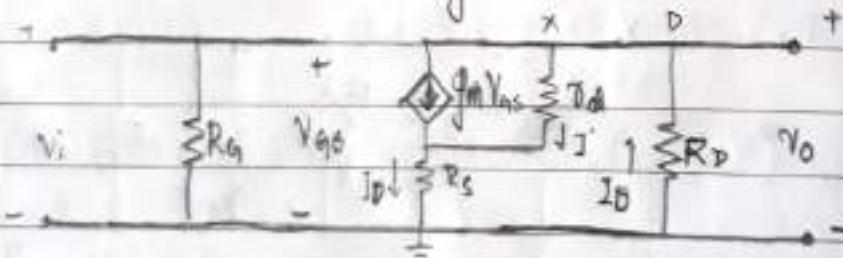
$$A_v = \underline{\underline{-3.34}}$$

* JFET Common Source Amplifier with unbypassed R_s :



Here no by pass capacitor C_S is used

ac small signal circuit



Input impedance

$$Z_i = R_g \quad -①$$

Gain

$$A_v = \frac{V_o}{V_i} \quad -②$$

$$V_o = -I_D R_D \quad -③$$

Apply KCL at node X

$$I_D = I' + g_m V_{AS} \quad \text{--- (4)}$$

Apply KVL

$$-I_D R_S - I' r_d + I_D R_D = 0$$

$$I' r_d = -I_D (R_D + R_S)$$

$$I' = \frac{-I_D (R_D + R_S)}{r_d} \quad \text{--- (5)}$$

Substituting eq (5) in eq (4)

$$I_D = \frac{-I_D (R_D + R_S) + g_m V_{AS}}{r_d} \quad \text{--- (6)}$$

To find V_{AS} , apply KVL to input loop.

$$V_i - V_{AS} - I_D R_S = 0$$

$$V_{AS} = V_i - I_D R_S \quad \text{--- (7)}$$

Substitute eq (7) in eq (6)

$$I_D = \frac{-I_D (R_D + R_S) + g_m (V_i - I_D R_S)}{r_d}$$

$$I_D + \frac{I_D (R_D + R_S)}{r_d} + I_D g_m R_S = V_i g_m$$

$$I_D \left[1 + \frac{(R_S + R_D)}{r_d} + g_m R_S \right] = V_i g_m$$

$$I_D = \frac{V_i g_m}{\left[1 + \frac{(R_S + R_D)}{r_d} + g_m R_S \right]} \quad \text{--- (8)}$$

Substituting eq (8) in eq (3)

$$V_o = \frac{-g_m R_D V_i}{\left[1 + \frac{(R_S + R_D)}{r_d} + g_m R_S \right]}$$

Substituting in eq (2)

$$A_V = \frac{1 - g_m R_D}{\left[1 + \frac{(R_S + R_D)}{r_d} + g_m R_S \right]}$$

Effect of unbypassed R_s on voltage gain

$$A_v = \frac{-g_m R_D}{[1 + (R_D + R_s) / r_d + g_m R_s]}$$

If C_S is used, then it is short circuit $R_S = 0$

$$A_v = \frac{-g_m R_D}{1 + R_D / r_d}$$

$$A_v = -g_m (r_d || R_D)$$

Expression of A_v neglecting the effect of r_d

$$r_d \geq 10(R_D + R_s)$$

Then $A_v \approx \frac{-g_m R_D}{1 + g_m R_s}$

- Q1: For the JFET amplifier shown in the figure, calculate
 i. Z_i ii. A_v iii. V_o when $V_i = 50mV$ (P-P)
 iv. Z_i , A_v , V_o neglecting the effect of r_d .

Sol:

$$\text{Given: } R_g = 2M\Omega$$

$$R_B = 1k\Omega$$

$$R_D = 3.3k\Omega$$

$$V_{DD} = 18V$$

$$I_{DSS} = 8mA$$

$$V_p = -6V$$

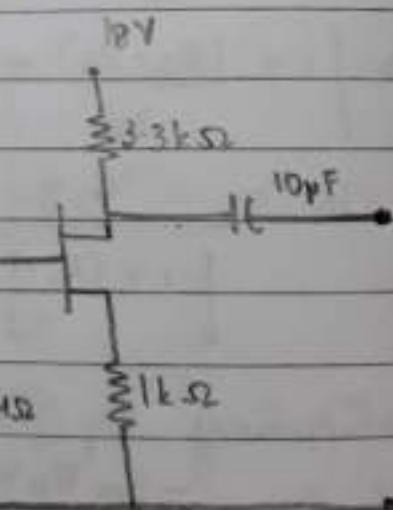
$$I_{DSQ} = 2.5mA$$

$$Y_{OS} = 25\mu s$$

$$\text{i. } Z_i = R_g = 2M\Omega$$

$$\text{ii. } A_v = \frac{-g_m R_D}{1 + (R_D + R_s) / r_d + g_m R_s}$$

$$\frac{1}{r_d} = \frac{1}{g_m R_s} = \frac{1}{g_m \cdot \frac{I_{DSQ}}{V_p}} = \frac{1}{g_m \cdot \frac{2.5 \times 10^{-3}}{-6}} = 1.55ms$$



$$g_m = \frac{-2V_{DSS}}{V_p} = \frac{-2(8)}{-6} = 2.67$$

$$r_d = \frac{1}{g_m Y_{OS}} = \frac{1}{2.67 \times 25 \mu s} = 40k\Omega$$

$$A_V = \frac{-1.59 \times 10^{-5} (3.3 \times 10^5)}{1 + \frac{(3.3k + 1k)}{40k} + (1.59 \times 10^{-5} \times 1 \times 10^3)} = \frac{-5.115}{2.60}$$

$$\underline{A_V = -2.00}$$

iii. V_o when $V_i = 50mV_{(P-P)}$

$$V_o = \frac{-g_m R_d V_i}{[1 + (R_d + R_s) + g_m R_s]}$$

$$V_o = \frac{-(1.59m)(3.3k)(50m)}{[1 + (3.3k + 1k) + (1.59 \times 1k)]}$$

$$\underline{V_o = -96.14mV_{(P-P)}}$$

iv. Neglecting effect of r_d

$$Z_i = R_g = 2M\Omega$$

$$A_V = \frac{-g_m R_d}{1 + g_m R_s} = \frac{-(1.59m)(3.3k)}{1 + (1.59m)(1k)} = \underline{-2.0}$$

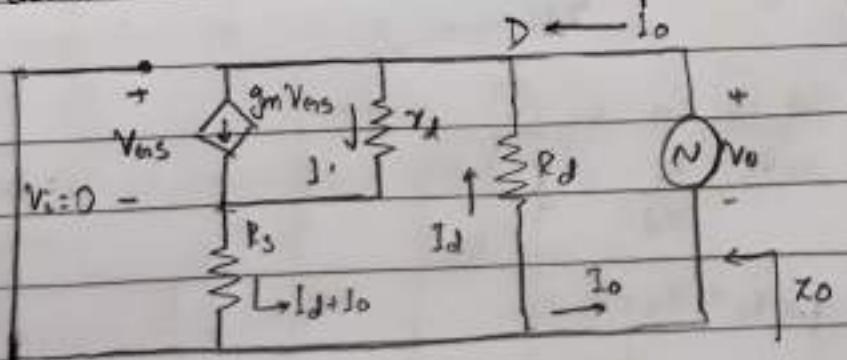
$$V_o = \frac{-g_m R_d V_i}{1 + g_m R_s} = \frac{-(1.59m)(3.3k)(50m)}{1 + (1.59m)(1k)}$$

$$\underline{V_o = -100mV_{(P-P)}}$$

Output Impedance

1. $V_i = 0$

2. connect V_o (source) at the output side of the circuit.



$$Z_0 = \frac{V_0}{I_0} \quad \text{--- (1)}$$

$$V_0 = -I_D R_D$$

Substituting in eq (1)

$$Z_0 = -\frac{I_D R_D}{I_0} \quad \text{--- (2)}$$

At node D applying KCL

$$I_o + I_D - I' - g_m V_{AS} = 0 \quad \text{--- (3)}$$

Applying KVL across γ_d, R_D, R_S

$$-I_D R_D + I' \gamma_d - (I_D + I_o) R_S = 0$$

$$-I' \gamma_d = I_D R_D + (I_D + I_o) R_S$$

$$-I' \gamma_d = I_D R_D + I_D R_S + I_o R_S$$

$$I' = -I_D \left[\frac{R_D + R_S}{\gamma_d} \right] - I_o \frac{R_S}{\gamma_d} \quad \text{--- (4)}$$

Applying KVL at the input side of the circuit

$$-V_{AS} - R_S [I_D + I_o] = 0$$

$$V_{AS} = -R_S [I_D + I_o] \quad \text{--- (5)}$$

Substituting eq (4) and eq (5) in eq (3)

$$I_o + I_D + I_D \left[\frac{R_D + R_S}{\gamma_d} \right] + I_o \frac{R_S}{\gamma_d} + g_m R_S [I_D + I_o] = 0$$

$$I_o \left[1 + \cancel{\frac{R_D + R_S}{\gamma_d}} + \frac{R_S}{\gamma_d} + g_m R_S \right] = -I_D \left[1 + g_m R_S + \frac{R_D + R_S}{\gamma_d} \right]$$

$$\frac{I_D}{I_o} = 1 + g_m R_S + \frac{R_S}{\gamma_d} \quad \text{--- (6)}$$

$$1 + g_m R_S + \frac{R_D + R_S}{\gamma_d}$$

Substituting eq (6) in eq (2)

$$Z_0 = \frac{\left[1 + g_m R_S + \frac{R_S}{\gamma_d} \right]}{\left[1 + g_m R_S + \frac{R_D + R_S}{\gamma_d} \right]} R_D$$

neglecting the effect of r_d

$$Z_0 \approx R_D$$

Q1: continued.

- i. Z_0 ii. Z_0 neglecting the effect of r_d

Sol: i. $Z_0 = \left[\frac{1 + g_m R_s + \frac{R_s}{r_d}}{1 + g_m R_s + \frac{R_D + R_s}{r_d}} \right] R_D$

$$Z_0 = \left[\frac{1 + (1.55m)(1k)}{40k} \right] 3.3k$$

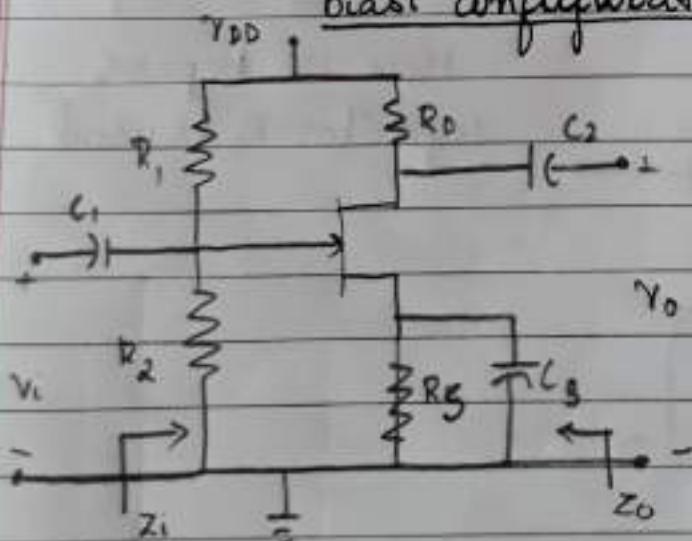
$$\left[1 + (1.55m)(1k) + \frac{3.3k + 1k}{40k} \right]$$

$$Z_0 = \frac{8.4975k}{2.6515}$$

$$\underline{\underline{Z_0 = 3.197k\Omega}}$$

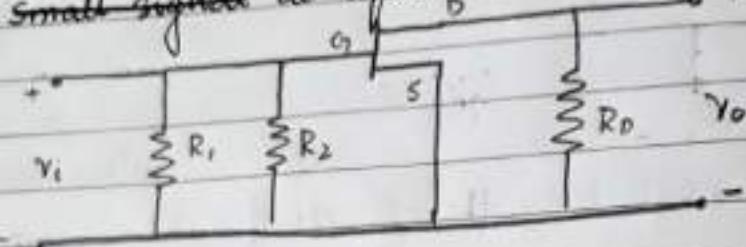
ii. $\underline{\underline{Z_0 \approx R_D = 3.3k\Omega}}$ (neglecting the effect of r_d)

* JFET Common source amplifier using voltage divider bias configuration:

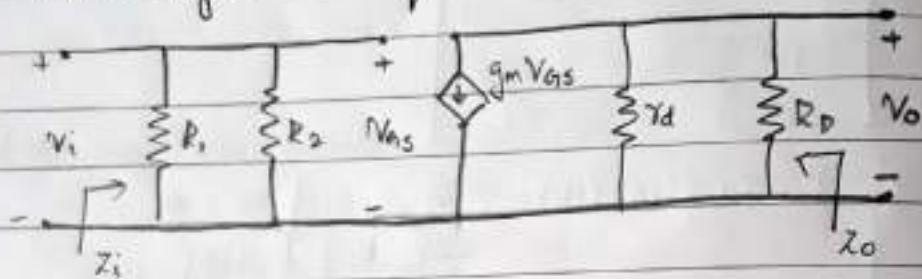


R_1 and R_2 are biasing resistors. C_1 and C_2 are the coupling capacitors. C_S - bypass capacitor.

small signal ac equivalent circuit



small signal ac equivalent circuit



Input impedance

$$Z_i = R_1 \parallel R_2$$

Neglecting the effect of γ_d

$$Z_i = R_1 \parallel R_2$$

Output impedance

$$Z_o = \gamma_d \parallel R_D$$

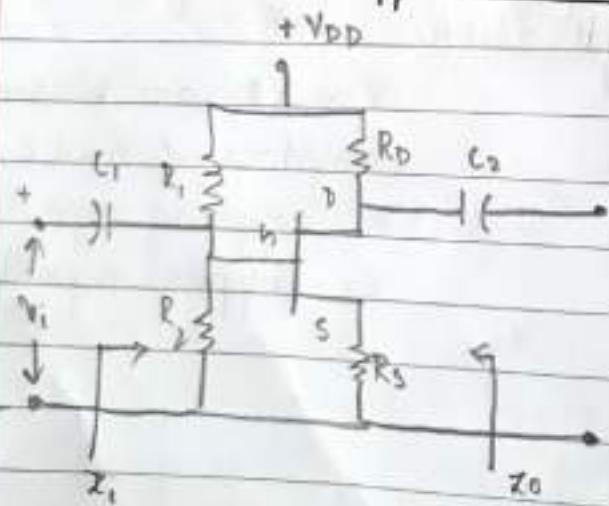
$$Z_o = R_D$$

Gain

$$A_v = -g_m [\gamma_d \parallel R_D]$$

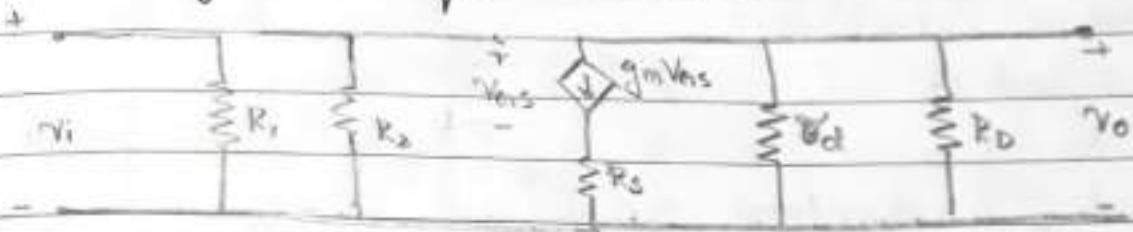
$$A_v = -g_m R_D$$

Without unbypassed R_s



Here no bypass capacitor R_s is used.

small signal ac equivalent circuit



Input impedance

$$Z_i = R_1 \parallel R_2$$

Output impedance

$$Z_o = \left[\frac{1 + g_m R_s + \frac{R_s}{\gamma_d}}{\frac{1 + g_m R_s + R_d + R_s}{\gamma_d}} \right] R_d$$

Gain

$$A_v = \frac{-g_m R_d}{1 + (R_d + R_s) + g_m R_s}$$

Neglecting the effect of γ_d

$$Z_i = R_1 \parallel R_2$$

$$Z_o \approx R_d$$

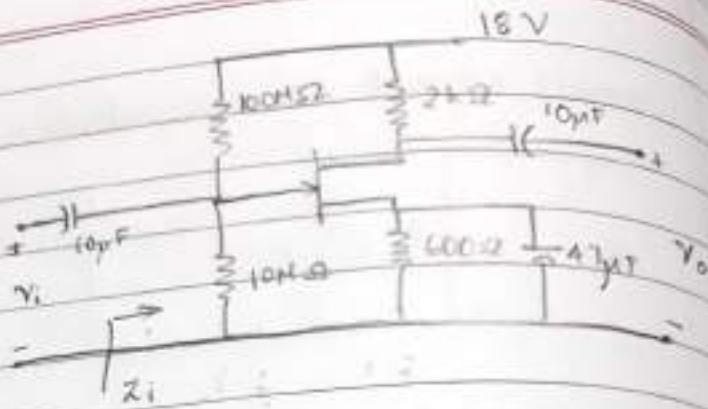
$$A_v = \frac{-g_m R_d}{1 + g_m R_s}$$

- Q1: For a JFET amplifier shown, calculate
 i. Z_i and Z_o
 ii. A_v
 iii. V_o if $V_i = 25\text{mV}$ (rms)

Given:

$$Y_{OS} = 10\mu\text{s} \quad V_{GSQ} = -1\text{V}$$

$$I_{DSS} = 12\text{mA} \quad V_P = -3\text{V}$$



$$\underline{\text{Sol:}} \quad \text{i. } Z_i = R_s \| R_2$$

$$Z_i = \frac{100\text{M} \times 10\text{M}}{(100+10)\text{M}} = \underline{\underline{9.09\text{M}\Omega}}$$

$$Z_o = Y_d \| R_D$$

$$Z_o = \frac{100\text{k} \times 2\text{k}}{(100+2)\text{k}} = \underline{\underline{1.96\text{k}\Omega}}$$

$$Y_d = \frac{1}{Y_{OS}} = \frac{1}{10\mu\text{s}} = 100\text{k}\Omega$$

$$\text{ii. } A_v = -g_m [Y_d \| R_D]$$

$$g_{m0} = \frac{2IDSS}{V_P} = \frac{2(12\text{m})}{3}$$

$$A_v = -5.33\text{m} \left[\frac{100\text{k} \times 2\text{k}}{102\text{k}} \right]$$

$$g_{m0} = 8\text{mS}$$

$$A_v = \underline{\underline{-10.45}}$$

$$g_m = g_{m0} \left[1 - \frac{V_{GS}}{V_P} \right]$$

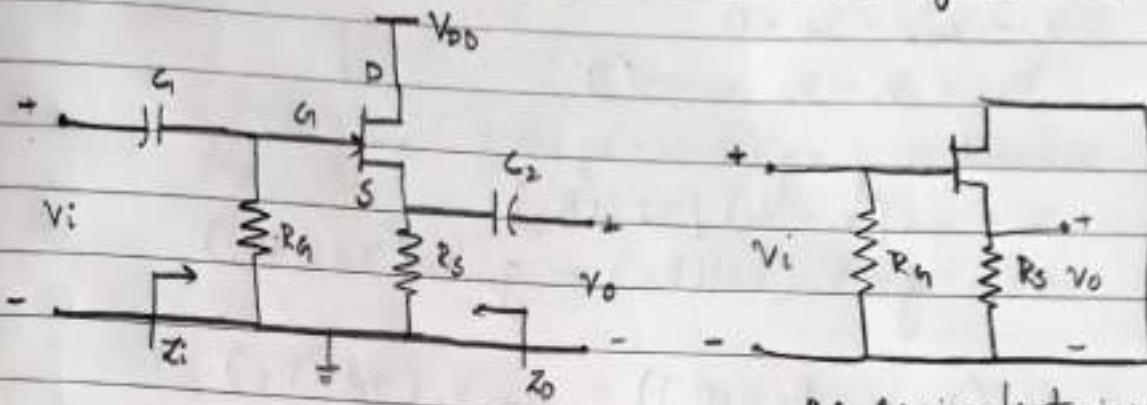
$$\text{iii. } V_o = A_v V_i$$

$$= -10.45 (25\text{m})$$

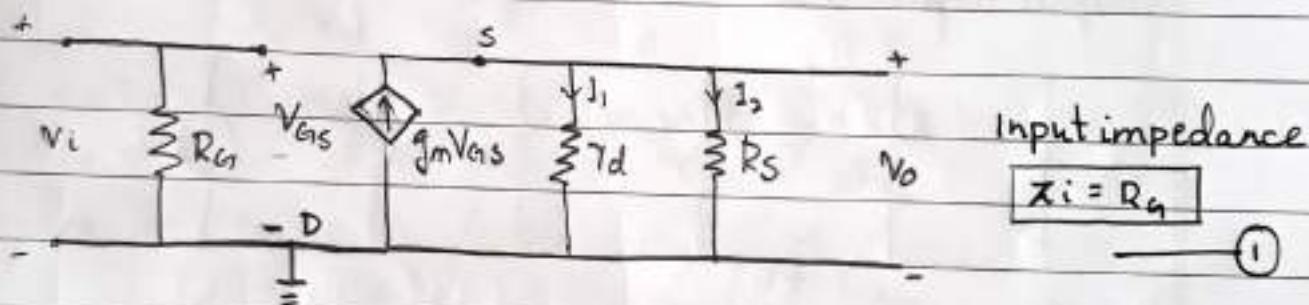
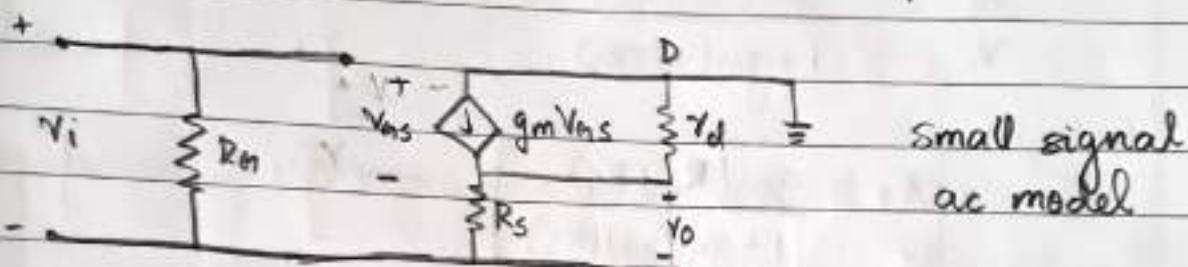
$$g_m = 8\text{m} \left[1 - \frac{1}{3} \right] = \underline{\underline{5.33\text{m}}}$$

$$V_o = \underline{\underline{-261\text{mV}}}$$

JFET Source Follower [common drain configuration]



ac equivalent circuit



Applying KCL at node S.

$$g_m V_{GS} = I_1 + I_2$$

$$g_m V_{GS} = \frac{V_o}{r_d} + \frac{V_o}{R_s}$$

$$g_m V_{GS} = V_o \left[\frac{1}{r_d} + \frac{1}{R_s} \right]$$

$$g_m V_{GS} = V_o \left[\frac{R_s + r_d}{R_s r_d} \right]$$

$$V_o = g_m V_{GS} [R_s || r_d] \quad \text{--- (2)}$$

Applying KVL at input loop.

$$V_i - V_{qs} - V_o = 0$$

$$V_{qs} = V_i - V_o \quad \text{--- (3)}$$

Substituting eq (3) in eq (2)

$$V_o = g_m (V_i - V_o) / (\gamma_d \parallel R_s)$$

$$V_o = g_m V_i (\gamma_d \parallel R_s) - g_m V_o (\gamma_d \parallel R_s)$$

$$V_o (1 + g_m (\gamma_d \parallel R_s)) = g_m V_i (\gamma_d \parallel R_s)$$

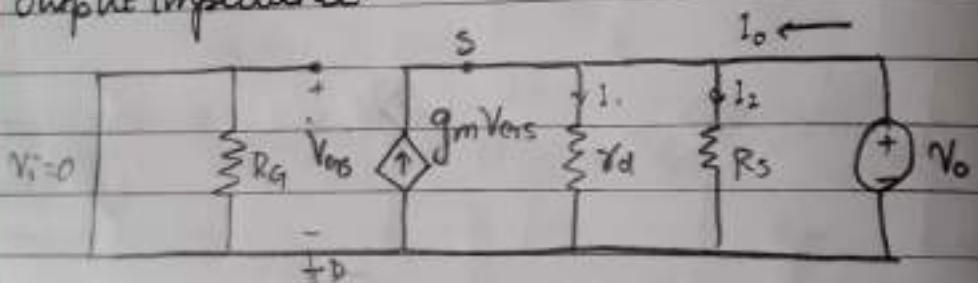
$$\frac{V_o}{V_i} = \frac{g_m (\gamma_d \parallel R_s)}{1 + g_m (\gamma_d \parallel R_s)}$$

$$\frac{V_o}{V_i} = \frac{1}{1 + g_m (\gamma_d \parallel R_s)}$$

Gain:

$$\therefore A_v = \frac{g_m (\gamma_d \parallel R_s)}{1 + g_m (\gamma_d \parallel R_s)} \quad \text{--- (4)}$$

Output impedance:



$$Z_o = \frac{V_o}{I_o} \quad \text{--- (5)}$$

Apply KCL at node S.

$$I_o + g_m V_{qs} = I_1 + I_2$$

$$I_o + g_m V_{qs} = \frac{V_o}{\gamma_d} + \frac{V_o}{R_s}$$

$$I_o + g_m V_{qs} = V_o \left[\frac{1}{\gamma_d} + \frac{1}{R_s} \right] \quad \text{--- (6)}$$

Applying KVL at the input loop.

$$V_i - V_{qs} - V_o = 0$$

$$\text{Since } V_i = 0 \quad V_{qs} = -V_o \quad \text{--- (7)}$$

Substituting eq ⑦ in eq ⑥

$$I_o - g_m V_o = V_o \left[\frac{1}{r_d} + \frac{1}{R_s} \right]$$

$$V_o \left[g_m + \frac{1}{r_d} + \frac{1}{R_s} \right] = I_o$$

$$\frac{V_o}{I_o} = \frac{1}{g_m + \frac{1}{r_d} + \frac{1}{R_s}}$$

$$Z_o = \frac{1}{g_m} || r_d || R_s$$

- Expression of A_v neglecting the effect of r_d

$$A_v = \frac{g_m R_s}{1 + g_m R_s}$$

$$r_d \gg 10R_s \therefore R_s || r_d \approx R_s$$

If $g_m R_s \gg 1$ then $A_v = 1$ (unity)

- Expression for Z_o neglecting the effect of r_d

$$r_d \gg 10R_s \therefore r_d || R_s \approx R_s$$

$$Z_o = \frac{1}{g_m} || R_s$$

If $\frac{1}{g_m} \ll R_s$ then $Z_o \approx \frac{1}{g_m}$

For a JFET common drain configuration shown below.

Calculate:

a. Z_i and Z_o

b. A_v

c. V_o if $V_i = 20mV_{(P-P)}$

d. Z_i , Z_o , A_v and V_o neglecting the effect of r_d

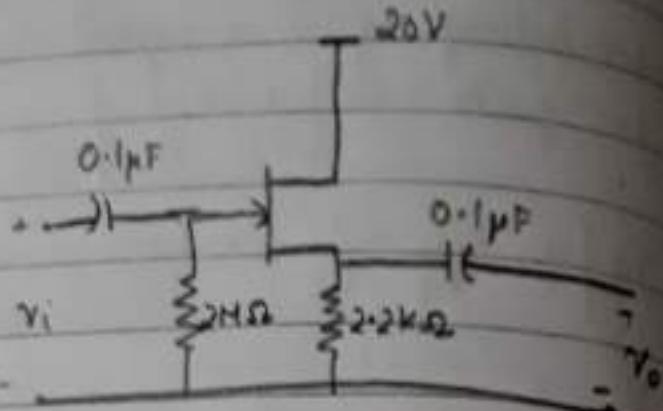
Given:

$$I_{DSS} = 10 \text{ mA}$$

$$V_P = -5V$$

$$\gamma_d = 40 \text{ mV}$$

$$V_{DSQ} = -2.85V$$



Sol: a. $Z_i = R_g = 2M\Omega //$

$$g_{mo} = \frac{2I_{DSS}}{V_P} = \frac{2(10m)}{5} = 4m^-$$

$$Z_o = \frac{1}{g_m} // \gamma_d // R_s$$

$$g_m = g_{mo} \left[1 - \frac{V_{DS}}{V_P} \right]$$

$$\begin{aligned} Z_o &= 0.58k // 40k // 2.2k \\ &= 0.58k // 12.2k \\ &= \frac{0.58k \times 2.2k}{2.58k} \end{aligned}$$

$$g_m = 4m^- \left[1 - \frac{2.85}{5} \right] = 1.72m^-$$

$$\frac{1}{g_m} = 0.58k\Omega$$

$$\underline{Z_o = 0.452k\Omega}$$

b. $A_v = \frac{g_m(\gamma_d // R_s)}{1 + g_m(\gamma_d // R_s)} = \frac{1.72(40k // 2.2k)}{1 + 1.72(40k // 2.2k)}$

$$A_v = \frac{3.586}{4.586} = 0.7818$$

c. V_o if $V_i = 20mV_{CP-P}$

$$V_o = A_v V_i$$

$$= 0.7818(20m)$$

$$\underline{V_o = 15.64mV_{CP-P}}$$

d. Neglecting effect of γ_d

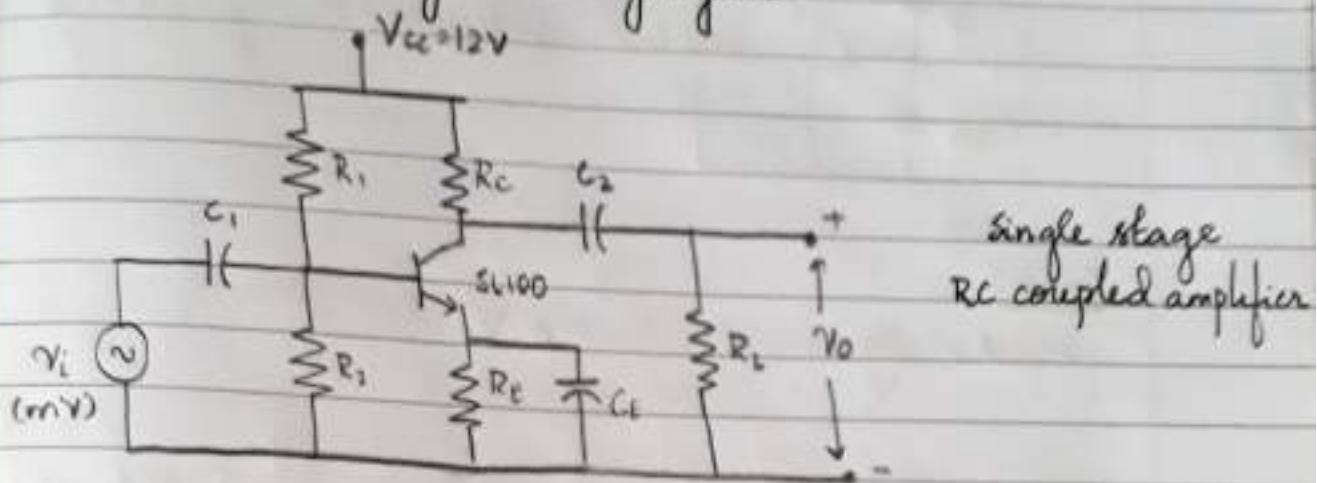
$$Z_i = R_g = 2M\Omega //$$

$$Z_o = \frac{1}{g_m} // R_s = \frac{0.58k \times 2.2k}{2.78k} = 0.458k\Omega$$

$$Av = \frac{g_m R_s}{1 + g_m R_s} = \frac{1.72m(2.2k)}{1 + 1.72m(2.2k)} = 0.79 //$$

$$V_o = Av V_i = 0.79(20m) = 15.8m V_{(pp)} //$$

UNIT - 3

RC coupled Amplifier

R_1 and R_2 - biasing resistors for voltage divider

R_C - improves gain

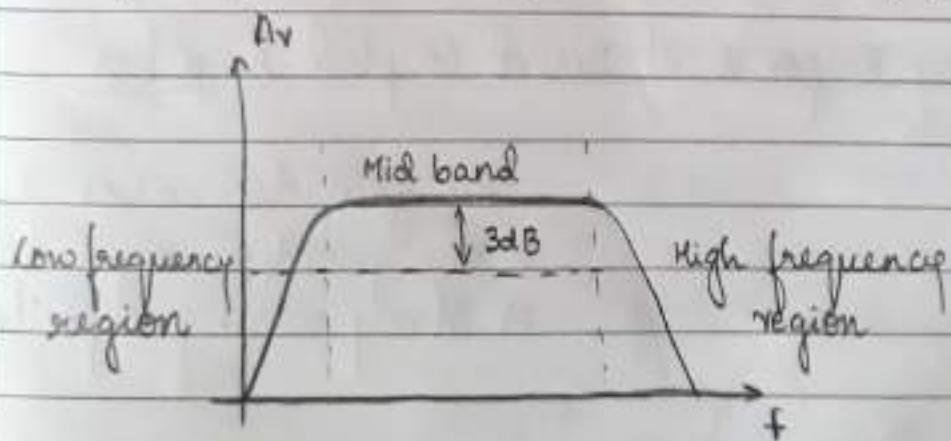
R_E - improves stability

C_1 and C_2 - dc blocking or coupling capacitors

C_E - bypass capacitor.

V_i - in terms of mV

* Frequency Response of RC coupled Amplifier

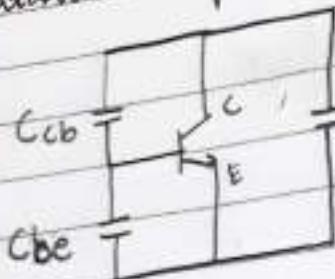


Low frequency region is governed by C_1 , C_2 and C_E .

Mid band region has no role of any capacitor.

High frequency region depends on transit junction capacitor.

or parasitic capacitor or stray wiring capacitor.

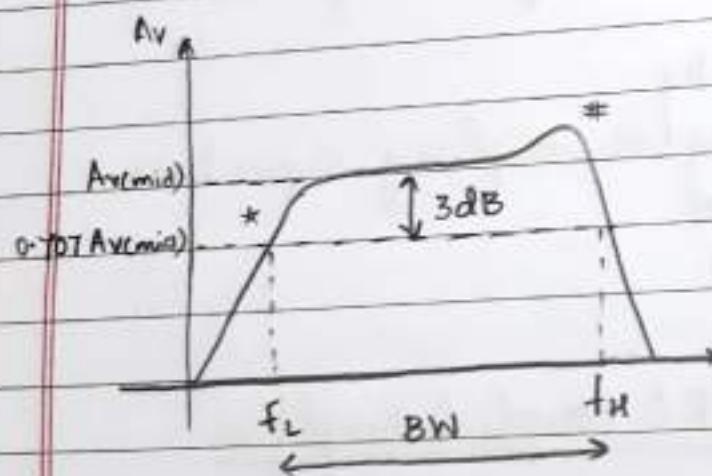


internal capacitance
between the junctions

Gain:

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

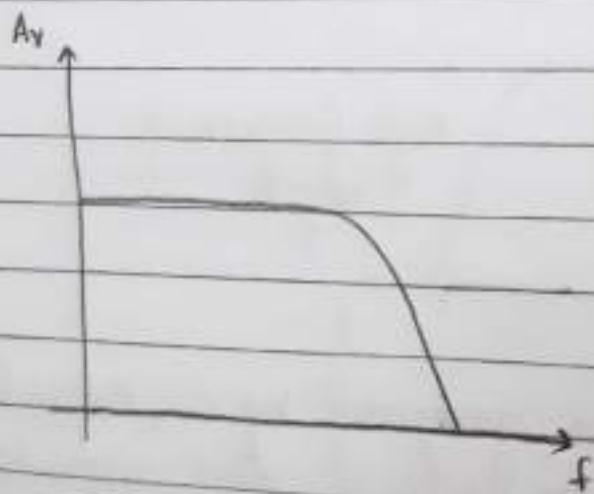
* Frequency Response of Transformer Coupled Amplifier



- * gain keeps increasing due to $X_L = 2\pi f L$ of the transformer drops and remains constant.

- # At high frequency the gain increases due to the turns ratio of the transformer.

* Frequency Response of Direct Coupled Amplifier:



The gain decreases due to the junction capacitance or stray wiring capacitance.

* Half Power frequency and bandwidth:

f_1 - lower cut off frequency

f_2 - higher cut off frequency

Bandwidth

$$BW = f_2 - f_1$$

Gain

$$|Av_l| = \frac{|V_o|}{|V_i|} \Rightarrow |V_o| = |Av_l| |V_i|$$

The output voltage at mid band frequency region

$$|V_o| = |Av_{mid}| |V_i| \quad \text{--- (1)}$$

The output power at mid band frequency region

$$P_o(\text{mid}) = \frac{V_o^2}{R} \quad \text{--- (2)}$$

Substituting eq (1) in eq (2)

$$P_o(\text{mid}) = \frac{(|Av_{mid}| |V_i|)^2}{R}$$

The output voltage at cut off frequency region

$$|V_o| = |0.707 Av_{mid}| |V_i| \quad \text{--- (3)}$$

The output power at cut off frequency region

$$P_o(\text{cut off}) = \frac{V_o^2}{R} \quad \text{--- (4)}$$

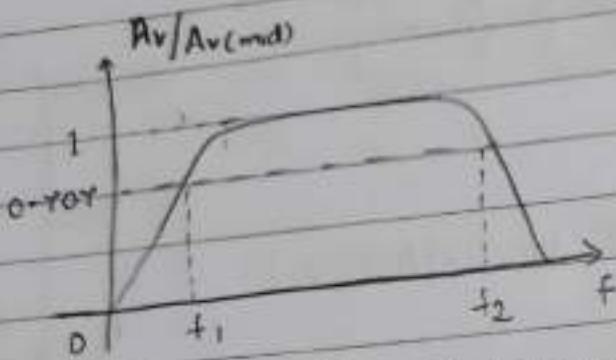
Substituting eq (3) in eq (4)

$$P_o(\text{cut off}) = \frac{(|0.707 Av_{mid}| |V_i|)^2}{R}$$

$$P_o(\text{cut off}) = \frac{0.5 (|Av_{mid}| |V_i|)^2}{R}$$

$$P_o(\text{cut off}) = 0.5 P_o(\text{mid})$$

* Normalised Gain versus Frequency Plot:



$$\text{Normalised Gain} = \frac{Av}{Av(\text{mid})}$$

$$\text{Normalised Midband Gain} = \frac{Av(\text{mid})}{Av(\text{mid})} = 1$$

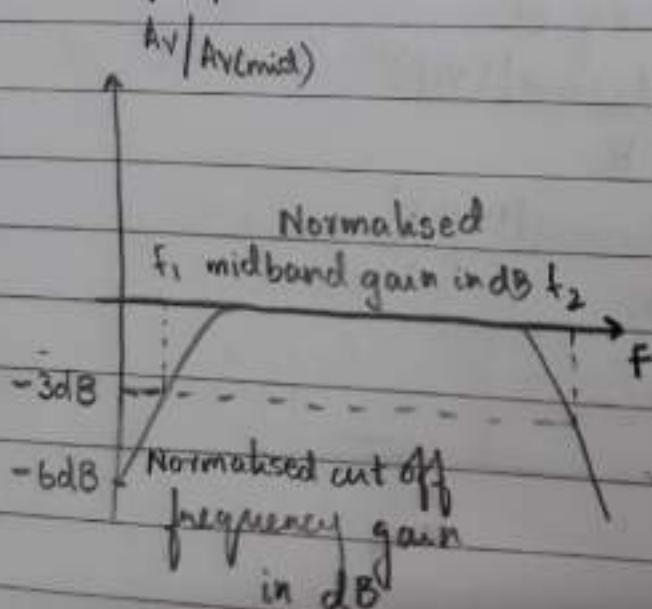
$$\text{Normalised Gain at cut off frequency} = \frac{0.707 Av(\text{mid})}{Av(\text{mid})}$$

* Normalised decibel voltage gain versus frequency:

$$\text{Normalised gain in dB} = \left(\frac{Av}{Av(\text{mid})} \right)_{\text{dB}} = 20 \log_{10} \left(\frac{Av}{Av(\text{mid})} \right)$$

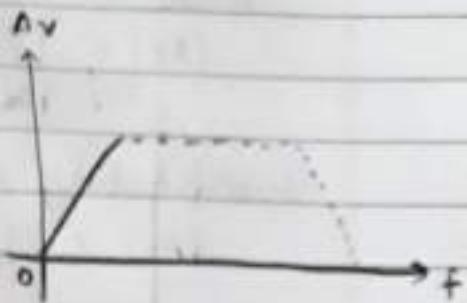
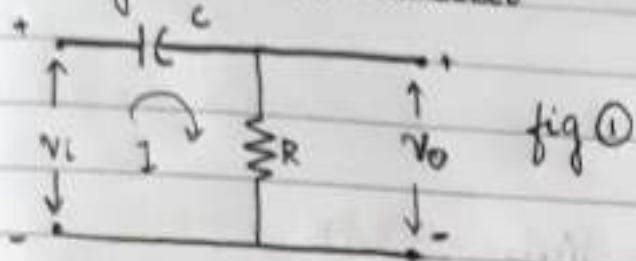
$$\text{Normalised Midband} = 20 \log_{10}(1) = 0 \\ \text{Gain in dB}$$

$$\text{Normalised Gain at cut off frequency in dB} = 20 \log_{10}(0.707) = -3 \text{ dB}$$



Low Frequency Analysis

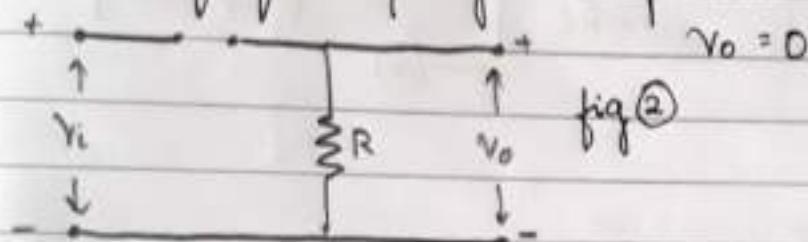
High Pass RC circuit



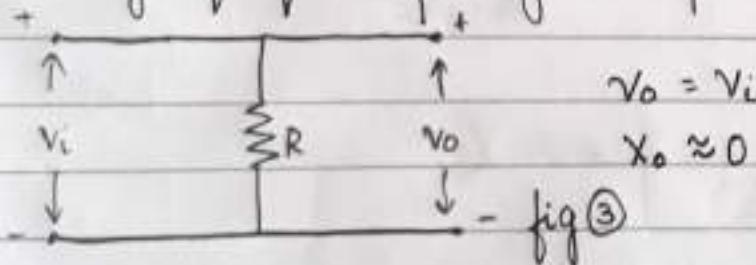
The reactance of the capacitor

$$X_C = \frac{1}{2\pi f C}$$

At low frequency region capacitor acts as open circuit



At high frequency region capacitor acts as short circuit.



Applying voltage divider rule for fig ①

$$V_o = 1R$$

$$I = \frac{V_i}{R - jX_C}$$

$$\therefore V_o = \frac{V_i R}{R - jX_C}$$

if $X_C = R$

$$V_o = \frac{V_i R}{\sqrt{2} R}$$

$$V_o = \frac{V_i}{\sqrt{2}} \quad \text{--- ②}$$

Magnitude of V_o

$$V_o = \frac{V_i R}{\sqrt{R^2 + X_C^2}} \quad \text{--- ①}$$

gain
 $|Av| = \frac{|V_o|}{|V_i|}$

substituting eq. ②
 $|Av| = \frac{|V_o| \sqrt{2}}{|V_i|}$

$|Av| = 0.707$ $|Av|_{dB} = -3dB$

when $X_C = R$
 $\frac{1}{2\pi f C} = R$

$2\pi f C$

$f_b = \frac{1}{2\pi RC}$

Break frequency.

③

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

Substituting eq. ①

$Av = \frac{R}{R-jX_C}$ $Av = \frac{R}{R-jX_C}$

X_C

$Av = \frac{1}{1 - j(X_C/R)}$ ④

$Av = \frac{1}{1 - j\left(\frac{1}{2\pi f C R}\right)}$

From eq. ③

$Av = \frac{1}{1 - j\left(\frac{f_b}{f}\right)}$

Magnitude

$|Av| = \frac{1}{\sqrt{1 + \left(\frac{f_b}{f}\right)^2}}$

$$\text{In dB: } |Av|_{dB} = 20 \log_{10} \left(\frac{1}{\sqrt{1 + (\frac{f_1}{f})^2}} \right)$$

$$|Av|_{dB} = -20 \log_{10} \left[1 + \left(\frac{f_1}{f} \right)^2 \right]^{1/2}$$

$$|Av|_{dB} = -10 \log_{10} \left[1 + \left(\frac{f_1}{f} \right)^2 \right]$$

If $f \ll f_1$

$$\text{then } \left(\frac{f_1}{f} \right)^2 \gg 1$$

$$\therefore |Av|_{dB} = -10 \log_{10} \left[\frac{f_1}{f} \right]^2$$

$$|Av|_{dB} = -20 \log_{10} \left[\frac{f_1}{f} \right]$$

Q: Calculate the gain for frequencies for

$$\text{i. } f = f_1 \quad \text{iii. } f = f_1/4$$

$$\text{ii. } f = f_1/2 \quad \text{iv. } f = f_1/10$$

Sol: i. When $f = f_1$,

$$|Av|_{dB} = -20 \log_{10} \left[\frac{f_1}{f} \right] = -20 \log_{10} 1 = 0 //$$

ii. When $f = f_1/2$

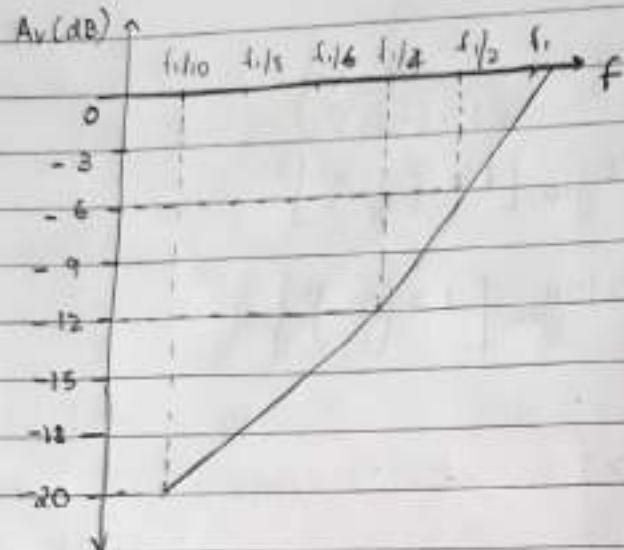
$$|Av|_{dB} = -20 \log_{10} \left[\frac{f_1}{f_1/2} \right] = -20 \log_{10} 2 = -6.02 // \text{dB}$$

iii. When $f = f_1/4$

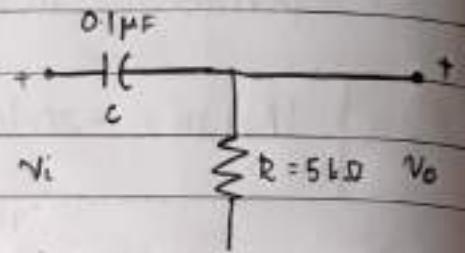
$$|Av|_{dB} = -20 \log_{10} \left[\frac{f_1}{f_1/4} \right] = -20 \log_{10} 4 = -12.04 \text{ dB} //$$

iv. When $f = f_1/10$

$$|Av|_{dB} = -20 \log_{10} \left[\frac{f_1}{f_1/10} \right] = -20 \log_{10} 10 = -20 \text{ dB} //$$



Q: For the network shown in the figure, determine the break frequency.



Sol: Break frequency

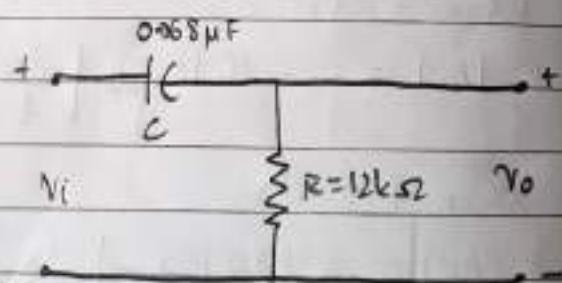
$$f_b = \frac{1}{2\pi RC} = \frac{1}{2\pi(5k)(0.1\mu)} = 318.3 \text{ Hz}$$

Q: For the circuit shown.

Determine:

i. the mathematical

expression for $\frac{|V_o|}{|V_i|} = |A_v|$



ii. calculate the break frequency

iii. calculate $\frac{|V_o|}{|V_i|}$ at 10Hz, 100Hz, 1kHz, 2kHz, 5kHz, 10kHz

iv. Sketch the frequency response of $\frac{|V_o|}{|V_i|}$

v. construct the Bode Magnitude plot.

- v. Sketch the actual frequency response.
 vi. compare the results obtained in iv and v.

i. $|Av| = \frac{|V_o|}{|V_i|} = \left[\frac{1}{1 + (f_b/f)^2} \right]$

ii. Break frequency

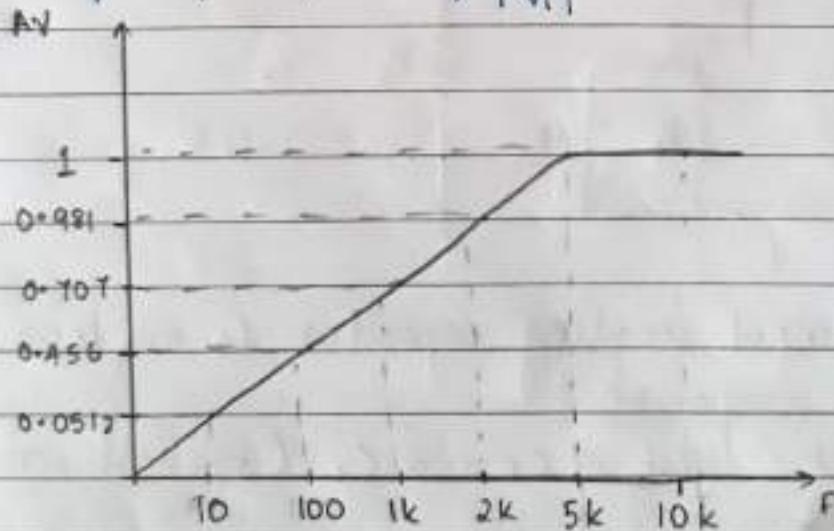
$$f_b = \frac{1}{2\pi RC} = \frac{1}{2\pi(12k)(0.008\mu)} = 195 \text{ Hz}$$

iii. at 10Hz, 100Hz, 1kHz, 2kHz, 5kHz, 10kHz

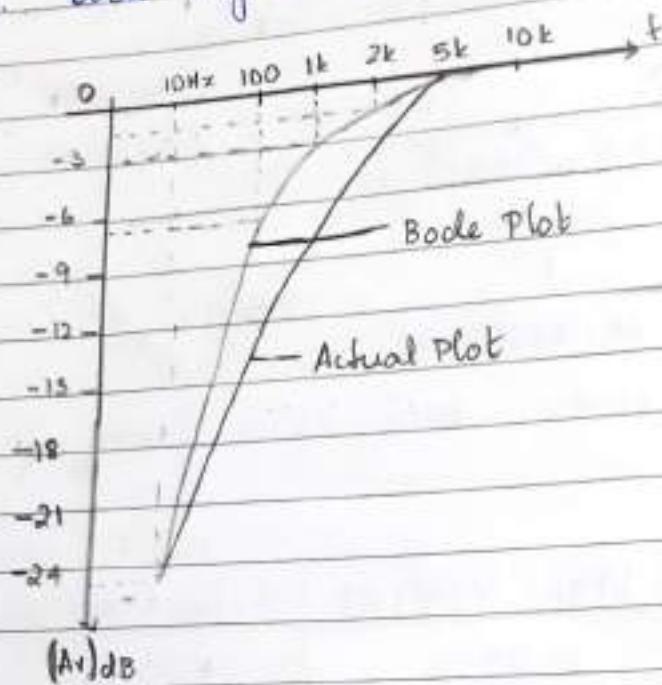
$$\left| \frac{V_o}{V_i} \right| = ?$$

f	f_b/f	$ Av = V_o / V_i $	$ Av _{dB} = 20 \log_{10}(Av)$
10	19.5	0.0512	-25.815
100	1.95	0.0456	-6.82
1k	19.5m	0.000805 ^{0.707}	-3.0000
2k	9.75m	0.000402 ^{0.981}	-0.166
5k	3.9m	0.999	0
10k	1.95m	0.9999999999999999	0

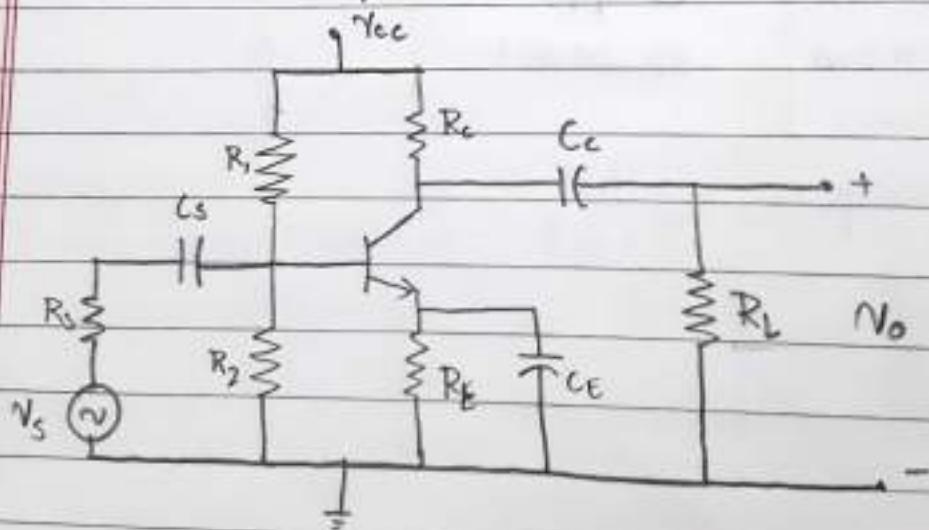
iv. Frequency response of $\frac{|V_o|}{|V_i|}$



v. Bode Magnitude Plot

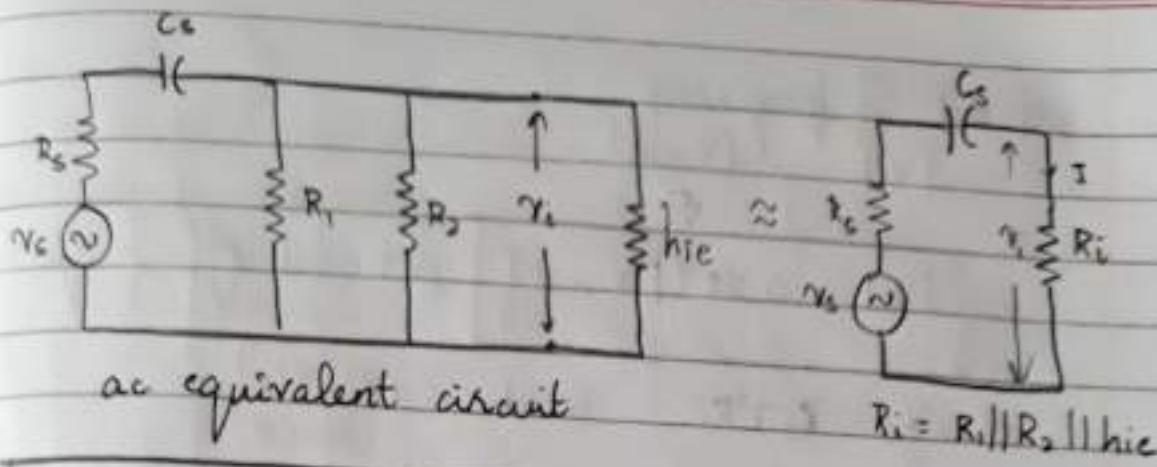


* Low Frequency Response of BJT Amplifier:



Effect of input coupling capacitor C_s on low frequency response

Neglect the effect of C_E and C_c (by short circuiting)



$$R_i = R_1 \parallel R_2 \parallel h_{ie}$$

$$h_{ie} = \beta r_e$$

$$V_i = I R_i$$

$$I = \frac{V_s}{R_i + R_s - j X_{cs}} \quad \text{--- (2)}$$

Substituting eq (2) in eq (1)

$$V_i = \frac{V_s R_i}{R_i + R_s - j X_{cs}}$$

$$V_i = \frac{V_s R_i}{(R_i + R_s) \left[1 - j \frac{X_{cs}}{R_i + R_s} \right]}$$

Dividing by $R_s + R_i$

$$\frac{V_i}{R_s + R_i} = \frac{V_s R_i}{\left[1 - j \frac{X_{cs}}{R_s + R_i} \right]}$$

$$|V_i| = |V_s| \frac{R_i}{R_s + R_i}$$

$$\sqrt{1 + \left(\frac{X_{cs}}{R_s + R_i} \right)^2}$$

In mid band frequency, f is sufficiently large as a result $X_{cs} = 0$.

$$\therefore V_i = \frac{V_s R_i}{R_s + R_i} \quad \text{at mid band.}$$

At cut off frequency

$$|V_i| = \frac{|V_{mid}|}{\sqrt{2}}$$

$$\boxed{|V_i| = 0.707 |V_{mid}|} \quad \text{at cut off frequency}$$

when $X_S = R_S + R_I$ because $1 + \left[\frac{X_{CS}}{R_S + R_I} \right]^2 = \omega^2$

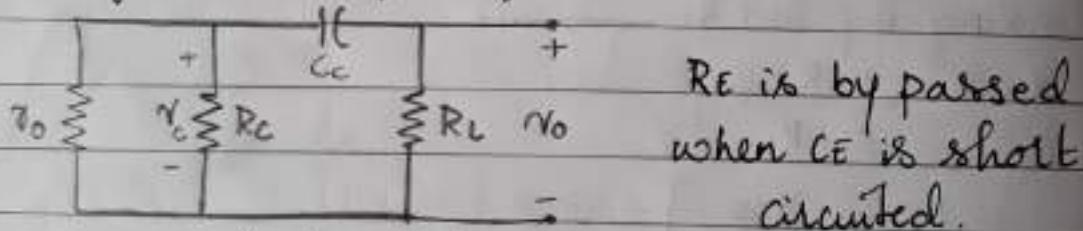
$$\frac{1}{2\pi f_{LS} X_S} = R_S + R_I$$

$$\frac{X_{CS}}{R_S + R_I} = 1 \Rightarrow X_{CS} = R_S + R_I$$

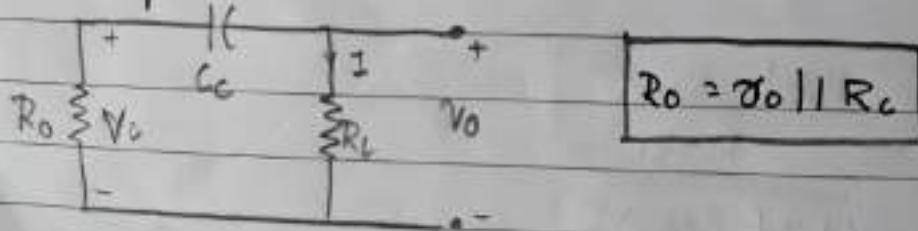
$$\therefore f_{LS} = \frac{1}{2\pi C_S (R_S + R_I)}$$

Effect of output coupling capacitor C_C on low frequency response.

Neglect the effect of C_S and C_E . (by short circuiting)



ac equivalent circuit



$$V_o = I R_L$$

$$I = \frac{V_C}{R_o + R_L - j X_{C_C}}$$

$$\text{--- (1)} \qquad \text{--- (2)}$$

Substituting eq (2) in eq (1)

$$V_o = \frac{V_C R_L}{(R_o + R_L) - j X_{C_C}}$$

$$V_o = \frac{V_c R_L}{(R_0 + R_L) \left[1 - j \frac{X_C}{R_0 + R_L} \right]}$$

dividing by $(R_0 + R_L)$

$$V_o = \frac{V_c R_L}{R_0 + R_L} \left[1 - j \frac{X_C}{R_0 + R_L} \right]$$

$$|V_o| = |V_c| \frac{R_L}{R_0 + R_L} \sqrt{1 + \left(\frac{X_C}{R_0 + R_L} \right)^2}$$

In mid band frequency, f is sufficiently large
 $\therefore X_C \approx 0$

$$\therefore |V_o| = \frac{|V_c| R_L}{R_0 + R_L} \quad \text{at mid band}$$

at cut off frequency

$$|V_o| = \frac{|V_{o \text{ mid}}|}{\sqrt{2}}$$

$$|V_o| = 0.707 |V_{o \text{ mid}}| \quad \text{at cut off frequency}$$

when $X_C = R_0 + R_L$

$$\frac{1}{2\pi f_{LC} C_C} = R_0 + R_L$$

$$\therefore f_{LC} = \frac{1}{2\pi C_C (R_0 + R_L)}$$

Q: For the circuit shown:
Calculate the following:

i. I_E

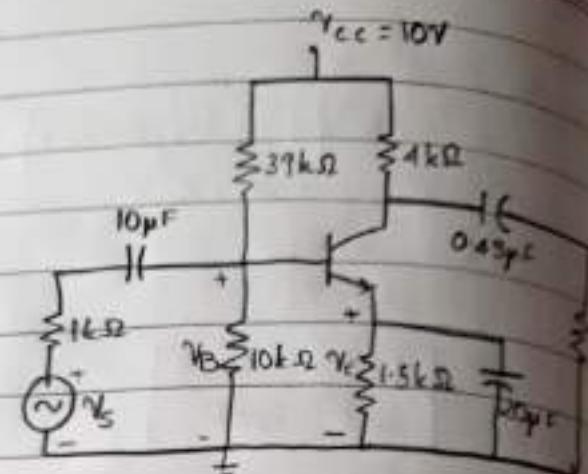
ii. input resistance

iii. mid band voltage gain

$$A_v = \frac{V_o}{V_i} \quad A_{v_s} = \frac{V_o}{V_s}$$

iv. lower cut off frequency
due to C_s .

v. lower cut off frequency due to C_c



$$\beta = 100$$

$$r_o = \infty$$

Sol: i. Calculation of r_e

Voltage divider bias circuit

$$\beta R_b \geq 10 R_2$$

$$100(1.5k) \geq 10(10k)$$

This condition is valid, hence approximate analysis is considered.

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

$$V_B = \frac{10(10k)}{39k + 10k} = 2.04V$$

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

$$V_E = 2.04 - 0.7 = 1.34V$$

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

$$I_E = \frac{1.34}{1.5k} = 0.893mA$$

$$r_e = \frac{26mV}{I_E}$$

$$r_e = \frac{26m}{0.893m} = 29.1\Omega$$

ii. Input resistance

$$R_i = R_1 \parallel R_2 \parallel h_{ie}$$

$$R_i = 39k \parallel 10k \parallel 2.91k$$

$$R_i = 4.96k \parallel 2.91k$$

$$\underline{R_i = 2.13k \Omega}$$

$$h_{ie} = \beta r_e$$

$$h_{ie} = 100(29.1)$$

$$h_{ie} = \underline{\underline{2.91k \Omega}}$$

iii. Midband voltage gain

$$A_v = \frac{V_o}{V_i} = -\frac{R_o \parallel R_L}{r_e}$$

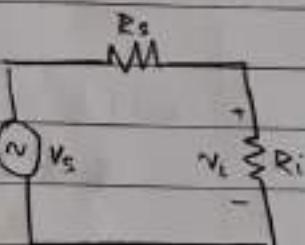
$$R_o = 70 \parallel R_C \therefore R_o = R_C = 4k$$

$$A_v = -\frac{4k \parallel 10k}{29.1} = \underline{-98.183}$$

$$A_{vs} = \frac{V_o}{V_s} = \frac{V_o}{V_i} \times \frac{V_i}{V_s} = \frac{A_v V_i}{V_s}$$

$$\therefore A_{vs} = \frac{A_v V_i}{V_s}$$

$$V_i = \frac{V_s R_i}{R_i + R_s} \Rightarrow V_i = \frac{V_s}{R_i + R_s} R_i$$



$$\therefore A_{vs} = A_v \frac{R_i}{R_i + R_s}$$

$$A_{vs} = (-98.183) \left[\frac{2.13k}{1k + 2.13k} \right] = \underline{-66.81}$$

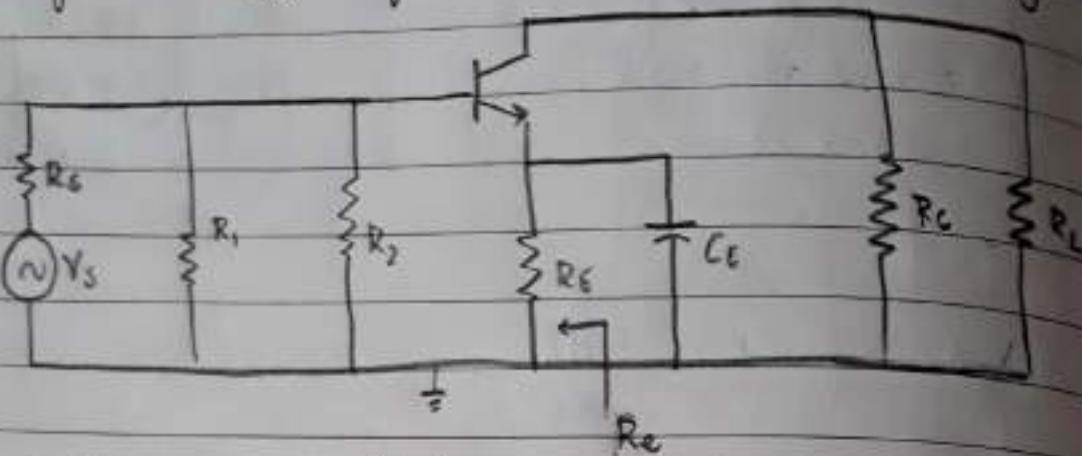
iv. lower cut off frequency due to C_s

$$f_{ls} = \frac{1}{2\pi C_s (R_i + R_s)} = \frac{1}{2\pi (10\mu)(2.13k + 1k)} = \underline{5.1 \text{ Hz}}$$

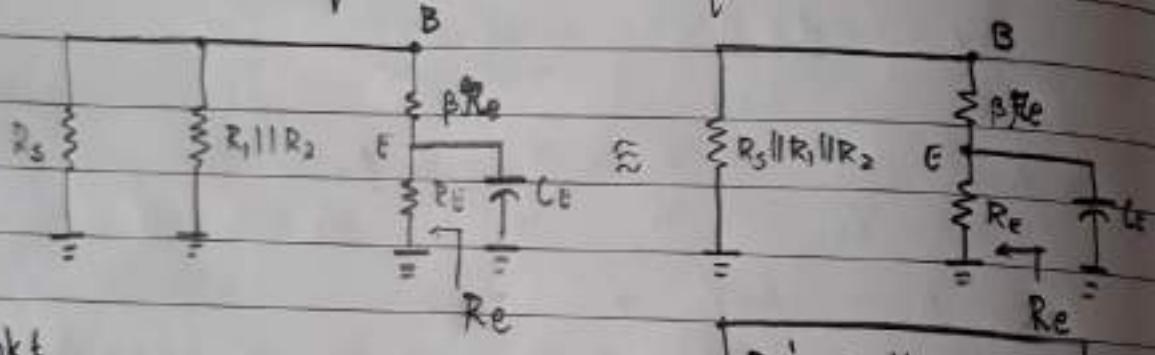
v. lower cut off frequency due to C_c

$$f_{lc} = \frac{1}{2\pi C_c (R_o + R_L)} = \frac{1}{2\pi (0.45\mu)(4k + 10k)} = \underline{25.26 \text{ Hz}}$$

Effect of bypass capacitor C_E on low frequency response
 Neglect the effect of C_S and C_C (by short circuiting)



R_E is the ac equivalent seen by C_E



note

$$I_E \approx I_C = \beta I_B$$

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

$$\underline{\underline{R'_s + \beta R_E}} = I_B$$

$$\therefore \underline{\underline{\frac{R'_s}{\beta} + R_E}} = R_E$$

$$\therefore R_E = R_E \parallel \left[\frac{R'_s}{\beta} + r_E \right]$$

$$\underline{\underline{f_{LE} = \frac{1}{2\pi R_E C_E}}}$$

continued.

vi. lower cut off frequency due to C_o

$$R'_s = R_s \parallel R_1 \parallel R_2$$

$$R'_s = 1k \parallel 39k \parallel 10k$$

$$\underline{R_s = 0.88k\Omega}$$

$$\begin{aligned} R_{e'c'} &= R_e \parallel \left[\frac{R'_s}{B} + r_o \right] \\ &= 1.5k \parallel \left[\frac{0.88k}{100} + 29.1 \right] \\ &= 1.5k \parallel 29.9 \end{aligned}$$

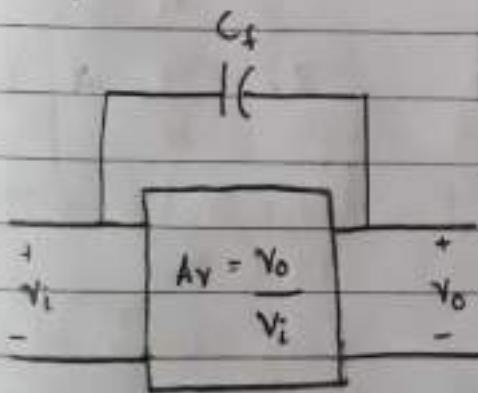
$$\underline{R_e = 37.52}$$

$$f_{LE} = \frac{1}{2\pi R_e C_o}$$

$$f_{LE} = \frac{1}{2\pi(29.1)(20\mu)} = 215 \text{ Hz}$$

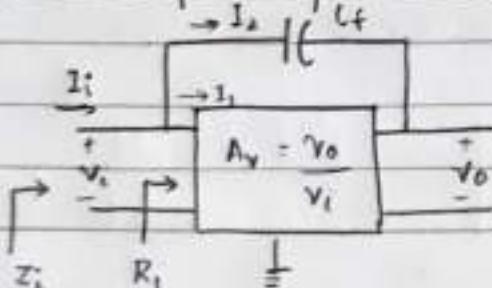
* Miller Effect Capacitance:

Inverting amplifiers with capacitance between input and output nodes.



To find the Miller input capacitance and Miller output capacitance where C_m and C_{mo} are input and output capacitance respectively.

Junction capacitance reduces gain, hence to overcome this Miller capacitance is used.

Miller Input capacitance

$$R_i = \frac{V_i}{I_i} \Rightarrow I_i = \frac{V_i}{R_i}$$

$$X_i = \frac{V_i}{I_i} \Rightarrow I_i = \frac{V_i}{Z_i}$$

$$I_2 = \frac{V_i - V_o}{X_{cf}} = \frac{V_i(1 - A_v)}{X_{cf}}$$

By KCL

$$I_i = I_1 + I_2$$

$$\text{because } V_o = A_v V_i$$

Substituting I_i and I_1 and I_2

$$\frac{V_i}{Z_i} = \frac{V_i}{R_i} + \frac{V_i(1 - A_v)}{X_{cf}}$$

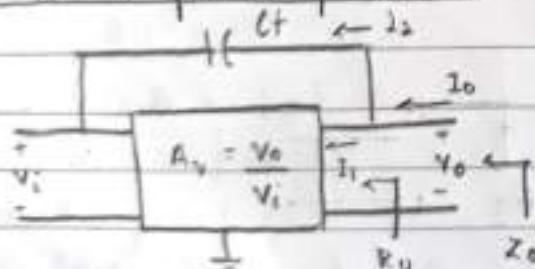
$$\frac{1}{Z_i} = \frac{1}{R_i} + \frac{1 - A_v}{X_{cf}}$$

Here $X_{cf} = X_{cmi}$
 $\frac{1}{1 - A_v}$

$$\frac{1}{Z_i} = \frac{1 - A_v}{2\pi f C_m}$$

$$C_{mii} = (1 - A_v) C_f$$

$$X_{cmi} = \frac{1}{2\pi f C_{mi}}$$

Miller Output capacitance

$$R_o = \frac{V_o}{I_i} \Rightarrow I_i = \frac{V_o}{R_o}$$

$$Z_o = \frac{V_o}{I_o} \Rightarrow I_o = \frac{V_o}{Z_o}$$

$$I_2 = \frac{V_o - V_i}{X_{cf}} = \frac{V_o(1 - 1/A_v)}{X_{cf}}$$

By KCL

$$I_o = I_i + I_2$$

$$\text{because } V_o = A_v V_i$$

Substituting I_i , I_2 , and I_o

$$\frac{V_o}{Z_o} = \frac{V_o}{R_o} + \frac{V_o(1 - 1/A_v)}{X_{cf}}$$

$$\frac{1}{Z_0} = \frac{1}{R_o} + \frac{(1 - 1/A_v)}{X_{C_f}} \quad \text{--- (1)}$$

Here $\frac{X_{C_f}}{1 - 1/A_v} = X_{C_m}$

$$\frac{1}{2\pi f C_f} = \left(1 - \frac{1}{A_v}\right) \frac{1}{2\pi f C_m}$$

$$C_m = \left(\frac{1 - 1}{A_v}\right) C_f$$

R_o is large so neglecting $\frac{V_o}{R_o}$ in eq (1)

$$\frac{1}{Z_0} = \frac{X_{C_f}}{1 - 1/A_v}$$

$$Z_0 = \frac{1}{2\pi f [1 - 1/A_v] C_f}$$

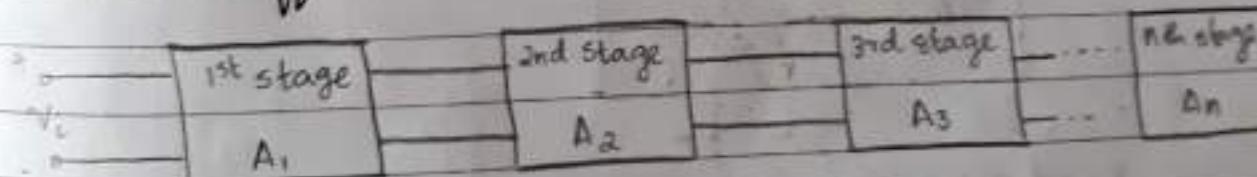
$$Z_0 = \frac{1}{2\pi f C_m}$$

For a noninverting amplifier

$$C_m = (1 + A_v) C_f$$

$$C_m = \left(1 + \frac{1}{A_v}\right) C_f$$

Cascaded Effect:



For low frequency region

$$A_{v(\text{low})}_{\text{overall}} = A_{v_1(\text{low})} A_{v_2(\text{low})} A_{v_3(\text{low})} \dots A_{v_n(\text{low})}$$

wkt $A_{v(\text{low})} = \frac{|A_{v(\text{mid})}|}{\sqrt{1 + (f_i/f)^2}}$



$$\therefore \frac{A_v(\text{low})}{A_v(\text{mid})} = \frac{1}{\sqrt{1 + (f_1/f)^2}} \quad (\text{For single stage})$$

For n stages

$$\left| \frac{A_v(\text{low})}{A_v(\text{mid})} \right|^n = \left[\frac{1}{\sqrt{1 + (f_1/f)^2}} \right]^n \quad \textcircled{1}$$

When for $f = f_{L(n)}$ - cut off frequency

$$\left| \frac{A_v(\text{low})}{A_v(\text{mid})} \right|^n \Big|_{f=f_{L(n)}} = \frac{1}{\sqrt{2}} \quad \textcircled{2}$$

Equating eq. ① and eq. ②

$$\frac{1}{\sqrt{2}} = \left[\frac{1}{\sqrt{1 + (f_1/f_{L(n)})^2}} \right]^n$$

$$\sqrt{2} = \left[\sqrt{1 + \left(\frac{f_1}{f_{L(n)}} \right)^2} \right]^n$$

Squaring on both sides

$$2 = \left[1 + \left(\frac{f_1}{f_{L(n)}} \right)^2 \right]^n$$

$$2^{1/n} = 1 + \left(\frac{f_1}{f_{L(n)}} \right)^2$$

$$\frac{f_1}{f_{L(n)}} = \sqrt{2^{1/n} - 1}$$

$$f_{L(n)} = \frac{f_1}{\sqrt{2^{1/n} - 1}}$$

for $A_v(\text{high})$ wkt $A_v(\text{high}) = \frac{|A_v(\text{mid})|}{\sqrt{1 + (f/f_2)^2}}$

$$\therefore \frac{A_v(\text{high})}{A_v(\text{mid})} = \frac{1}{\sqrt{1 + (f/f_2)^2}} \quad (\text{For single stage})$$

for $A_v(\text{mid})$

for n stages

$$\left| \frac{A_{v(\text{high})}}{A_{v(\text{mid})}} \right|_n = \left[\frac{1}{\sqrt{1 + (f/f_2)^2}} \right]^n \quad \textcircled{3}$$

for $f = f_{H(n)}$ - higher cut off frequency

$$\left| \frac{A_{v(\text{high})}}{A_{v(\text{mid})}} \right|_n \stackrel{f = f_{H(n)}}{=} \frac{1}{\sqrt{2}} \quad \textcircled{4}$$

Equating eq. ③ and eq. ④

$$\frac{1}{\sqrt{2}} = \left[\frac{1}{\sqrt{1 + (f_{H(n)}/f_2)^2}} \right]^n$$

$$\sqrt{2} = \left[\sqrt{1 + \left(\frac{f_{H(n)}}{f_2} \right)^2} \right]^n$$

Squaring on both sides

$$2 = \left[1 + \left(\frac{f_{H(n)}}{f_2} \right)^2 \right]^n$$

$$2^{1/n} = 1 + \left(\frac{f_{H(n)}}{f_2} \right)^2$$

$$f_{H(n)} = f_2 \sqrt{2^{1/n} - 1}$$

An amplifier consists of 3 identical amplifiers cascaded. The bandwidth of overall amplifier extends from 20Hz to 20kHz. Calculate the bandwidth of individual stage.

Given: $n = 3$

$$f_{L(n)} = 20\text{Hz}$$

$$f_{H(n)} = 20\text{kHz}$$

$$f_{L(n)} = \frac{f_1}{\sqrt{2^{1/n} - 1}} \Rightarrow f_1 = f_{H(n)} \sqrt{2^{1/n} - 1}$$

$$f_1 = \frac{20(\sqrt{2^{1/3}} - 1)}{}$$

$$f_1 = 10.196 \text{ Hz}$$

$$f_{H(n)} = f_2 \sqrt{2^{1/n} - 1}$$

$$\therefore f_2 = \frac{f_{H(n)}}{\sqrt{2^{1/n} - 1}}$$

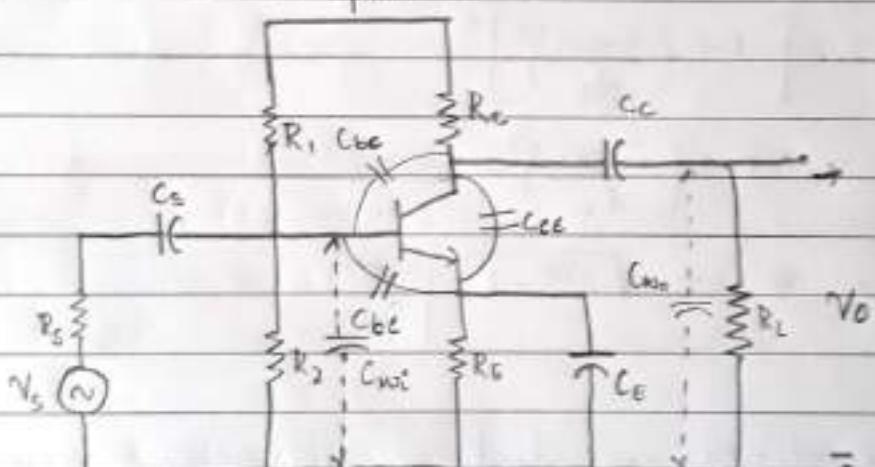
$$f_2 = \frac{20 \times 10^3}{\sqrt{2^{1/3} - 1}}$$

$$f_2 = 39.23 \text{ kHz}$$

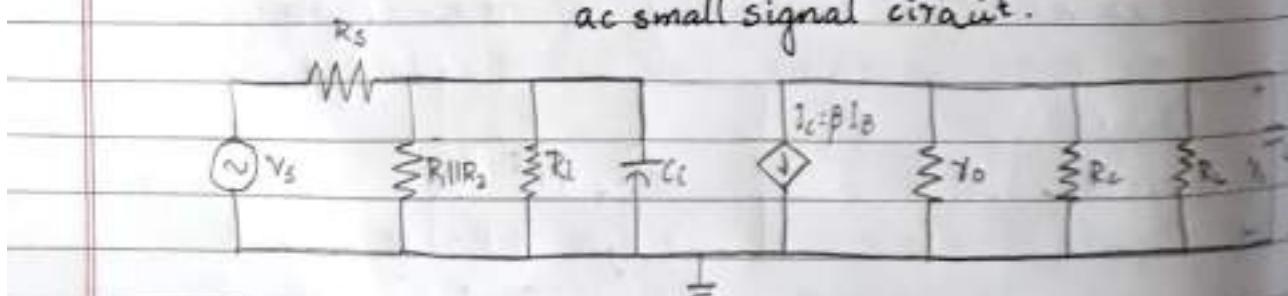
$$BW = 39.23 \text{ kHz} - 10.196 \text{ Hz}$$

$$BW = \underline{\underline{39.22 \text{ kHz}}}$$

* High Frequency Respns. of BJT Amplifier:



ac small signal circuit.



C_{FB}

$$C_j = C_{boi} + C_{ce} + C_{mi}$$

C_{FB}/C_{ce}

$$C_o = C_{bo} + C_{ce} + C_{mo}$$

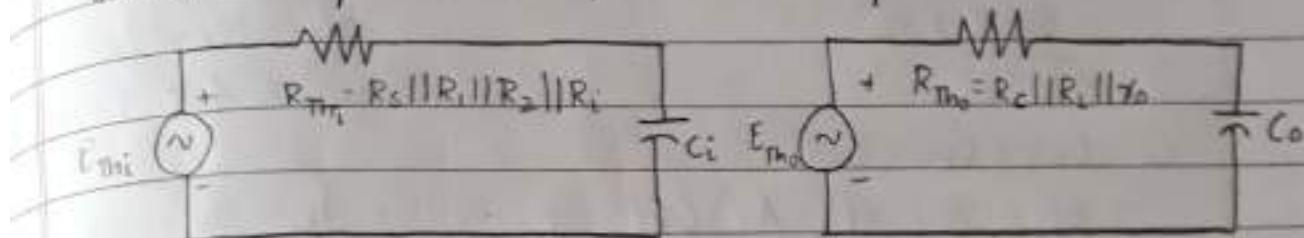
$$\text{wkt } C_{mi} = [1 - A_v] C_f \text{ or}$$

$$\text{Here } C_f = C_{bc} \therefore C_{mi} = [1 - A_v] C_{bc}$$

$$\text{wkt } C_{mo} = [1 - 1/A_v] C_f$$

$$\text{Here } C_f = C_{bc} \therefore C_{mo} = [1 - 1/A_v] C_{bc}$$

Theremin's Equivalent input and output circuit.



$$R_{mi} = R_s || R_1 || R_2 || R_3$$

$$R_{mo} = R_C || R_L || Z_0$$

$$f_{Hi} = \frac{1}{2\pi R_{mi} C_i}$$

$$f_{Ho} = \frac{1}{2\pi R_{mo} C_o}$$

Determine the lower cut off frequency for the network given $\beta = 100$, $Z_0 = \infty$. ~~Ans~~

Determine mid band gain if $C_{be} = 36 \mu F$ and $C_{bc} = 4 \mu F$ and $C_{wi} = 6 \mu F$ and $C_{wo} = 8 \mu F$.

Determine f_{Hi} and f_{Ho} and sketch the frequency response for low and high frequency region using the results.

Assume $C_C = 1 \mu F$

Given: $\beta = 100$

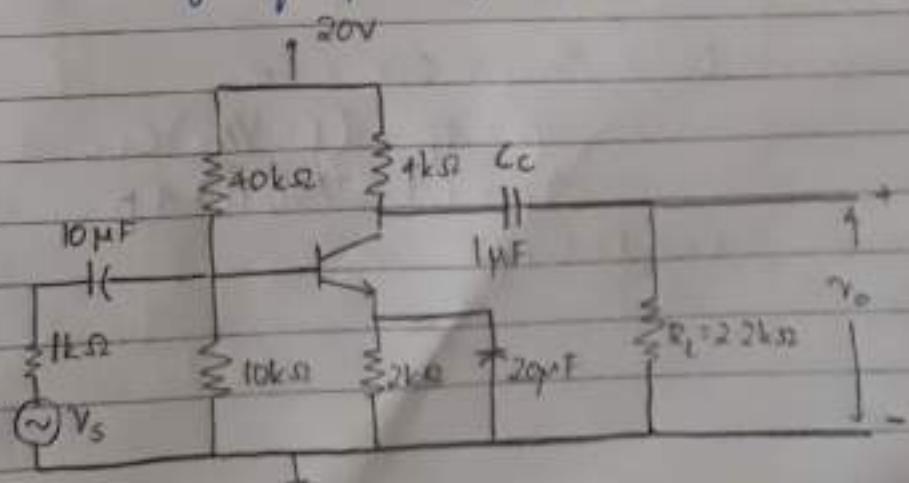
$Z_0 = \infty$

$C_{be} = 36 \mu F$

$C_{bc} = 4 \mu F$

$C_{wi} = 6 \mu F$

$C_{wo} = 8 \mu F$



$$R_i = \beta r_0$$

$$R_i = 100(15 + 5)$$

$$\underline{R_i = 1.575 k\Omega}$$

$$V_e = \frac{26 mV}{I_E}$$

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

$$R_{mi} = R_s || R_1 || R_2 || R_i$$

$$R_{mi} = \frac{1k || 40k || 10k || 1.575k}{= 568.2 \Omega}$$

$$V_B = \frac{10k(20)}{10k + 40k} = 4V$$

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

$$= 4 - 0.7 = 3.3V$$

$$C_i = C_{wi} + C_{be} + C_{mi}$$

$$= 6p + 36p + (1 - A_v) C_{bc}$$

$$= 42p + (1 + 90 \cdot 11) 4p$$

$$\underline{C_i = 406 pF}$$

$$I_E = \frac{V_E}{R_E} = \frac{3.3}{2k} = 1.65 mA$$

$$Y_E = \frac{2Gm}{1.65mA} = 15.75 \Omega$$

$$f_{H_i} = \frac{1}{2\pi R_{mi} C_i}$$

$$= \frac{1}{2\pi (568.2)(406p)}$$

$$\underline{f_{H_i} = 689.91 kHz}$$

$$A_V = -\frac{R_L || R_L}{r_{de}}$$

$$A_V = -\frac{4k || 2.2k}{15.75}$$

$$A_V = -90 \cdot 11$$

$$R_{Tho} = R_C || R_L || \gamma_o$$

$$R_{Tho} = 4k || 2.2k || \infty$$

$$= 1.4193 k\Omega$$

$$f_{H_o} = \frac{1}{2\pi R_{Tho} C_o}$$

$$= \frac{1}{2\pi (1.4193k)(13.04p)}$$

$$= 8.599 MHz$$

$$C_o = C_{wo} + C_{ce} + C_{mo}$$

$$= 8p + 1p + (1 - 1/A_v) C_{bc}$$

$$= 9p + (1 + 1/90 \cdot 11) 4p$$

$$\underline{C_o = 13.04 pF}$$

$$f_{LS} = \frac{1}{2\pi(R_s + R_i)C_s} = \frac{1}{2\pi(1k + 1.515k)10\mu} = 6.87 \text{ Hz}$$

$$= \frac{1}{2\pi(1k + 1.316k)10\mu}$$

$$f_{LS} = 6.87 \text{ Hz}$$

$$f_{LC} = \frac{1}{2\pi(R_o + R_L)C_C}$$

$$= \frac{1}{2\pi(4k + 2.2k)1\mu}$$

$$f_{LC} = 25.67 \text{ Hz}$$

$$R_i = R_1 \parallel R_2 \parallel \beta r_e$$

$$= 40k \parallel 10k \parallel 100(15 + 5)$$

$$= 1.316k \Omega$$

$$R_o = r_o \parallel R_C$$

$$R_o = \infty \parallel 14k$$

$$= 4k \Omega$$

$$R_E = R_E \parallel \left[\frac{R_s'}{\beta} + r_E \right]$$

$$f_{LE} = \frac{1}{2\pi R_E C_E}$$

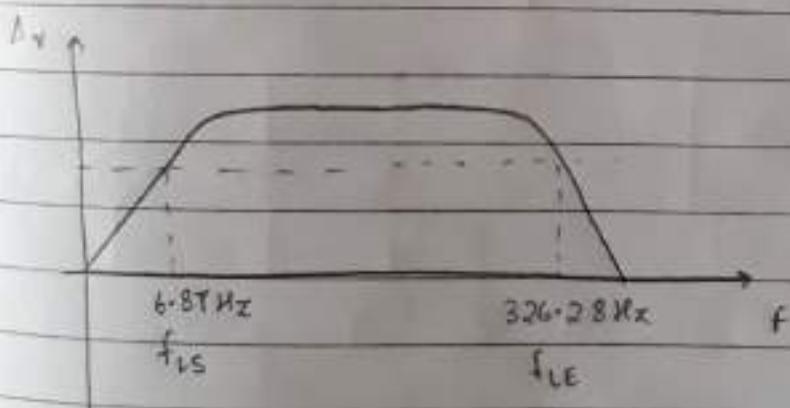
$$= \frac{1}{2\pi(24.3)20\mu}$$

$$f_{LE} = 327.48 \text{ Hz}$$

$$R_s' = R_s \parallel R_1 \parallel R_2 \\ = 1k \parallel 40k \parallel 10k \\ = 888.9 \Omega$$

$$R_E = 2k \parallel \left[\frac{888.9}{100} + 15.45 \right]$$

$$R_E = 24.3 \Omega$$



UNIT - 2

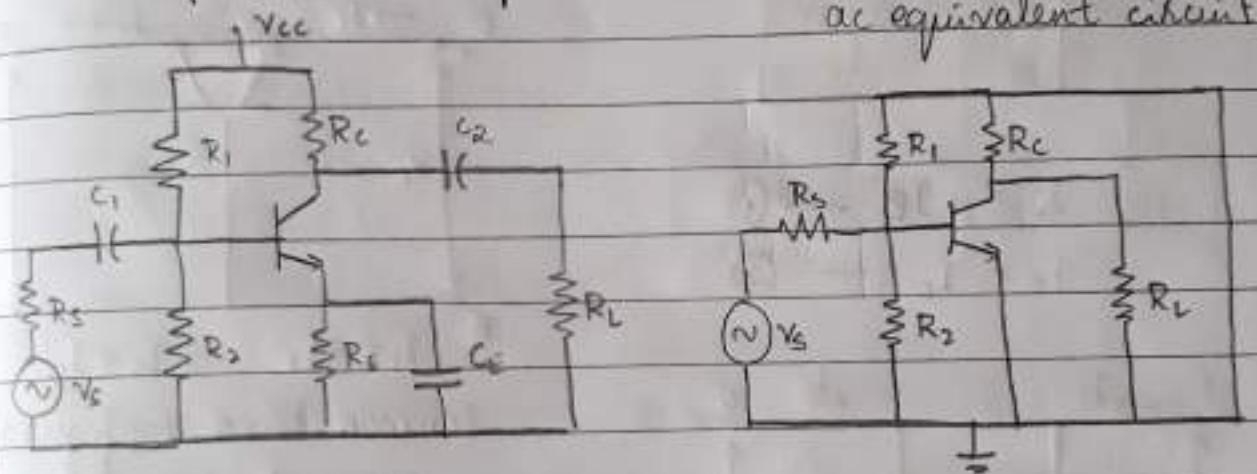
Transistor as Amplifier

dc equivalent circuit

- V_{cc} is grounded (dc source)
- capacitors are short circuited.

dc equivalent circuit

- V_s is grounded (ac source)
- capacitors are open circuited.



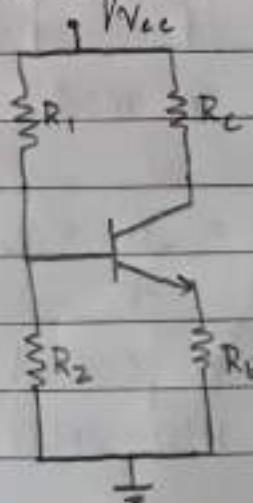
ac equivalent circuit

V_{cc} grounded, C_1, C_2, C_E
are short circuited

dc equivalent circuit

V_s grounded, C_1, C_2, C_E
are open circuited.

dc equivalent circuit



* Modeling of Transistor:

1. γ_e model
 2. hybrid mode
 3. hybrid π model
- } low frequency analysis
} high frequency analysis (SLE)

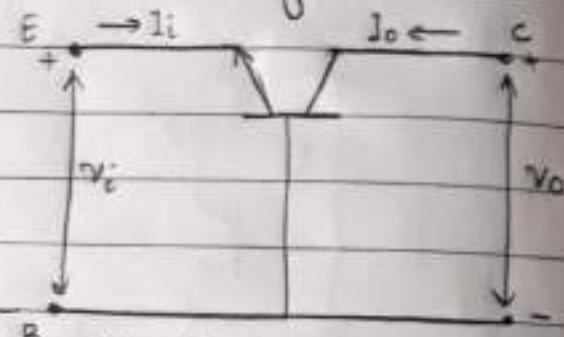
* γ_e Model:

a. γ_e model of a transistor in common base configuration.
ac resistance of transistor in active region

$$\boxed{\gamma_e = \frac{26mV}{I_E}}$$

$$I_i = -I_E \quad \text{--- (1)}$$

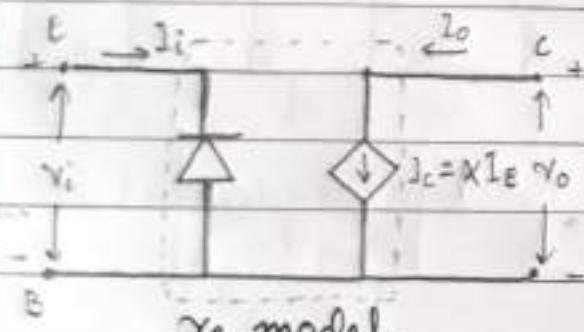
$$I_o = I_c \quad \text{--- (2)}$$



$$I_i = -I_E \quad I_o = I_c$$

common base configuration
current gain

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



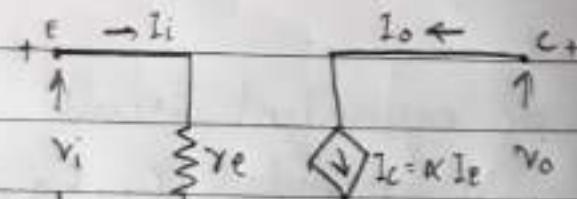
γ_e model

$$I_c = \alpha I_E$$

$$\boxed{Z_i = \frac{V_i}{I_i} = \gamma_e}$$

$$Z_o = \infty \text{ (ideal)}$$

$$Z_o = 1M\Omega - 2M\Omega \text{ (practical)}$$



Z_i γ_e equivalent circuit

$$\boxed{A_v = \frac{v_o}{v_i} = \alpha R_L / \gamma_e}$$

$$\boxed{A_i = \frac{I_o}{I_i} = \frac{-I_E}{I_E} = -\alpha}$$

For a common base configuration $I_e = 4\text{mA}$ and $\alpha = 0.991$. An ac signal of 3mV is applied between base and emitter terminal if $R_L = 610\Omega$ calculate:

i. r_e and Z_i

ii. A_v and A_i

iii. V_o, I_i, I_o

iv. Z_o with $r_o = \infty$ and I_c, I_e, I_b .

$$i. r_e = \frac{26\text{mV}}{I_e} = \frac{26\text{mV}}{4\text{mV}} = \underline{\underline{6.5\Omega}}$$

$$Z_i = r_e = \underline{\underline{6.5\Omega}}$$

$$ii. A_v = \frac{\alpha R_L}{r_e} = \frac{0.991(610)}{6.5} = \underline{\underline{93}}$$

$$A_i = -\alpha = \underline{\underline{-0.991}}$$

$$iii. V_o = A_v V_i = 93(3\text{m}) = \underline{\underline{249\text{mV}}}$$

$$I_i = \frac{V_i}{Z_i} = \frac{3\text{m}}{6.5} = \underline{\underline{461.5\mu\text{A}}}$$

$$I_o = A_i I_i = (-0.991)(461.5\mu\text{A}) = \underline{\underline{-457.34\mu\text{A}}}$$

$$iv. Z_o = r_o = \infty //$$

$$I_i = -I_e \Rightarrow I_e = -461.5\mu\text{A} //$$

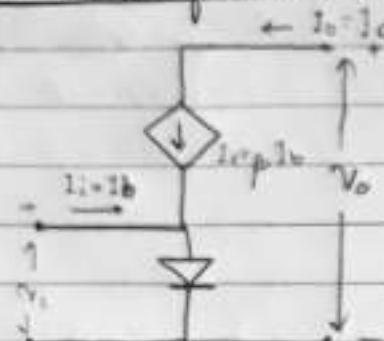
$$I_o = I_c \Rightarrow I_c = -457.34\mu\text{A} //$$

$$I_e = I_c + I_b$$

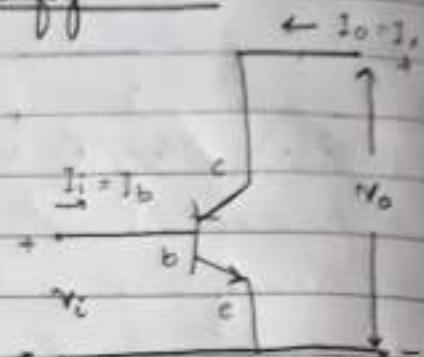
$$I_b = I_e - I_c = -461.5\mu\text{A} - (-457.34\mu\text{A})$$

$$I_b = \underline{\underline{-4.15\mu\text{A}}}$$

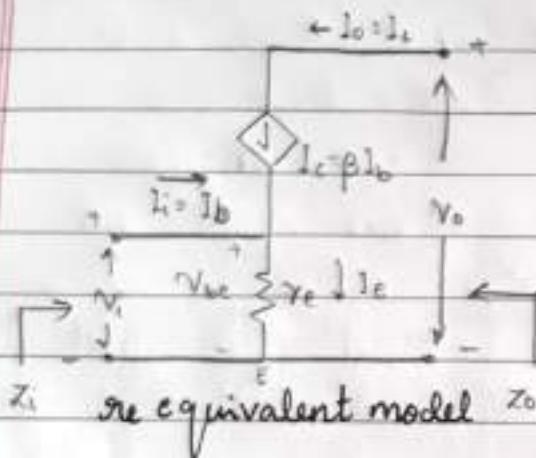
b. re model for common Emitter configuration:



re model



Common emitter configuration



re equivalent model

$$V_i = V_{bc} = I_e \gamma_e$$

$$I_e = I_b + I_c$$

$$I_e = I_b + \beta I_b$$

$$I_e = I_b(1 + \beta)$$

$$I_e \approx \beta I_b$$

$$Z_i = \frac{V_i}{I_i} = \frac{\beta I_b r_e}{\beta I_b}$$

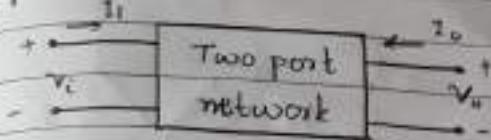
$$Z_o = 40k \text{ to } 50k \Omega$$

$$Z_i = \beta r_e$$

$$A_v = -\frac{R_L}{r_e}$$

$$A_i = \frac{I_o}{I_i} = \frac{I_c}{I_b} = \frac{\beta I_b}{I_b}$$

$$A_i = \beta$$

Hybrid model:h parameter

$$V_i = h_{11}I_i + h_{12}V_o$$

$$I_o = h_{21}I_i + h_{22}V_o$$

V_i, I_o : dependent variable
 I_i, V_o : independent variable

$$V_i = f_1(I_i, V_o)$$

$$I_o = f_2(I_i, V_o)$$

$$h_{11} = \left. \frac{V_i}{I_i} \right|_{V_o=0} \text{ ohms}$$

$$h_{12} = \left. \frac{V_i}{V_o} \right|_{I_i=0}$$

$$h_{21} = \left. \frac{I_o}{I_i} \right|_{V_o=0}$$

$$h_{22} = \left. \frac{I_o}{V_o} \right|_{I_i=0} \text{ mho}$$

$$V_i = h_{11}I_i + h_{12}V_o$$

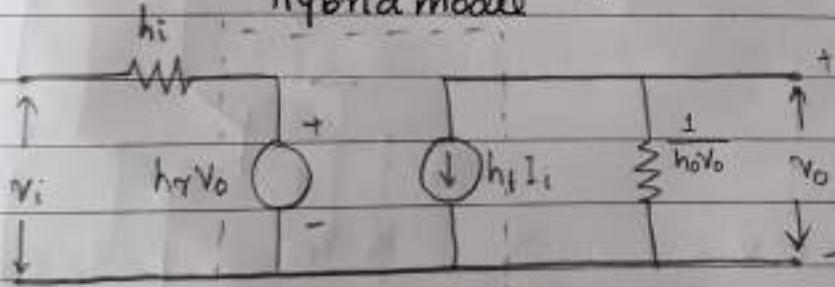
$$I_o = h_{21}I_i + h_{22}V_o$$

$h_{11} = h_i \Rightarrow$ voltage drop across impedance ($h_i I_i$)

$h_{12} = h_r \Rightarrow$ controlled voltage source ($h_r V_o$)

$h_{21} = h_f \Rightarrow$ controlled current source ($h_f I_i$)

$h_{22} = h_o \Rightarrow$ current through admittance ($h_o V_o$)

Hybrid modelHybrid parameter nomenclature for transistors

<u>h parameter</u>	CB	CE	CC
h_i	h_{ib}	h_{ie}	h_{ic}
h_r	h_{rb}	h_{re}	h_{rc}
h_f	h_{fb}	h_{fe}	h_{fc}
h_o	h_{ob}	h_{oe}	h_{oc}

a. Hybrid model for common base configuration

$$V_i = V_{be}$$

$$I_i = I_e$$

$$V_o = V_{cb}$$

$$I_o = I_c$$

$$\text{wkt } V_i = h_f I_i + h_r V_o$$

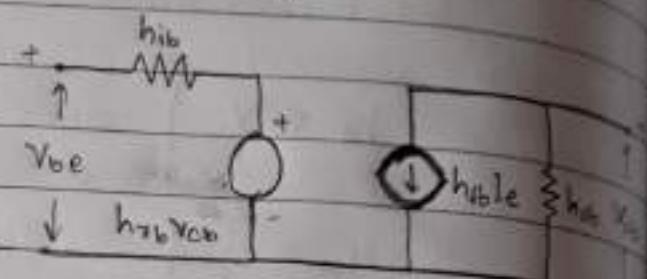
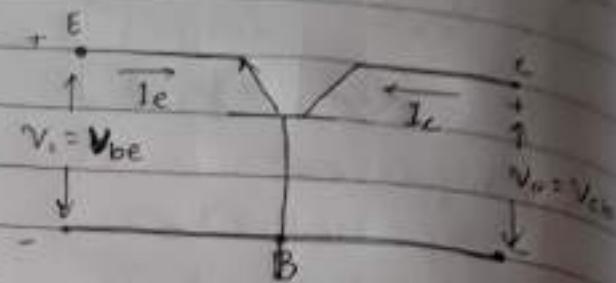
$$V_{be} = h_{fb} I_e + h_{rb} V_{cb}$$

$$\text{wkt } I_o = h_f I_i + h_o V_o$$

$$I_c = h_{fb} I_e + h_{rb} V_{cb}$$

$$h_{fb} = \frac{V_{be}}{I_e}, \quad h_{rb} = \frac{V_{be}}{V_{cb}}$$

$$h_{fb} = \frac{I_c}{I_e}, \quad h_{rb} = \frac{I_c}{V_{cb}}$$



b. Hybrid model for common emitter configuration:

$$V_i = V_{be}$$

$$I_i = I_b$$

$$V_o = V_{ce}$$

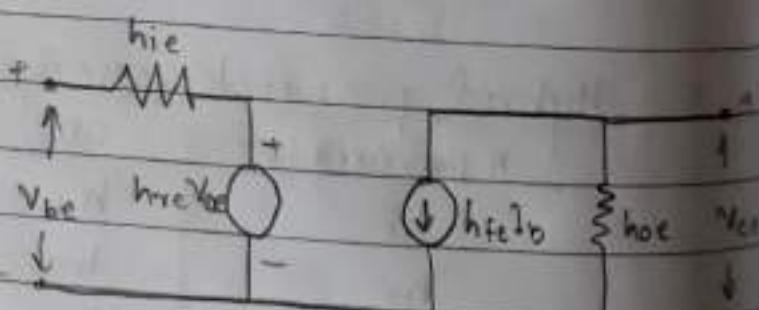
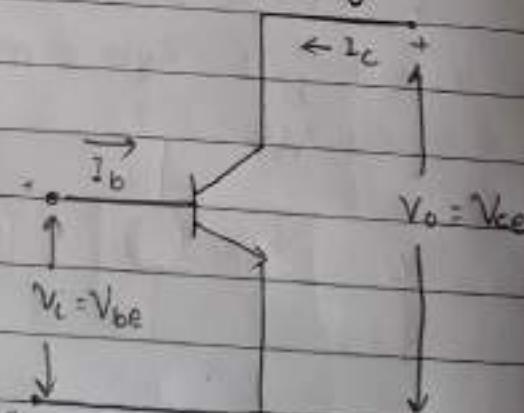
$$I_o = I_c$$

$$\text{wkt } V_i = h_{ie} I_i + h_{re} V_o$$

$$V_{be} = h_{ie} I_b + h_{re} V_{ce}$$

$$\text{wkt } I_o = h_f I_i + h_o V_o$$

$$I_c = h_{fe} I_b + h_{oe} V_{ce}$$



$$h_{ie} = \frac{V_{be}}{I_b}, \quad h_{re} = \frac{V_{be}}{V_{ce}}$$

$$h_{fe} = \frac{I_c}{I_b}, \quad h_{oe} = \frac{I_c}{V_{ce}}$$

Hybrid model for common collector configuration:

$$v_i = V_{bc}$$

$$i_i = I_b$$

$$v_o = V_{ec}$$

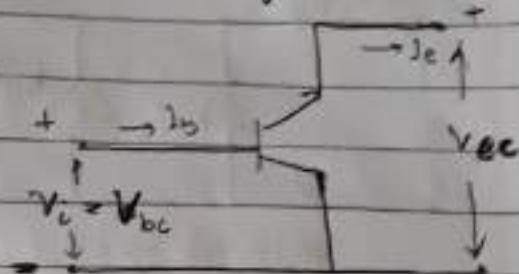
$$i_o = I_e$$

$$\text{wkt } v_i = h_i i_i + h_r v_o$$

$$V_{bc} = h_{ic} I_b + h_{rc} V_{ec}$$

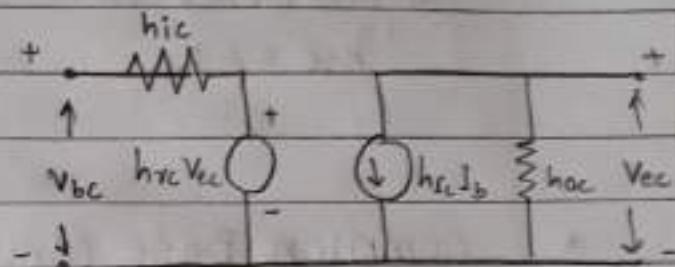
$$\text{wkt } i_o = h_f i_i + h_o v_o$$

$$I_e = h_{fc} I_b + h_{oc} V_{ec}$$



$$h_{ic} = \frac{V_{bc}}{I_b}, \quad h_{rc} = \frac{V_{be}}{V_{ec}}$$

$$h_{fc} = \frac{I_e}{I_b}, \quad h_{oc} = \frac{I_e}{V_{ec}}$$



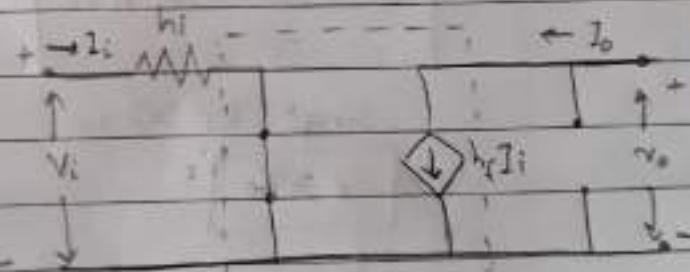
* Approximate Hybrid Equivalent Circuit:

$$h_r = 0.25 m$$

h_r is very low, hence it is short circuited.

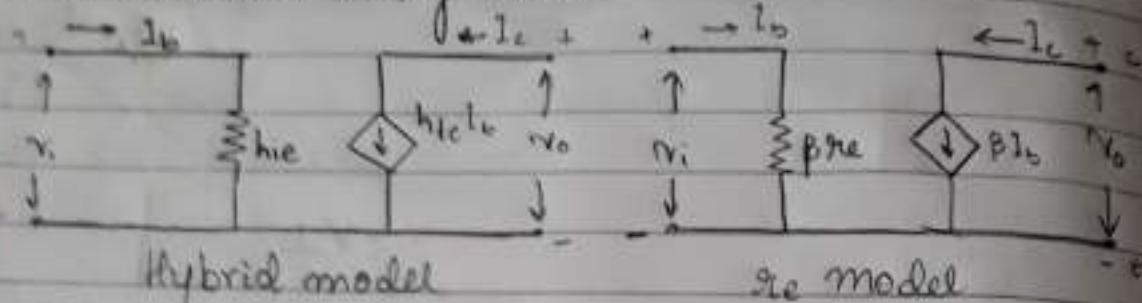
$$h_o = 40 k\Omega - M\Omega$$

When h_o parallel with R_L , since R_L is small, h_o is neglected hence open circuited.



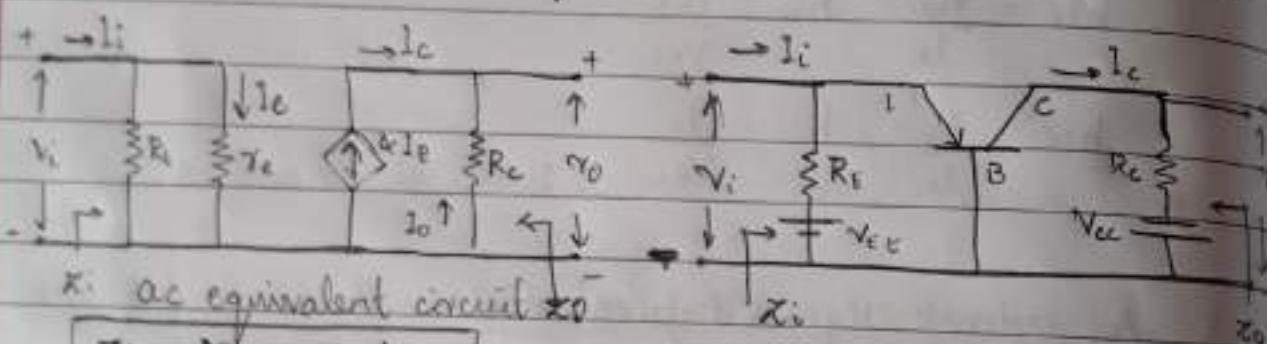
* Relationship between hybrid model and re model:
approximate hybrid equivalent circuit is considered.

common Emitter Configuration



$$h_{ie} = \rho r_e$$

$$h_{fe} = \beta$$

★ Common Base Configuration:

$$Z_i = \frac{V_i}{I_i} = R_E \parallel r_E$$

Since $R_E \gg r_E$

$$Z_i \approx r_E$$

For Z_o

$$V_i = 0 \Rightarrow I_i = 0 \Rightarrow I_E = 0$$

then $I_C = 0 \therefore I_C = \alpha I_E = 0$
(open circuit)

$$Z_o = R_C$$

Gain

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

$$\Rightarrow V_o = -I_o R_C$$

$$\text{Since } I_o = -I_C$$

$$V_o = I_C R_C$$

$$\Rightarrow V_i = I_i (R_E \parallel r_E)$$

$$V_i = I_i r_E$$

$$\text{Since } I_i = I_E$$

$$V_i = I_E r_E$$

$$V_i = \frac{I_C r_E}{\alpha} \quad (\because I_C = \alpha I_E)$$

$$A_V = \frac{\alpha R_C}{r_E}$$

$$\text{If } \alpha = 1 \quad A_V = \frac{R_C}{r_E}$$

~~Av = Since $r_e \gg R_e$~~

$$\Rightarrow I_e \approx I_i \quad I_o \approx -I_e$$

$$A_I = \frac{I_o}{I_i} = \frac{-I_e}{I_e} = -\alpha \frac{I_e}{I_e}$$

$$A_I = -\alpha$$

Important characteristics of common base configuration.

- Input impedance

$$Z_i = r_e \Rightarrow \text{low input impedance.}$$

- Gain

$$A_V = \frac{R_c}{r_e} \Rightarrow \text{high voltage gain}$$

- Current gain

$$A_I = -\alpha \Rightarrow \text{approximately unity}$$

- Output impedance

$$Z_o = R_c \Rightarrow \text{high output impedance}$$

Applications of common base re model:

Used for impedance matching

(Couples low impedance current source with high impedance load)

Q: For a common base configuration shown below, calculate

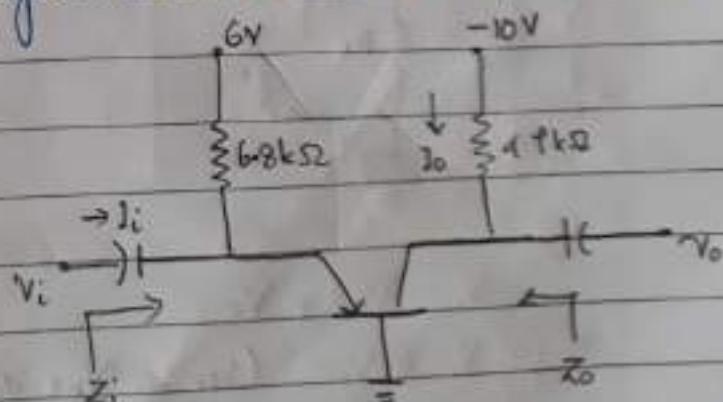
a. r_e

b. Z_i and Z_o

c. A_V and A_I

Take $\beta = 499$

and $r_o = 1M\Omega$



Sol:

$$V_{EE} = 6V \quad I_E = \frac{V_{EE} - V_{BE}}{R_E} = \frac{6 - 0.7}{6.8k} = 0.78mA$$

$$V_{CC} = -10V$$

$$i. \quad r_e = \frac{26mV}{I_E} = \frac{26m}{0.78m} = 33.33\Omega$$

$$ii. \quad Z_i = R_E \parallel r_e \\ = 6.8k \parallel 33.33 \\ Z_i = \underline{\underline{33.33\Omega}}$$

$$Z_o = R_C$$

$$Z_o = \underline{\underline{4.7k\Omega}}$$

$$iii. \quad A_v = \frac{r_e R_C}{g_m} \quad \alpha = \frac{\beta}{\beta + 1}$$

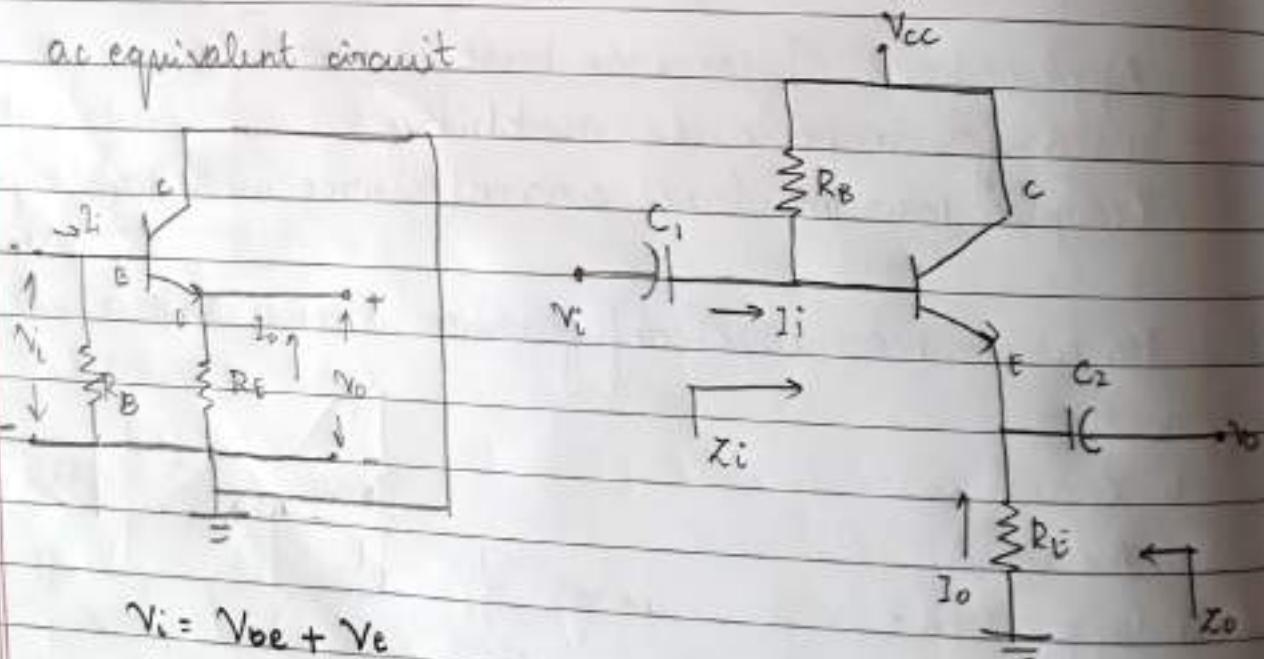
$$A_v = \frac{(0.998)(4.7k)}{33.33}$$

$$\alpha = \frac{499}{499+1} = 0.999$$

$$A_v = \underline{\underline{140.73}}$$

$$A_i = -\alpha = -0.998$$

* Emitter Follower Configuration (using r_e model):



$$V_i = V_{be} + V_E$$

$$V_i \approx V_E \quad (\text{since } V_{be} \text{ is small})$$

$$V_i \approx V_o$$

$$A_v = \frac{V_o}{V_i} = 1$$

Input impedance

Applying KVL to input side

$$V_i = I_b \beta r_e + I_e R_E$$

$$V_i = I_b \beta r_e + I_b (1+\beta) R_E$$

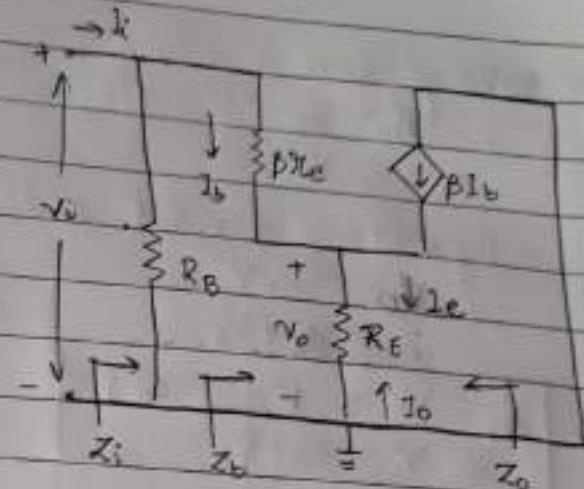
$$\frac{V_i}{I_b} = \beta r_e + \frac{R_E + \beta R_E}{(1+\beta)} \approx \beta r_e$$

$$Z_b = \frac{R_E + \beta (r_e + R_E)}{\beta}$$

$$Z_b \approx \beta R_E$$

$$Z_i = \frac{V_i}{I_i} = R_B || Z_b$$

ie model

Output impedance

$$Z_b = \frac{V_i}{I_b} \Rightarrow I_b = \frac{V_i}{Z_b}$$

$$I_b = \frac{I_e}{1+\beta}$$

$$\therefore \frac{I_e}{1+\beta} = \frac{V_i}{Z_b} \Rightarrow I_e = \frac{(1+\beta)V_i}{Z_b}$$

Substituting for Z_b

$$I_e = \frac{(1+\beta)V_i}{\beta(r_e + R_E)}$$

$$I_e = \frac{\beta V_i}{(r_e + R_E)} \quad 1+\beta \approx \beta$$

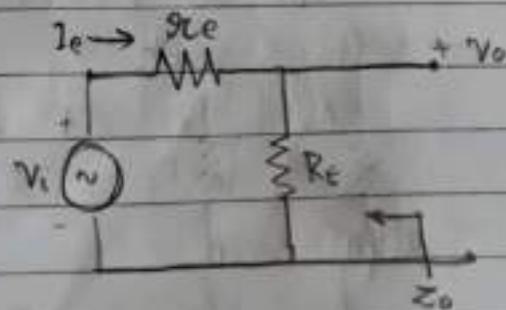
$$I_e = \frac{V_i}{r_e + R_E}$$

$$\Rightarrow V_i = I_e r_e + I_e R_E$$

For Z_o : $V_i = 0$

$$Z_o = r_e || R_E$$

$$Z_o = r_e$$



- voltage gain

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

By voltage divider rule

$$V_o = \frac{R_E V_i}{r_E + R_E}$$

$$A_v = \frac{V_o}{V_i} = \frac{R_E}{r_E + R_E} \approx 1$$

- current gain

$$V_o = I_C R_E = -I_O R_E$$

$$\Rightarrow I_O = -\frac{V_o}{R_E}$$

$$I_i = \frac{V_i}{Z_i}$$

$$A_i = \frac{I_o}{I_i} = -\frac{V_o}{R_E} \times \frac{Z_i}{V_i}$$

$$A_i = -\frac{A_v Z_i}{R_E}$$

Important characteristics :

- Input impedance

$$Z_i = R_B || Z_b \rightarrow \text{high input impedance}$$

- Output impedance

$$Z_o = r_E \rightarrow \text{low output impedance}$$

- Voltage gain

$$A_v = \frac{R_E}{r_E + R_E} \approx 1 \rightarrow \text{approximately unity}$$

- Current gain

$$A_i = -\frac{A_v Z_i}{R_E} \rightarrow \text{high current gain}$$

Applications:
used as buffer

For emitter follower circuit, calculate

a. r_e

b. Z_i and Z_o

c. A_v and A_i

$$\beta = 100$$

$$r_{ce} = \infty$$

$$a. r_e = \frac{26mV}{I_c}$$

$$I_E = (1+\beta) I_B$$

$$I_E = (1+100) 20 \cdot 42 \mu A$$

$$I_E = \underline{\underline{2.063mA}}$$

$$r_e = \frac{26m}{2.063mA} = \underline{\underline{12.6\Omega}}$$

$$b. Z_o = r_e = \underline{\underline{12.6\Omega}}$$

$$Z_i = R_B \parallel Z_b$$

$$Z_i = 220k \parallel 334.56k$$

$$Z_i = \underline{\underline{132.72k\Omega}}$$

$$I_B = \frac{V_{cc} - V_{BE}}{R_B + (1+\beta)R_E} \quad (\text{fixed bias})$$

$$I_B = \frac{12 - 0.7}{220k + (1+\beta)3.3k} = \underline{\underline{20.42\mu A}}$$

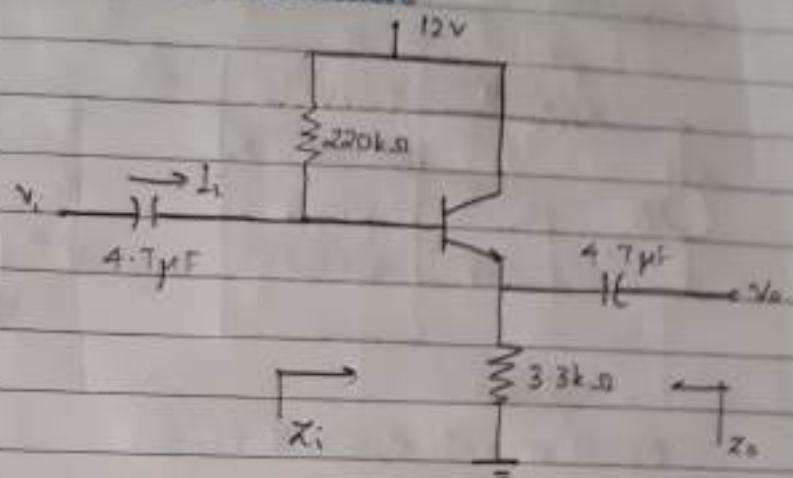
$$Z_b = \beta r_e + (1+\beta)R_E$$

$$Z_b = 100(12.6) + (1+100)3.3k$$

$$Z_b = \underline{\underline{334.56k\Omega}}$$

$$c. A_v = \frac{R_E}{r_e + R_E} = \frac{3.3k}{12.6 + 3.3k} = 0.996 //$$

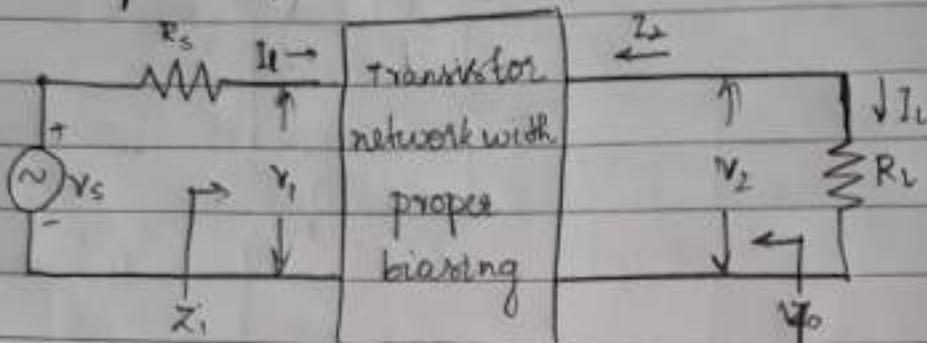
$$A_i = -\frac{A_v Z_i}{R_E} = -\frac{(0.996)(132.72k)}{3.3k} = \underline{\underline{-40.06}} //$$



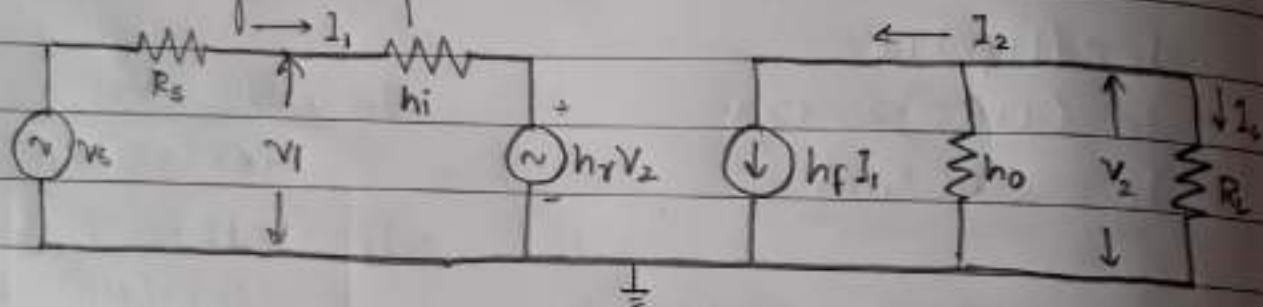
NOTE:

Emitter follower using voltage divider biasing circuit
Replace R_B by $R_1 \parallel R_2$

* Analysis of BJT Single stage Amplifier by hybrid model



Small signal Hybrid Model



- Current gain:

$$A_i = \frac{I_L}{I_b} = -\frac{I_2}{I_b} \quad \text{--- (1)}$$

$$\text{wkt } I_2 = h_f I_b + h_o V_2$$

$$\text{here } V_2 = I_L R_L = I_2 R_L$$

$$\therefore I_2 = h_f I_b - h_o I_2 R_L$$

$$h_f I_b = I_2 + h_o I_2 R_L$$

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

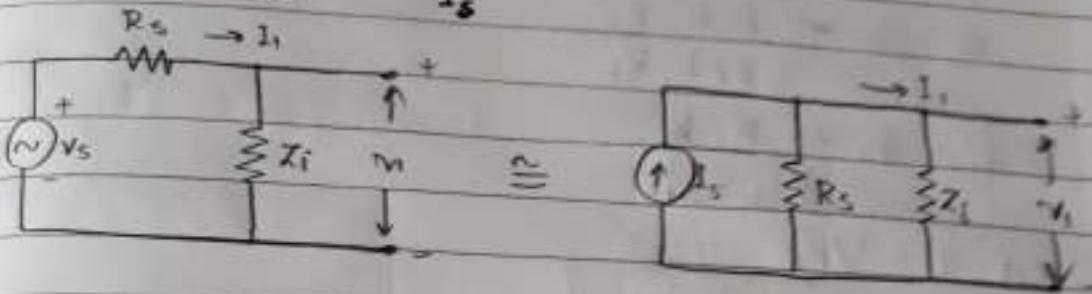
$$\frac{I_2}{I_b} = \frac{h_f}{1 + h_o R_L}$$

Substituting in eq (1)

$$A_i = \frac{-h_f}{1 + h_o R_L} \quad \text{--- (a)}$$

Current gain (w.r.t source):

$$A_{is} = \frac{I_2}{I_s} = -\frac{I_2}{I_s}$$



$$A_{is} = -\frac{I_2}{I_1} \times \frac{I_1}{I_s}$$

$$A_{is} = A_i \frac{I_1}{I_s} \quad \text{--- (2)} \quad (\text{From eq (1)})$$

$$I_1 = \frac{I_s R_s}{R_s + Z_i} \Rightarrow \frac{I_1}{I_s} = \frac{R_s}{R_s + Z_i}$$

Substituting in eq (2)

$$A_{is} = \frac{A_i R_s}{R_s + Z_i}$$

Input Impedance:

$$Z_i = \frac{V_1}{I_1} \quad \text{--- (3)}$$

$$\text{wkt } V_1 = h_i I_1 + h_r V_2$$

Substituting in eq (3)

$$Z_i = \frac{h_i I_1 + h_r V_2}{I_1}$$

$$Z_i = h_i + \frac{h_r V_2}{I_1}$$

$$\text{wkt } V_2 = -I_2 R_L$$

$$Z_i = h_i - \frac{h_r I_2 R_L}{I_1}$$

(From eq (1))

$$Z_i = h_i + A_i h_r R_L$$

(From eq (2))

$$Z_i = h_i + \left(\frac{-h_f}{1+h_o R_L} \right) R_L h_r$$

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

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

Let $Y_L = 1/R_L$

$$Z_i = h_i - \frac{h_r h_f}{Y_L + h_o}$$

Voltage gain

$$A_v = \frac{V_o}{V_i} = \frac{V_2}{V_i} \quad \text{--- (4)}$$

$$V_2 = -I_2 R_L$$

$$V_2 = A_i I_1 R_L \quad (\because I_1 = A_i)$$

$$A_v = \frac{A_i I_1 R_L}{V_i} \quad \left(\frac{V_i}{I_1} = Z_i \right)$$

$$A_v = \frac{A_i R_L}{Z_i} \quad \text{--- (b)}$$

Voltage gain (curr source)

$$A_{vs} = \frac{V_2}{V_s}$$

$$A_{vs} = \frac{V_2}{V_i} \times \frac{V_i}{V_s}$$

$$A_{vs} = A_v \frac{V_i}{V_s} \quad \text{--- (5)} \quad (\text{From eq (4)})$$



Voltage divider rule

$$V_i = \frac{R_i V_s}{R_s + R_i}$$

$$\frac{V_i}{V_s} = \frac{R_i}{R_s + R_i}$$

Substituting in eq (5)

$$A_{VS} = \frac{A_i Z_i}{R_s + Z_i}$$

Substituting eq (6)

$$A_{VS} = \frac{A_i R_L}{R_s + Z_i}$$

- Output admittance:

$$Y_o = \frac{I_2}{V_2} \quad \text{with } V_S = 0$$

wkt $I_2 = h_f I_1 + h_o V_2$

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

$$Y_o = h_f \frac{I_1}{V_2} + h_o \quad \text{--- (6)}$$

Applying KVL to input side

$$V_S = R_s I_1 + h_i I_1 + h_r V_2$$

but $V_S = 0 \Rightarrow I_1 (R_s + h_i) + h_r V_2 = 0$

$$I_1 (R_s + h_i) = -h_r V_2$$

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

Substituting in eq (6)

$$Y_o = h_f \left(\frac{-h_r}{R_s + h_i} \right) + h_o$$

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

Power gain:

$$A_P = \frac{P_2}{P_1} \quad \text{--- (7)}$$

$$P_2 = V_2 I_L = -V_2 I_2$$

$P_i = V_i I_i$,
Substituting in eq ①

$$\therefore A_p = -\frac{V_2 I_2}{V_i I_i}$$

$$A_p = -A_v A_i$$

From eq ① and eq ④

Substituting eq ⑤

$$A_p = \frac{A_i R_L}{Z_i} A_i$$

$$A_p = \frac{A_i^2 R_L}{Z_i}$$

Important formulae

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

$$A_{is} = \frac{A_i R_s}{Z_i + R_s}$$

$$Z_i = h_i + h_r A_i R_L = h_i - \frac{h_r h_f}{Y_L + h_o}$$

$$A_v = \frac{A_i R_L}{Z_i}$$

$$A_{vs} = \frac{A_v R_i}{R_i + Z_i} = \frac{A_i R_L}{Z_i + R_s} = \frac{A_{is} R_L}{R_s}$$

$$Y_o = h_o - \frac{h_f h_r}{h_i + R_s} = \frac{1}{Z_o}$$

$$A_p = A_v A_i$$

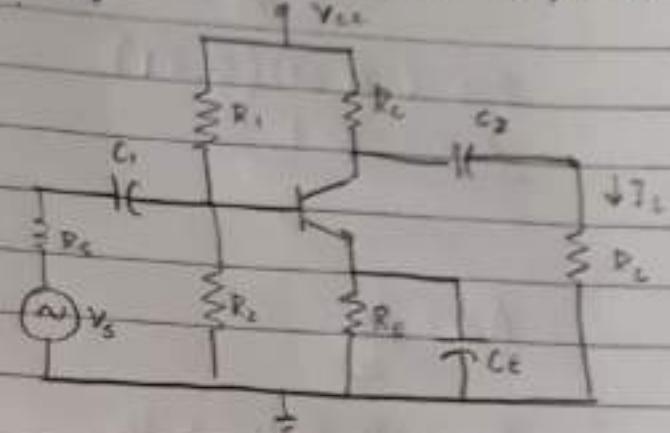
$$A_p = \frac{A_i^2 R_L}{Z_i}$$

Consider a single stage CE amplifier with $R_s = 1k\Omega$, $R_i = 50k\Omega$, $R_o = 2k\Omega$, $R_C = 1k\Omega$, $R_L = 1.2k\Omega$, $h_{FE} = 50$, $h_{ie} = 1.1k^2$, $h_{oe} = 25\mu A/V$, $A_{IS} = \frac{I_L}{I_S}$, $A_{VS} = V_o$ and R_o .

$$A_V = \frac{h_{FE}}{1 + h_{oe} R_L}$$

$$A_{VL} = \frac{1 + 50}{1 + 25\mu(1.2k)}$$

$$A_{VL} = 48.75 \text{ A}$$

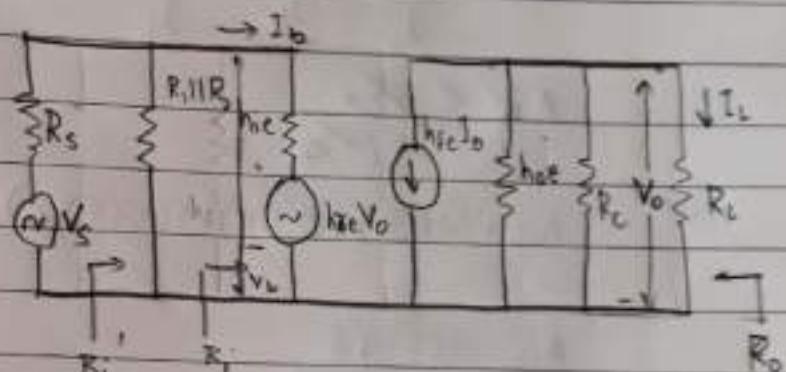


$R_o = h_{oe} + h_{re} A_{VL} R_C$

$$R_L' = R_C || R_L$$

$$R_L' = 1k || 1.2k$$

$$R_L' = 545.45 \Omega$$



$$B) A_V = -I_C = -h_{FE} \frac{I_B}{1 + h_{oe} R_L'}$$

$$A_V = \frac{-50}{1 + 25\mu(545.45)} = -49.32$$

$$R_i = h_{ie} + h_{re} A_V R_L'$$

$$= 1.1k + (0.25m)(-49.32)(545.45)$$

$$\underline{R_i = 1.093 k\Omega}$$

$$A_V = \frac{A_V R_L'}{R_i} = \frac{(-49.32)(545.45)}{1.093k} = -24.61$$

$$A_{IS} = \frac{I_L}{I_S} = \frac{A_V R_s}{R_i + R_s}$$

$$R_i' = R_i || R_1 || R_2$$

$$= (1.093k || 50k || 1.2k) = \underline{696.9 \Omega}$$

$$A_{VS} = \frac{V_o}{V_s} = \frac{V_o}{V_b} \times \frac{V_b}{V_s}$$

$$V_o = \frac{V_s R_i'}{R_s + R_i'}$$

$$A_{VS} = Av \left(\frac{V_b}{V_s} \right)$$

$$\frac{V_b}{V_s} = - \frac{R_i'}{R_s + R_i'} = \frac{696.9}{(1k + 696.9)}$$

$$A_{VS} = (-24.61)(0.11)$$

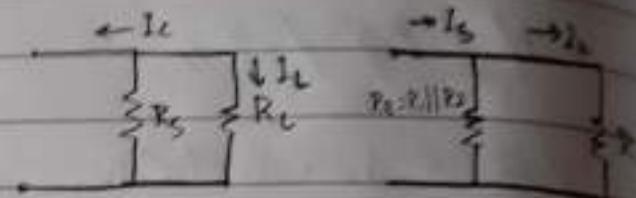
$$\frac{V_b}{V_s} = 0.41$$

$$\underline{\underline{A_{VS} = -10.1}}$$

$$\frac{V_o}{V_b} = Av = -24.61$$

$$A_{IS} = \frac{I_L}{I_S}$$

$$A_{IS} = \frac{I_L}{I_C} \times \frac{I_C}{I_B} \times \frac{I_B}{I_S}$$



~~A_{IS} = $\frac{R_C}{R_s + R_L}$~~

$$I_L = \frac{-I_C R_C}{R_C + R_L}$$

$$A_{IS} = -0.45(0.637k)(-19.32)$$

$$\underline{\underline{A_{IS} = 13.98}}$$

$$\frac{I_L}{I_C} = \frac{-R_C}{R_C + R_L}$$

$$\frac{I_L}{I_C} = \frac{-1k}{1k + 1.2k} = -0.45$$

$$I_B = \frac{I_S R_B}{R_B + R_i}$$

$$\frac{I_B}{I_S} = \frac{R_B}{R_B + R_i} = \frac{1.923k}{(1.923k + 1.093k)}$$

$$\frac{I_B}{I_S} = 0.637$$

$$\frac{I_C}{I_B} = 49.32$$