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UNIT - 1

Diode Circuits and its Applications

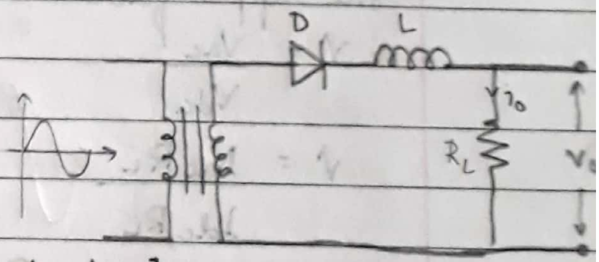
* **FILTERS:**

Types of filters:

1. Inductor ~~or~~ filter (choke filter)
2. capacitor filter
3. LC filter or L-section filter
4. CLC filter or π-section filter

1. **INDUCTOR FILTER:**

- HWR with inductor filter:



The analytical representation of output current from Fourier series.

$$i = I_m\left[\frac{1}{\pi} + \frac{1}{2}\sin\omega t - \frac{2}{\pi}\sum_{\substack{k=2,4,6\\k\neq 0}} \frac{\cos k\omega t}{(k+1)(k-1)}\right] \quad \text{——— (1)}$$

$$i = \frac{I_m}{\pi} + \underbrace{\frac{I_m}{2}}_{I_1}\sin\omega t - \underbrace{\frac{2I_m}{\pi}}_{I_2}\left[\frac{\cos 2\omega t}{3} + \frac{\cos 4\omega t}{15}\right] \quad \text{——— (2)}$$

wkt $I_{dc} = \dfrac{I_m}{\pi} = \dfrac{V_m}{\pi R_L}$ ——— (3)

The rms value of ac component is

$$I_1 = \frac{I_m}{2} \times \frac{1}{\sqrt{2}} = \frac{I_m}{2\sqrt{2}}$$

$$\therefore I_1 = \frac{V_m}{2\sqrt{2}(R_L + j\omega L)}$$

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

$$\boxed{I_1 = \frac{V_m}{2\sqrt{2}\,\omega L}}$$

Here I_2 is the rms value of second harmonic

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

$$\therefore I_2 = \frac{2V_m}{3\sqrt{2}\pi(R_L + 2\omega L)}$$

At operating frequency, $\omega L >> R_L$, hence neglecting R_L

$$I_2 = \frac{2V_m}{3\sqrt{2}\pi(2\omega L)}$$

$$\boxed{I_2 = \frac{V_m}{3\sqrt{2}\pi\omega L}}$$

The ac component is

$$I_{ac} = \sqrt{I_1^2 + I_2^2} \quad \text{--- (4)}$$

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

$$\gamma = \frac{\sqrt{\left(\frac{V_m}{2\sqrt{2}\omega L}\right)^2 + \left(\frac{V_m}{3\sqrt{2}\pi\omega L}\right)^2}}{\frac{V_m}{\pi R_L}}$$

$$\gamma = \frac{\frac{V_m}{\omega L}\sqrt{\left(\frac{1}{2\sqrt{2}}\right)^2 + \left(\frac{1}{3\sqrt{2}\pi}\right)^2}}{\frac{V_m}{\pi R_L}}$$

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

$$\boxed{\gamma = \frac{1.13 R_L}{\omega L}}$$

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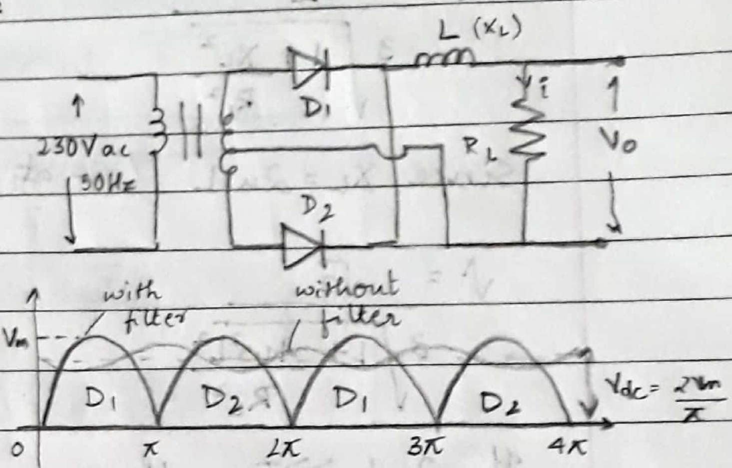
- FWR with inductor filter:

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



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

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

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

wkt $V_{dc} = \frac{2V_m}{\pi}$ —— (2)

The rms value of ac component

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

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

The ripple factor is given by

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

$$\gamma = \frac{\dfrac{\cancel{2}\sqrt{2}\cancel{V_m}R_L}{3\cancel{\pi}\sqrt{R_L^2 + X_L^2}}}{\dfrac{\cancel{2V_m}}{\cancel{\pi}}}$$

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

$$\gamma = \frac{\sqrt{2}}{3\sqrt{1+\frac{X_L^2}{R_L^2}}}$$

Since $X_L = 2\omega L$ (ac at 2^{nd} harmonic)

$$\gamma = \frac{\sqrt{2}}{3\sqrt{1+\frac{4\omega^2L^2}{R_L^2}}}$$

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

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

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

NOTE:

Demerits of inductive filter

→ A drop across the inductor reduces the output voltage across load resistance

→ Bulky and expensive.

Q A: A FWR with a load resistance of 15kΩ 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: $R_L = 15k\Omega$; $L = 15H$; $V_m = 250V$; $f = 50Hz$

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

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

~~$r = \frac{R_L}{3\sqrt{2}\omega L} = \frac{15\times10^3}{3\times\sqrt{2}\times2\pi\times50\times15} = 0.45$~~

~~$i = I_m\left[\frac{2}{\pi} - \frac{4}{\pi}\frac{\cos 2\omega t}{3} - \frac{4}{15\pi}\cos 4\omega t\right]$~~

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

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

$I_{ac} = 4.24mA$

$r = \frac{I_{ac}}{I_{dc}} = \frac{4.24m}{10.6m} = 0.4$

3. **LC FILTER:** (Choke input filter)

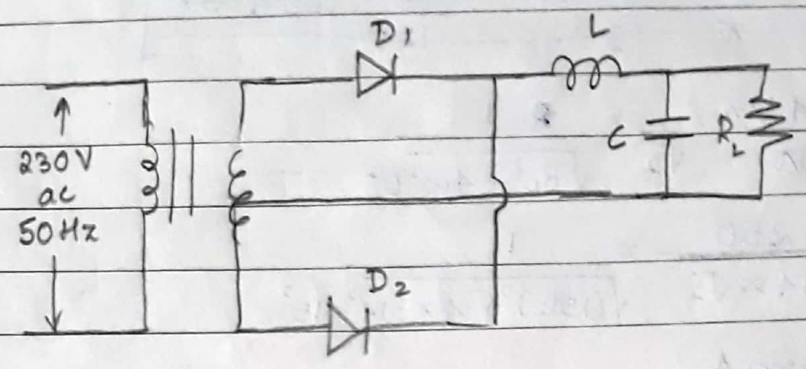
Capacitor Filter	Inductor Filter
Advantage - Ripple factor is not dependent on load resistance HWR : $r = \frac{1}{2\sqrt{3}fCR_L}$ FWR : $r = \frac{1}{4\sqrt{3}fCR_L}$	- Ripple factor is dependent on load resistance. HWR : $\frac{1.13R_L}{\omega_1 L}$ FWR : $\frac{R_L}{3\sqrt{2}\omega L}$
Disadvantage - Diode current increases due to which transistor heats up reducing efficiency.	Advantage - Any variation in current is smoothened out in case of inductor filter. Disadvantage - Reduces the output current and output voltage due to the drop across the inductor.

Desired Characteristics:

C filter: voltage stability action

L filter: Current smoothening action

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



Ripple Factor in an LC filter

condition: $X_C << R_L$ and $X_L >> X_C$ at $2\omega = 4\pi f$ (at 2^{nd} harmonic)
(To maintain the diode current to minimum)

wkt $V_{rms} = \frac{V_m}{\sqrt{2}}$

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

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

$\therefore V_{rms} = \frac{4V_m}{3\pi} \times \frac{1}{\sqrt{2}} \Rightarrow V_{rms} = \frac{2\sqrt{2}\,V_m}{3\pi}$ —— (1)

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

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

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

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

$\cancel{V_{ac(rms)} = I_{ac(rms)} X_c}$

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

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

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

$$r = \frac{\sqrt{2}}{3} \frac{1/2\omega C}{2\omega L}$$

$$\boxed{r = \frac{1}{6\sqrt{2}\,\omega^2 LC}}$$

Bleeder Resistor:

It helps to stabilise 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 doesnot fall to zero.

considering the Fourier series of output current

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

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

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

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

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

$$\cancel{2}\omega L = \frac{\cancel{2}R_L}{3}$$

$$\boxed{L_{cr} = \frac{R_L}{3\omega}}$$ 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 40-0-40V 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: $L = 2H$ $\quad I_L = 0.2A$

$C = 40\mu F$ $\quad V_m = 40V$

DC output voltage

$$V_{dc} = \frac{2V_m}{\pi} = \frac{2\times 40}{3.14}$$

$$V_{dc} = 25.46V$$

Ripple factor

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

$$\gamma = 0.0149$$

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: $\gamma = 0.02$ $\quad V_{dc} = 10V$

$f = 50Hz$ $\quad I_L = 100mA$

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

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

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

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

$$R_L = 100\,\Omega$$

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

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

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

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

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

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

$V_{dc} = 350V$

$$\gamma = \frac{V_{ac}}{V_{dc}} = \frac{10}{350} \qquad \gamma = 0.028$$

$$R_L = \frac{V_{dc}}{I_{dc}} = \frac{350}{100m} = 3.5\,k\Omega$$

$$L_{cr} = \frac{R_L}{3\omega} = \frac{3.5k}{3 \times 2\pi\, 50} = 3.71\,H$$

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

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

$$LC = 4.26\times10^{-5} = 42.6\mu$$

$$C = \frac{4.26\times10^{-5}}{3.41}$$

$$C = 1.15\times10^{-5}F = 11.5\mu F$$

Q4: A full wave rectifier with LC type filter is to supply 100 mA at 30V with a ripple that must not exceed 1V. Calculate the suitable filter components assuming a supply frequency to be 50 Hz.

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

$V_{dc} = 30V$ $\quad f = 50Hz$

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

$$R_L = 300\Omega$$

$$\gamma = \frac{V_{ac}}{V_{dc}} = \frac{1}{30}$$

$$\gamma = 0.033$$

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

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

$$LC = 3.62\times10^{-5}$$

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

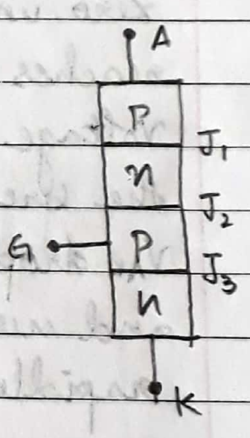
$$\underline{L_{cr} = 318\,mH}$$

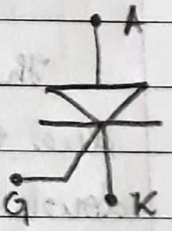
$$C = \frac{3.62 \times 10^{-5}}{318.3\,m}$$

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

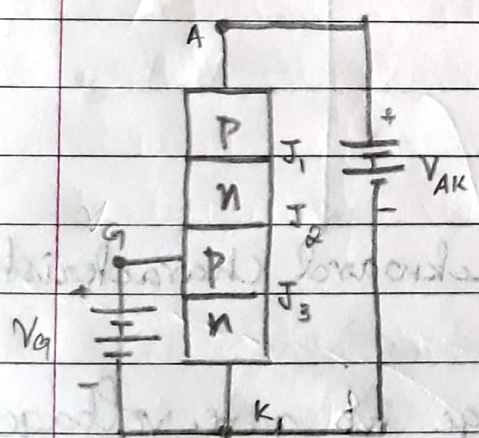
★ POWER DEVICES:

1. **Silicon control Rectifier:**
   - Current conduction: unidirection
   - It is a 4 layer, 3 terminal device
   - It has 3 junctions.
   - Used in switching devices



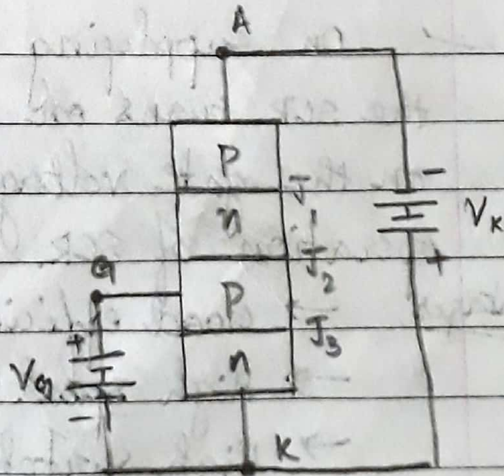


Biasing



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.



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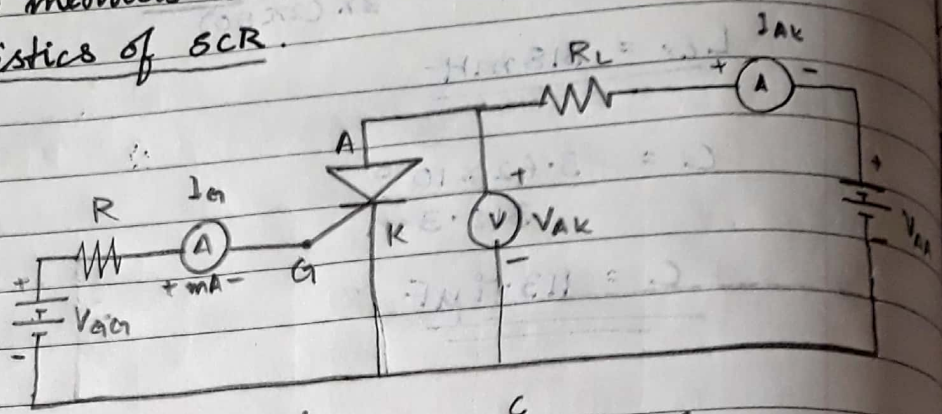
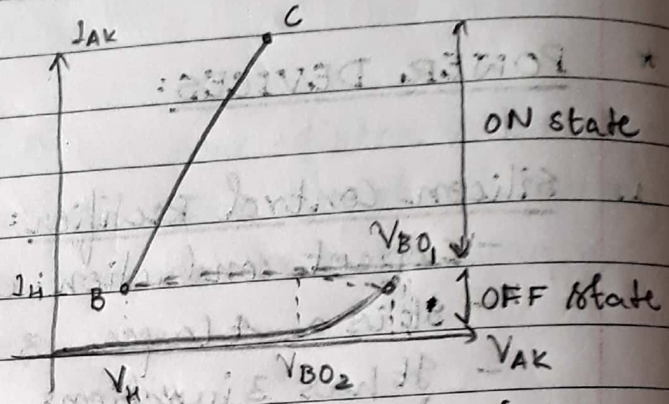
there are two methods to turn on a SCR.

V-I characteristics of SCR.





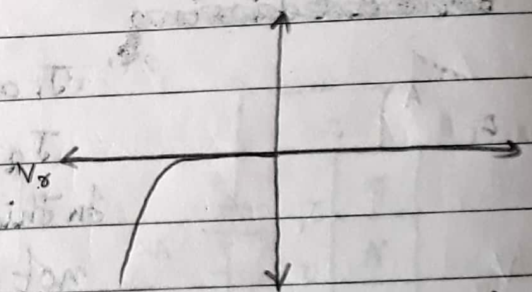
— The current remains zero untill the supply V_{AA} reaches the Break over voltage. Once it reaches the break over voltage the V_{AK} drops to minimum and current increases rapidly.

Forward characteristics

I_H - Holding current

V_{BO_1}, $I_G = 0$

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



Backward Characteristics

— On supplying a certain voltage at gate voltage the SCR turns on ~~the~~ 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:

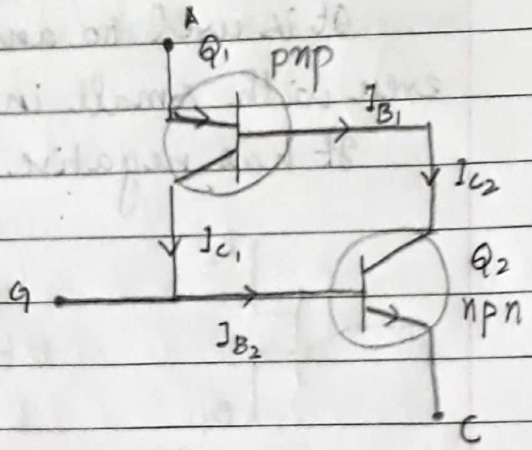
$$I_A = \frac{\alpha_2 I_g}{1-(\alpha_1+\alpha_2)}$$

I_A - anode current

I_g - gate current

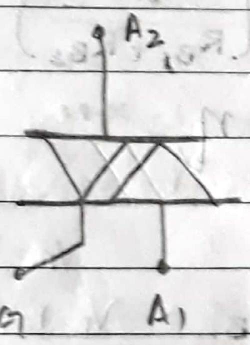
α_1 - current gain of Q_1

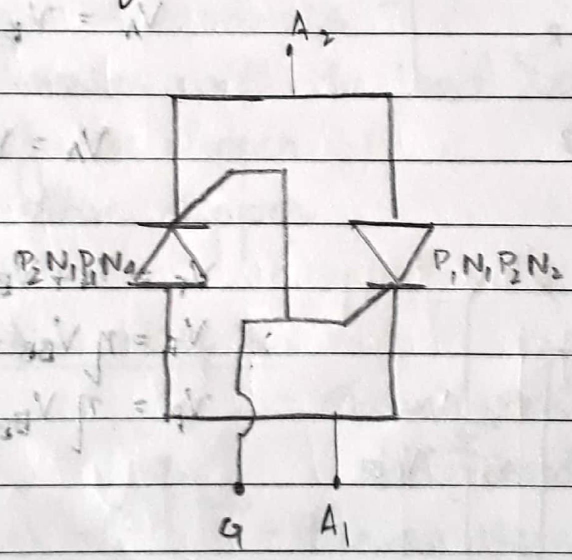
α_2 - current gain of Q_2.

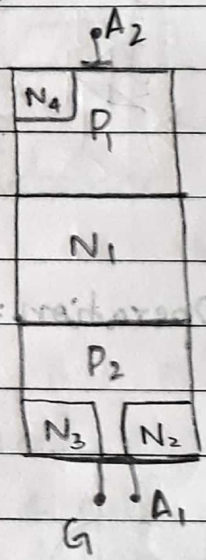


2. **TRIAC:**

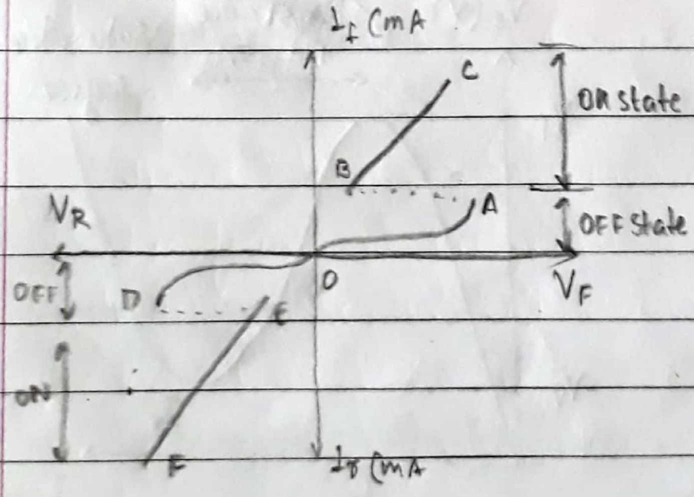
- Current conduction - bidirectional
- It is 5 layer and 3 terminal device
- combination of two SCR







VI characteristics



OA - Off state - less than break over voltage hence small leakage current

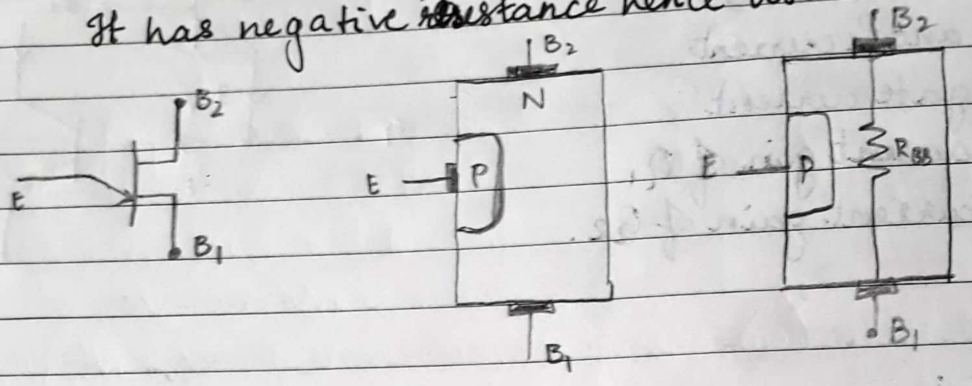
BC - On state - on positive voltage greater that break over voltage.

→ light application

3. **UJT : Uni Junction Transistor**

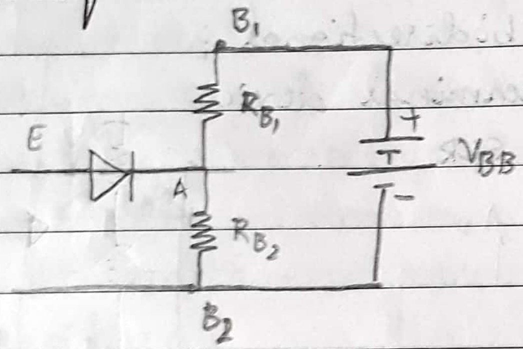
It is used to analyse ac power delivered to the load even with small input.

It has negative resistance hence used in oscillators.



R_{BB} = interbase resistance

Equivalent circuit



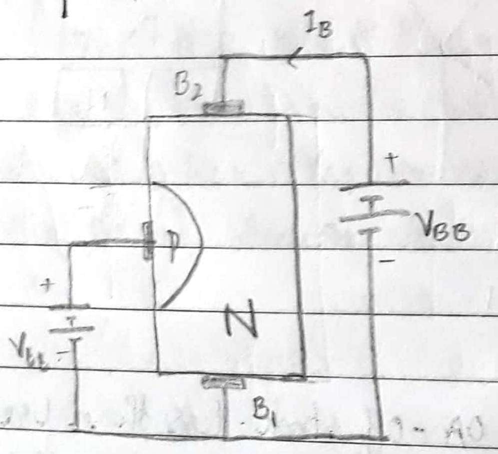
η - intrinsic stand off ratio

$$R_{BB} = R_{B_1} + R_{B_2}$$

$$V_A = V_{BB}\left(\frac{R_{B1}}{R_{B_1} + R_{B_2}}\right)$$

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

Operation:



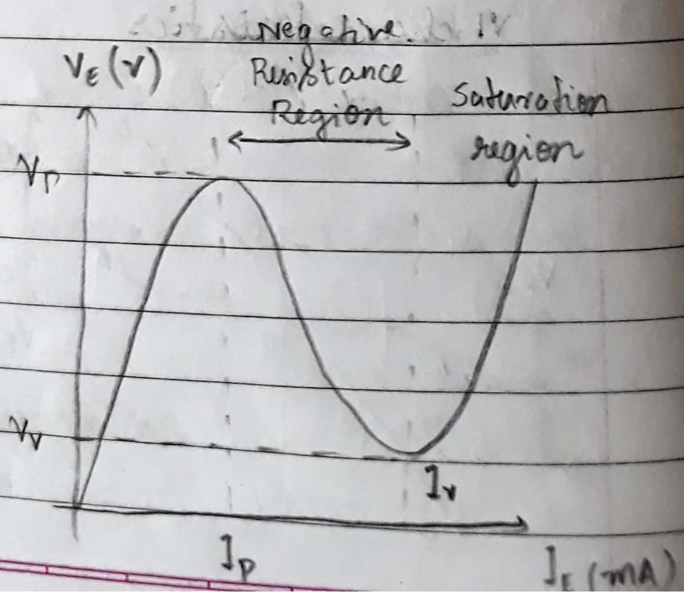
$$V_T = V_A + V_B$$

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

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

$V_A = V_{BB}\eta$

V_B - Barrier Voltage

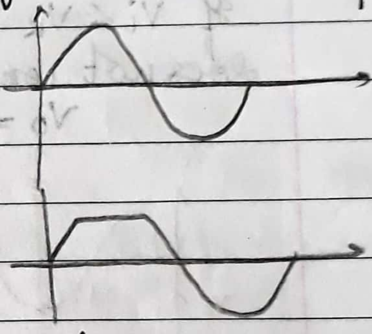


As V_E decreases I_E increases hence called as negative resistance region.

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

* CLIPPING CIRCUITS:

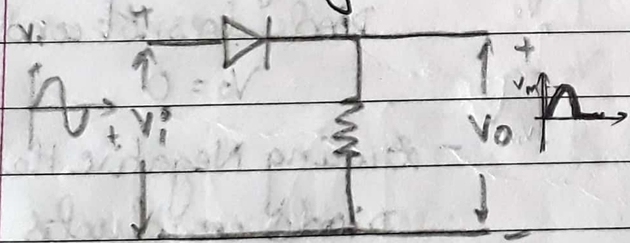
Part of the input wave is clipped off with out any distortion in the signal.



Types:
1. Series clipper
2. Parallel clipper

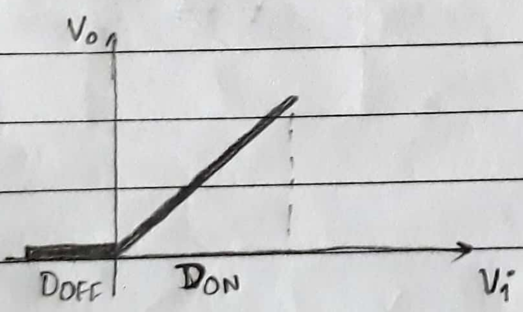
- Series clipper: A diode is connected in series with the load resistance.
  - → series negative clipper
  - → series positive clipper

* Series Negative clipper

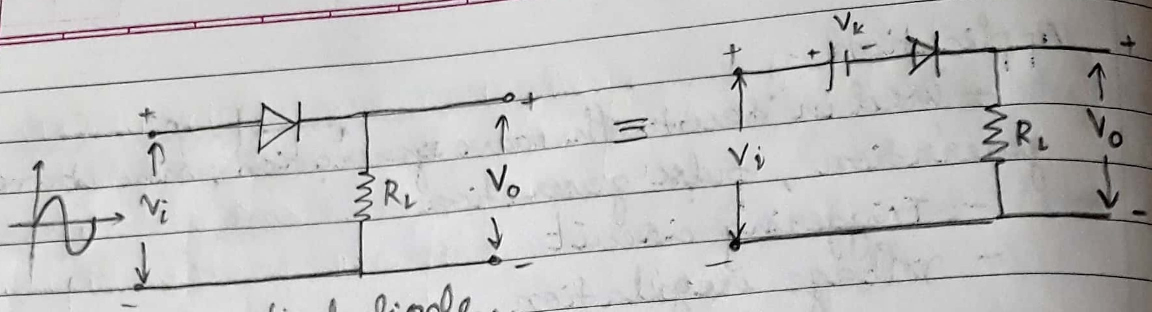


- During Positive cycle
  Diode conducts ⇒ $V_o = V_i = V_m$
- During Negative half cycle
  Diode doesnot conduct ⇒ $V_o = 0$

Ideal diode



Transfer characteristics.



Practical diode.

Only if $V_i > V_K$ only then the diode conducts.

$$V_i - V_K - V_o = 0$$

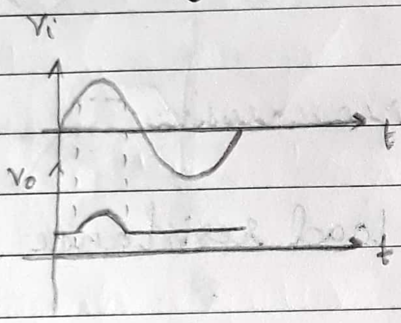
$$V_o = V_i - V_K$$

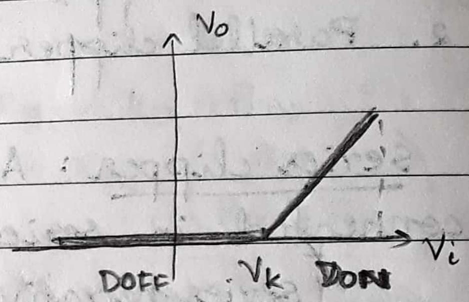
} Positive Half cycle

If $V_i < V_K$ then the diode does not conduct

$$V_o = 0$$

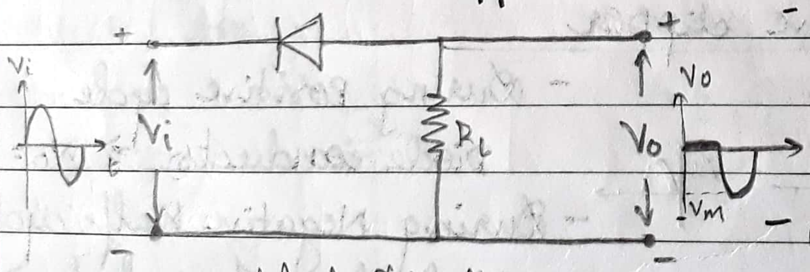
} Negative Half cycle





Transfer Characteristics

★ <u>Series Positive Clipper:</u>



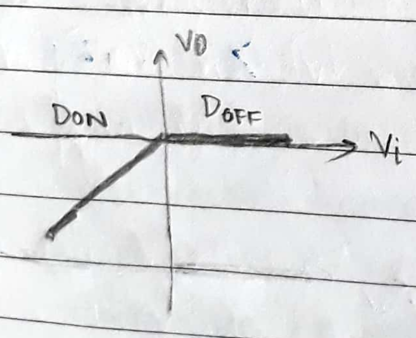
Ideal Diode

- During Positive Half cycle Diode doesnot conduct

$$V_o = 0$$

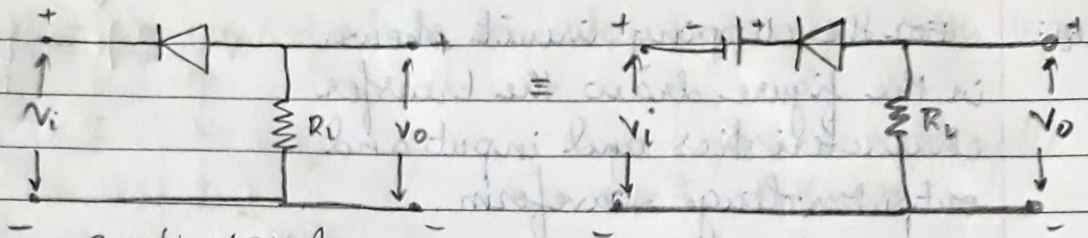
- During Negative Half cycle Diode conducts

$$V_o = -V_i = -V_m$$



Transfer Characteristics

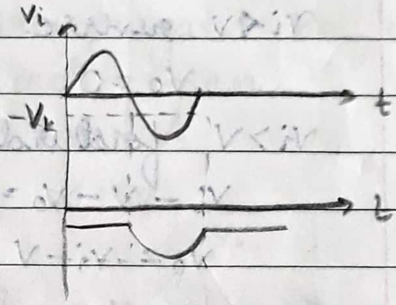
Page No.: Keerthana Ashok



Practical Diode

During positive Half cycle the diode does not conduct

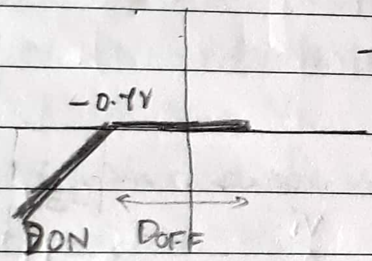
$V_0 = 0$



During negative Half cycle the diode conducts

$V_i + V_k = V_0$

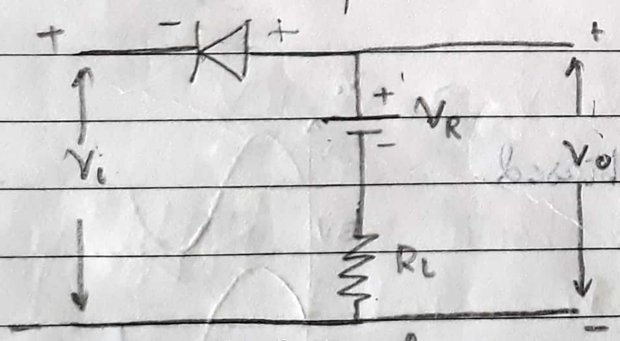
$V_0 = -V_m + V_k$



Transfer characteristics

Biased Clipper:

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



Ideal diode

- During positive half cycle

$V_i < V_R$ - forward biased

Hence diode conducts.

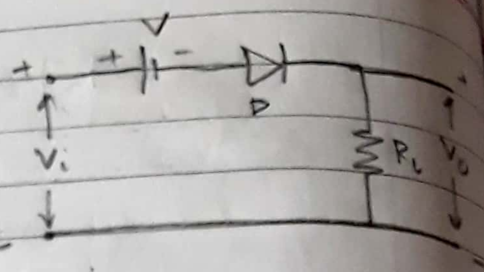
$V_0 = V_i - V_R$

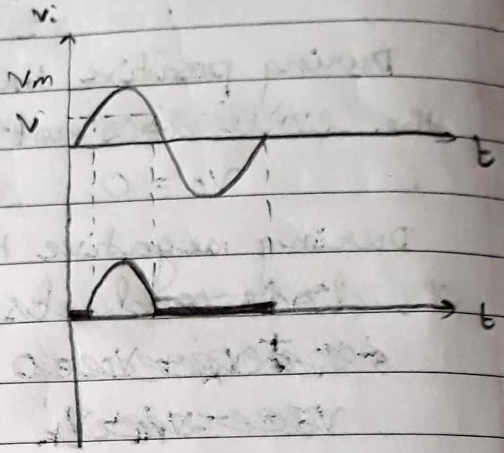
$V_i > V_R$ - reverse biased

Hence diode does not conduct

$V_0 = V_R$

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

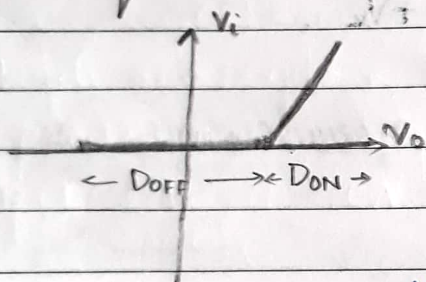
$V_0 = 0$

$V_i > V$ forward biased

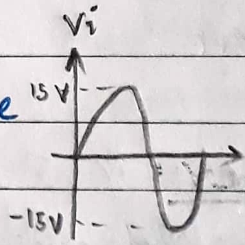
$V_i - V - V_0 = 0$

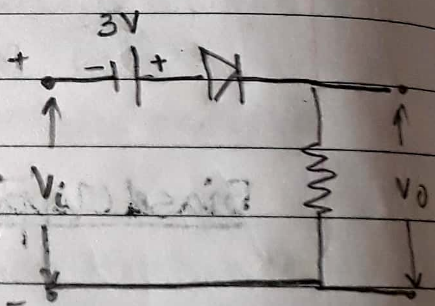
$V_0 = V_i - V$

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 level in the output.





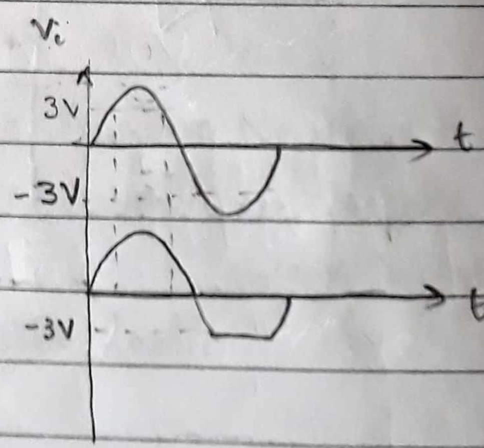
Sol: $V_i > 0V$ - forward biased

$V_i + V_R - V_0 = 0$

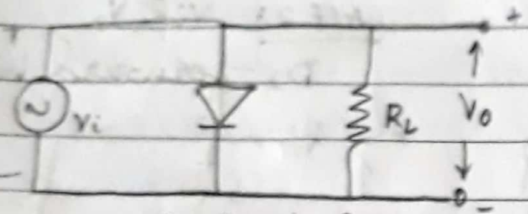
$V_0 = V_i + V_R$

$V_i < -3V$ - reverse biased

$V_0 = 0$

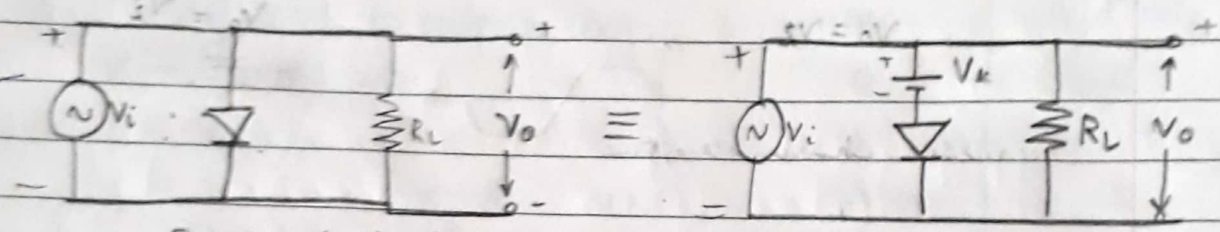


- — Parallel Clipper: A diode is connected in parallel with load.



Ideal diode

- During positive half cycle
  Diode - short
  $V_0 = 0$
- During negative half cycle
  Diode - open
  $V_0 = V_i$.

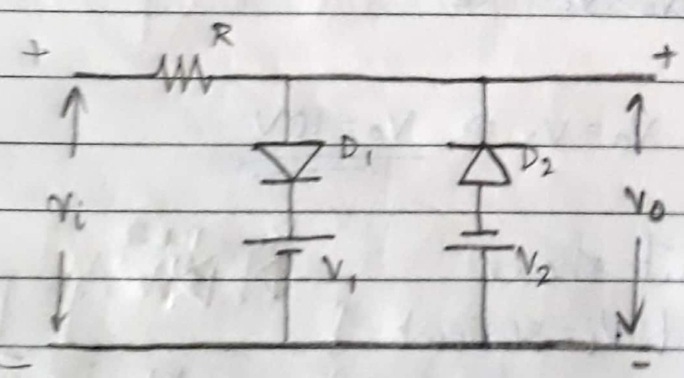


Practical diode

If $V_i > V_k$ - diode is forward biased and acts as short.
$\Rightarrow V_0 = V_k$

If $V_i < V_k$ - diode is reverse baised and acts as open circuit
$\Rightarrow V_0 = V_i$

★ Two way Parallel clipper / Double Ended clipper:

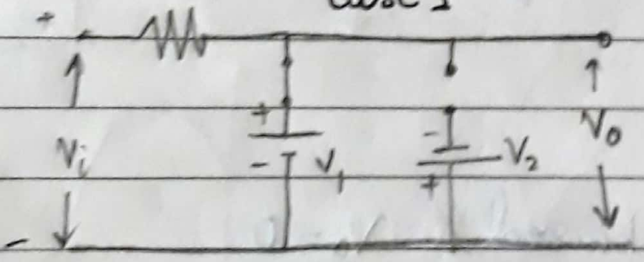


During Positive Half cycle
D_2 - ~~Reve~~ Reverse biased

CASE 1: $V_i > V_1$
D_1 - Forward biased

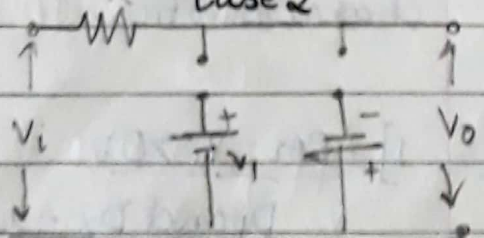
CASE 2: $V_i < V_1$
D_1 - Reverse biased

Case 1



$V_i > V_1$ $V_0 = V_1$

Case 2



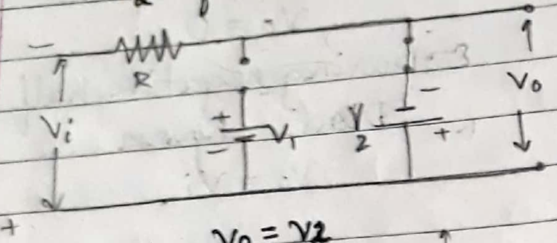
$V_i < V_1$ $V_0 = V_i$

During negative half cycle

D_1 - always reverse biased

CASE 1: $V_i < V_2$

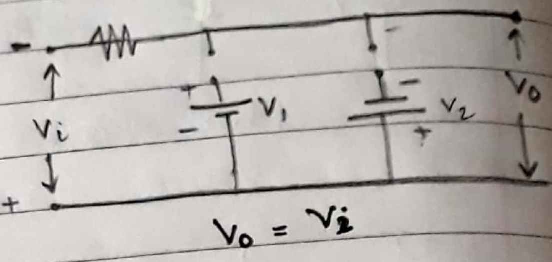
D_2 - forward biased



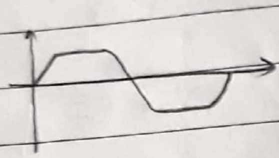
$V_o = V_2$

CASE 2: $V_i > V_2$

D_2 - reverse biased



$V_o = V_i$

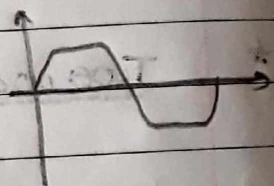


Q1: Sketch and explain the circuit of double-ended clipper using ideal p-n junction diode which limits the output between 10V.

Sol: $V_1 = 10V$ $V_2 = 10V$

Positive Half cycle:

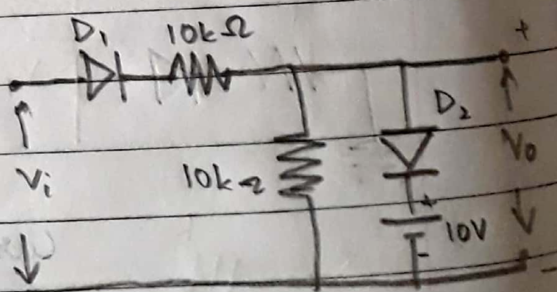
CASE 1: $V_i > V_1$ → $V_o = V_1$ ⇒ $\underline{V_o = 10V}$



Negative Half Cycle:

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

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

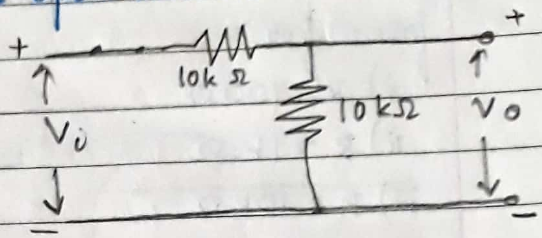
$\underline{V_o = 0}$

Keerthana Ashok

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

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

$V_i = (20k)I$

$I = \frac{V_i}{20k\Omega}$ —— ①

Applying KVL to output loop

$V_o - (10k)I = 0$

$V_o = (10k)I$

$I = \frac{V_o}{10k\Omega}$ —— ②

Equating eq ① and eq ②

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

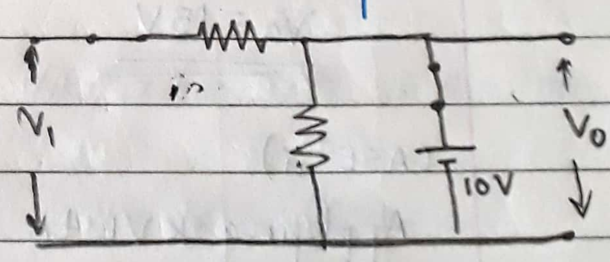
$\Rightarrow V_o = V_i/2$

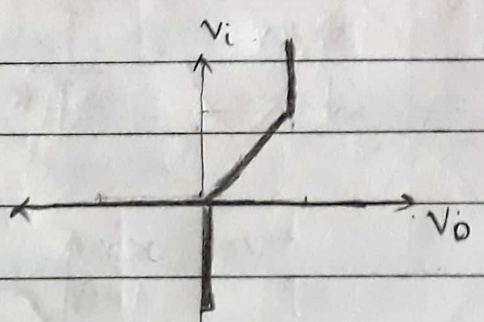
V_i	$V_o = V_i/2$
0	0
1	0.5
2	1
3	1.5
4	2
10	5
~~20~~	~~10~~

iii] for $V_i > 10V$:

D_1 and D_2 are ~~forward~~ biased and act as ~~open~~ short circuit

$V_o = 10V$





Transfer Characteristics

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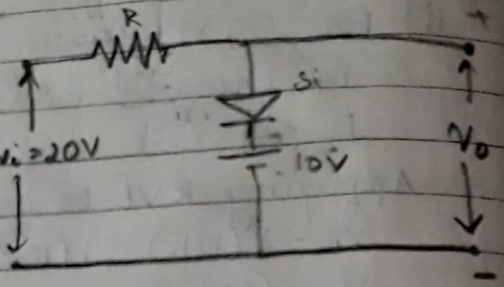
Q3: For the diode clipping circuit shown in the figure, draw the input and output wave form for



i) $R = 100\Omega$

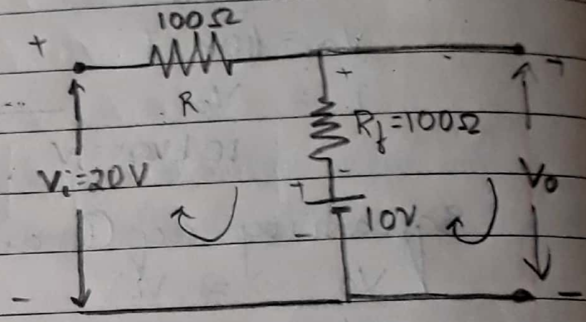
ii) $R = 1k\Omega$

iii) $R = 10k\Omega$

for $v_i = 20 \sin \omega t$ and $V_R = 10V$. Assume $R_f = 100\Omega$ and $R_r = \infty$ and $V_\gamma = 0$.

CASE i)

Sol: Applying KVL to i/p



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

$20 = 200I + 10$

$200I = 10$

$I = \frac{10}{200} = 50mA$

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

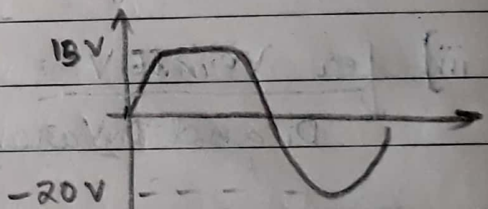
Applying KVL to o/p

$V_o = 10 + I(100)$

$V_o = 10 + (50m)(100)$

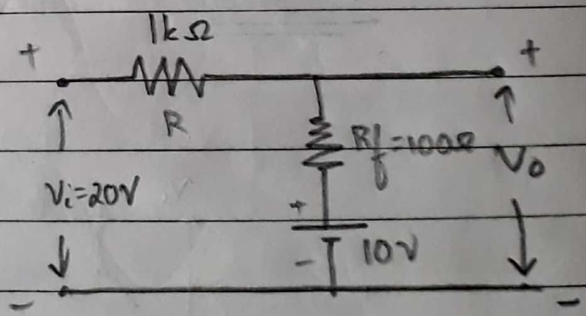
$V_o = 10 + 5$

$V_o = 15V$



CASE ii)

Applying KVL to i/p



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

$10 = 1100(I)$

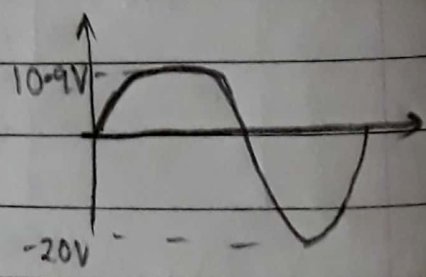
$I = \frac{10}{1100} = 9.09mA$

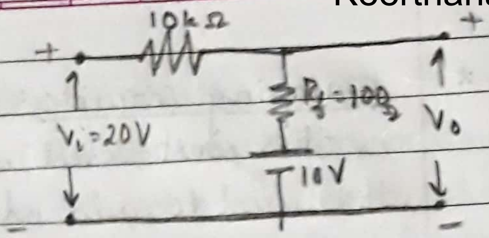
Applying KVL to o/p

$V_o = 10 + (100)I$

$V_o = 10 + 9.09m(100)$

$V_o = 10.9V$





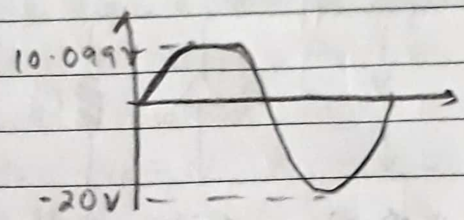
CASE iii)

Applying KVL to i/p

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

$10 = 10100(I)$

$I = \frac{10}{10100} = \underline{0.99 mA}$



Applying KVL to o/p

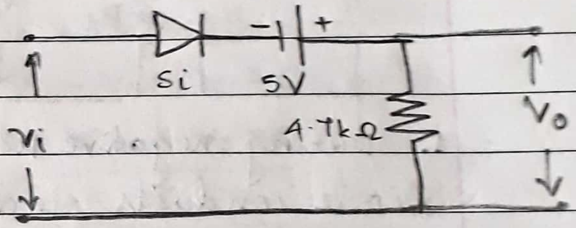
$V_o = 10 + 100(I)$

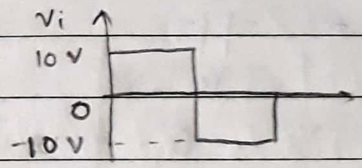
$V_o = 10 + 100(0.99m)$

$\underline{V_o = 10.099 V}$

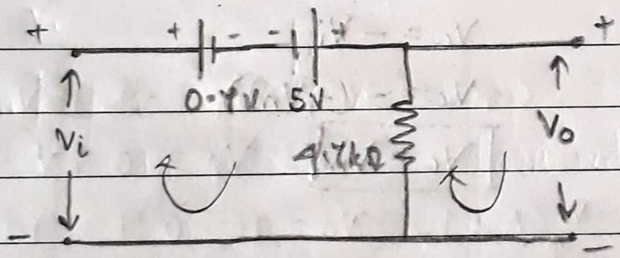
$\boxed{\text{If } V_i \leq 0 \quad V_o = V_i}$

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





Sol: During positive half cycle the diode conducts



Applying KVL to i/p loop

$V_i = 0.7 - 5 + 4.7k(I)$

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

$14.3 = 4.7k(I)$

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

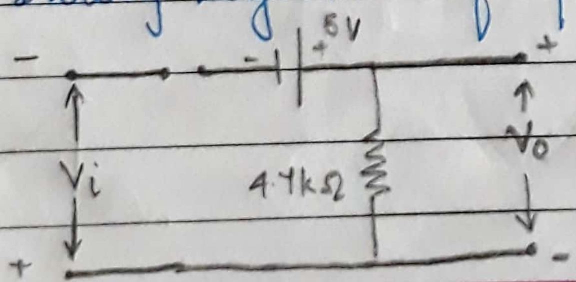
Applying KVL to o/p loop

$V_o = 4.7k(I)$

$V_o = 4.7k(3.04m)$

$\underline{V_o = 14.3 V}$

During negative half cycle, the diode does not conduct



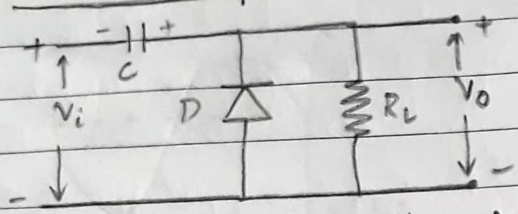
$\underline{V_o = 0 V}$

* Clamping circuits:

It is constructed using resistor, diode and capacitor.

It is used to add dc level to the input signal.

- Positive Clamper

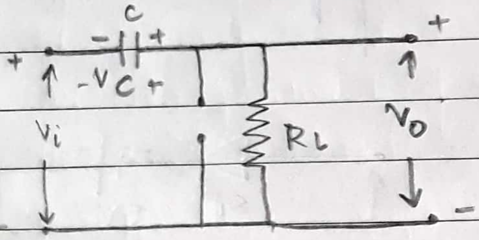


Procedure:

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 ~~[illegible]~~ does not conduct since it is reverse biased



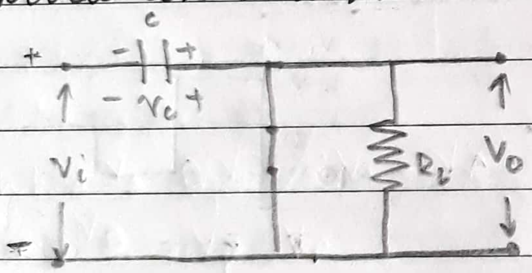
$V_i + V_c - V_o = 0$

$V_o = V_i + V_c$

$\boxed{V_o = V_i + V_m}$

1. During negative half cycle

Diode conducts since it is forward biased



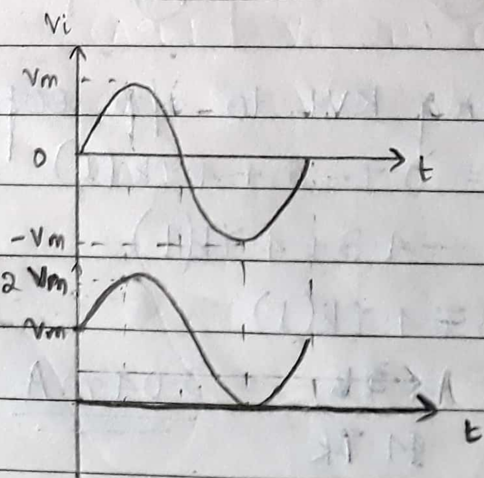
$V_i + V_c = 0$

$V_c = -V_i$

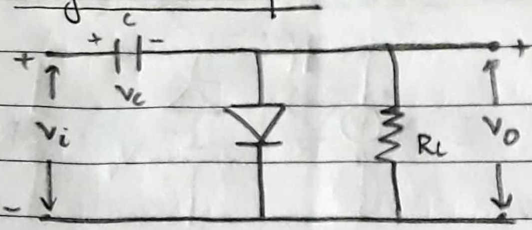
$V_c = -(-V_m)$

$\boxed{V_c = V_m}$

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



Negative Clamper

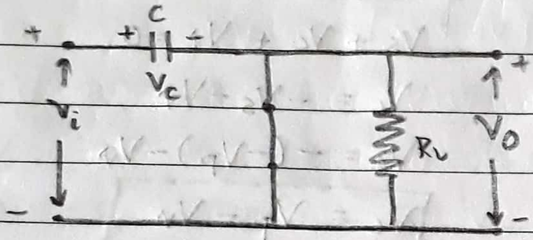


Procedure:

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

1. During positive half cycle:

Diode conducts since it is forward biased



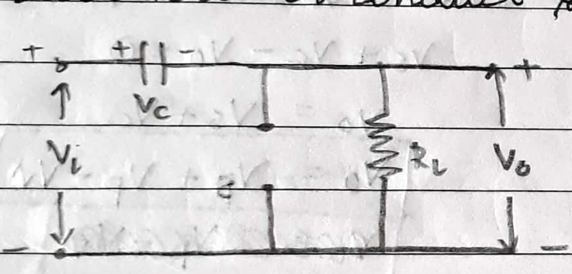
$$V_i - V_c = 0$$

$$V_c = V_i$$

$$\boxed{V_c = V_m}$$

2. During negative half cycle:

Diode does not conduct since it is reverse biased.

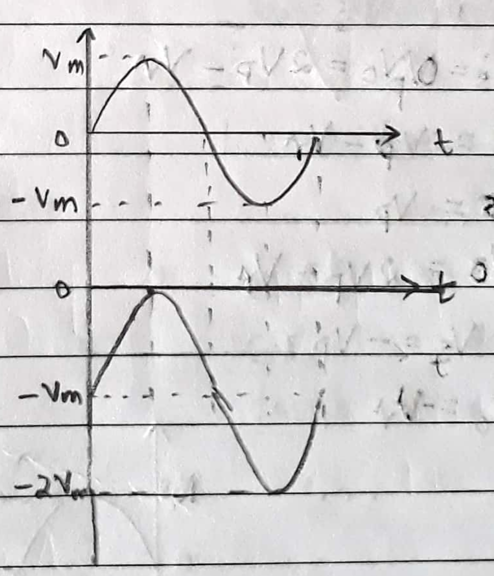


$$V_i - V_c - V_o = 0$$

$$V_i - V_m - V_o = 0$$

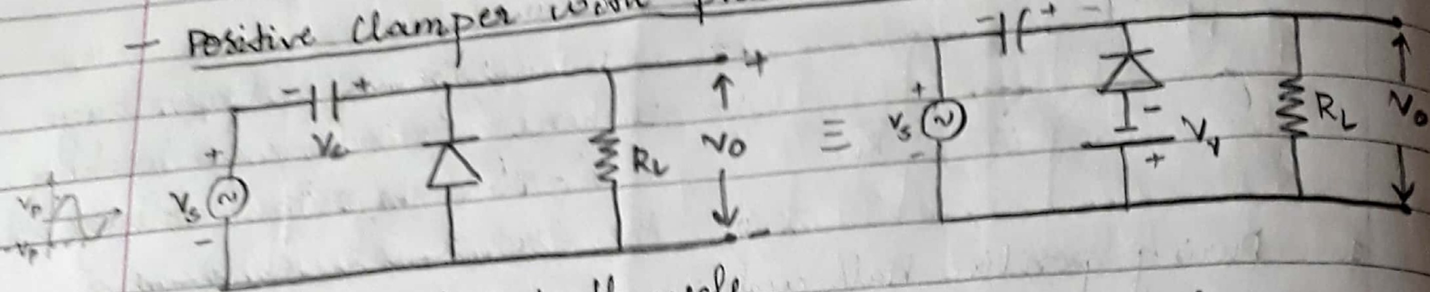
$$\boxed{V_o = V_i - V_m}$$

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

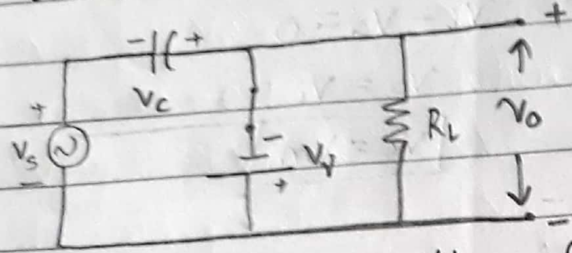


Keerthana Ashok

– Positive clamper with practical diode:



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



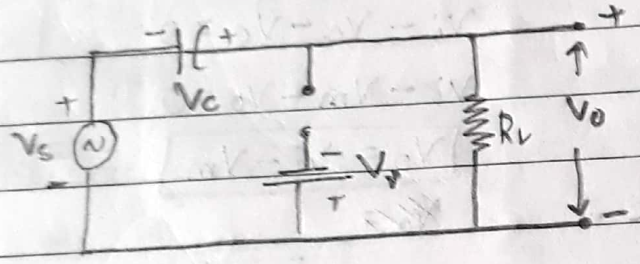
$V_s + V_c + V_\gamma = 0$

$V_c = -V_s - V_\gamma$

$V_c = -(-V_p) - V_\gamma$

$\boxed{V_c = V_p - V_\gamma}$

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



$V_s + V_c - V_o = 0$

$V_o = V_s + V_c$

$\boxed{V_o = V_s + V_p - V_\gamma}$

CASE 1: When $V_s = 0$

$V_o = V_p - V_\gamma$

CASE 2: When $V_s = V_p$

$V_o = 2V_p - V_\gamma$

CASE 3: When $V_s = -V_p$

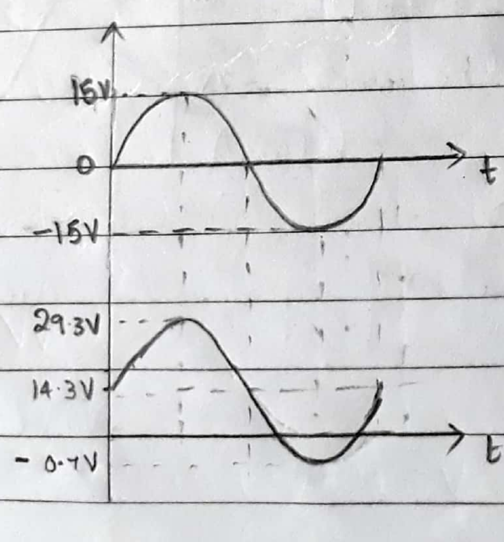
$V_o = -V_\gamma$

considering $V_p = \pm 15V$
and $V_\gamma = 0.7V$

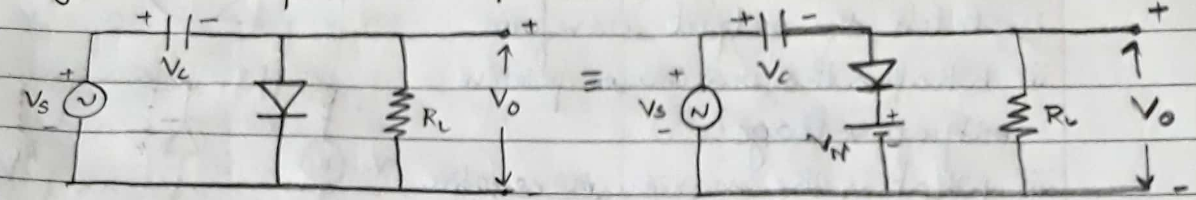
CASE 1: $V_o = 15 - 0.7 = 14.3V$

CASE 2: $V_o = 30 - 0.7 = 29.3V$

CASE 3: $V_o = -0.7V$

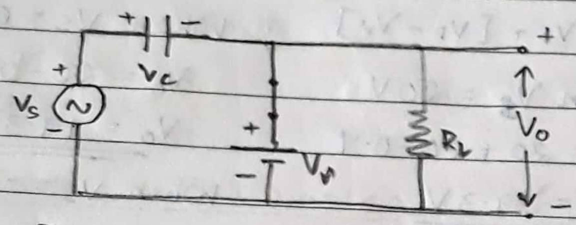


– Negative clamper with practical diode:



1. During positive half cycle

The diode conducts since it is forward biased



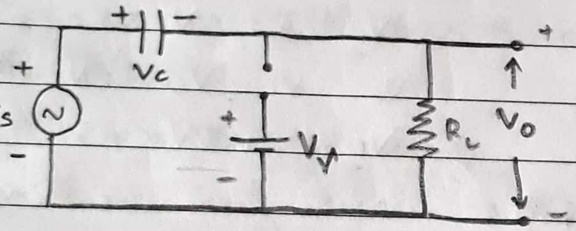
$$V_s - V_c - V_\gamma = 0$$

$$V_c = V_s - V_\gamma$$

$$\boxed{V_c = V_p - V_\gamma}$$

2. During negative half cycle

The diode does not conduct since it is reverse biased



$$V_s - V_c - V_o = 0$$

$$V_o = V_s - V_c$$

$$V_o = V_s - [V_p - V_\gamma]$$

$$\boxed{V_o = +V_s - V_p + V_\gamma}$$

CASE 1: When $V_s = 0$

$$V_o = V_\gamma - V_p$$

CASE 2: When $V_s = V_p$

$$V_o = V_\gamma$$

CASE 3: When $V_s = -V_p$

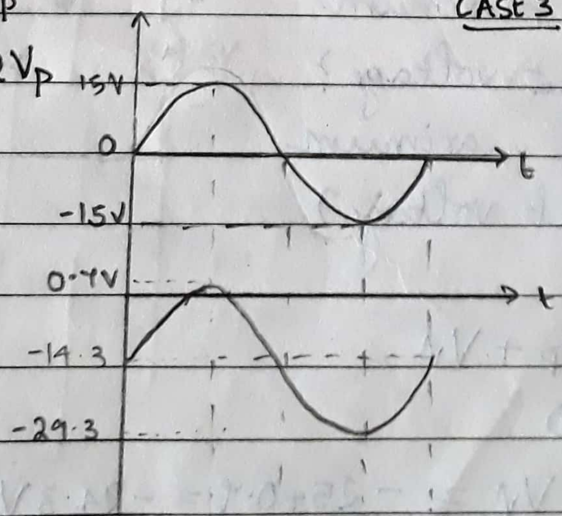
$$V_o = V_\gamma - 2V_p$$

considering $V_p = \pm 15V$ and $V_\gamma = 0.7V$

CASE 1: $V_o = 0.7 - 15 = -14.3V$

CASE 2: $V_o = 0.7V$

CASE 3: $V_o = 0.7 - 30 = -29.3V$



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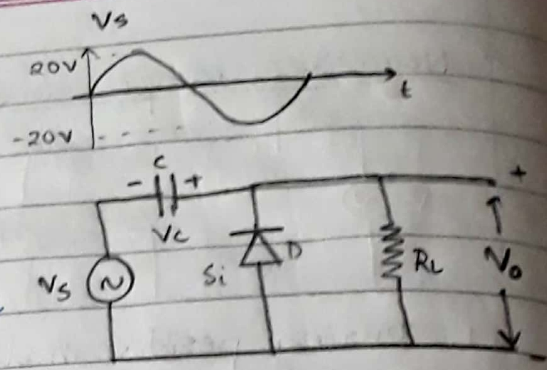
Q1: For the circuit shown
i. sketch the output waveform
ii. What is the maximum positive output voltage?
iii. What is the maximum negative output voltage?



Sol: $V_c = V_p - V_\gamma$

$V_c = 20 - 0.7$

$V_c = 19.7V$

$V_o = V_s + [V_p - V_\gamma]$

When $V_s = 20V$

$V_o = 20 + 20 - 0.7$

$\underline{V_o = 39.3V}$

When $V_s = 0$

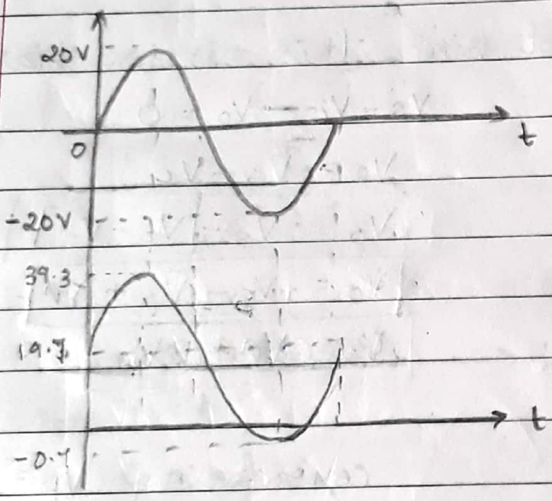
$V_o = 20 - 0.7$

$\underline{V_o = 19.3V}$

When $V_s = -20$

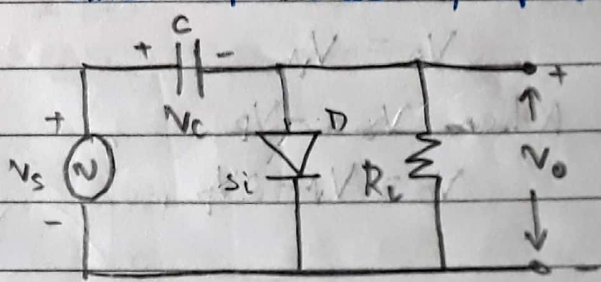
$V_o = -20 + 20 - 0.7$

$\underline{V_o = -0.7V}$



Q2: For the circuit shown
i. sketch the output waveform
ii. What is the maximum positive output voltage?
iii. What is the maximum negative output voltage?

Given: $V_p = 25V$, $V_\gamma = 0.7V$



Sol: $V_o = V_s - V_p + V_\gamma$

When $V_s = 0$

$V_o = -V_p + V_\gamma = -25 + 0.7 = \underline{-24.3V}$

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When $V_s = 25V$

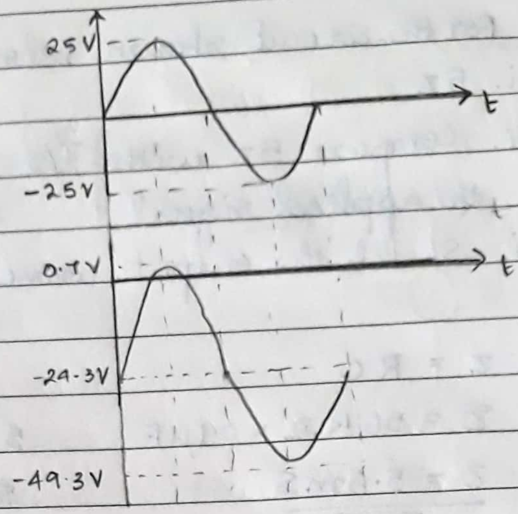
$V_o = 25 - 25 + 0.7$

$\underline{V_o = 0.7\,V}$

When $V_s = -25V$

$V_o = -25 - 25 + 0.7$

$\underline{V_o = -49.3V}$

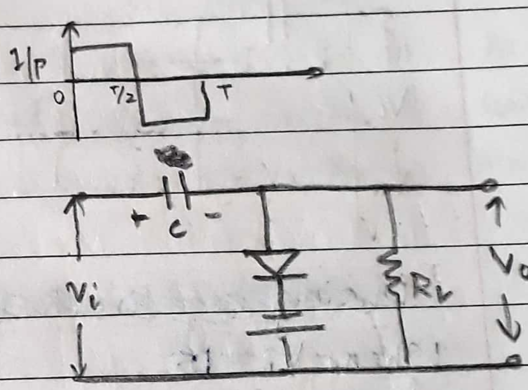


* <u>Capacitor in clamping:</u>

τ_f - charging time

$\tau_f \approx T/2$

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



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

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

$$\boxed{5\tau >> T/2}$$

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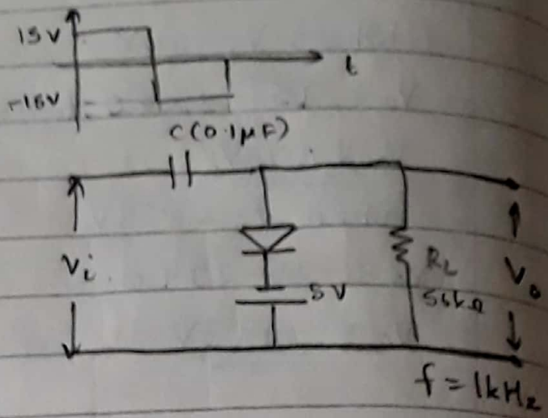
Q1: For the circuit shown below

i. 5τ

ii. compare 5τ with $T/2$ of the applied signal.

iii. Sketch the output waveform



Sol:

i. $\tau = RC$

$\tau = 56k\Omega \times 0.1\mu F$

$\tau = 5.6mS$

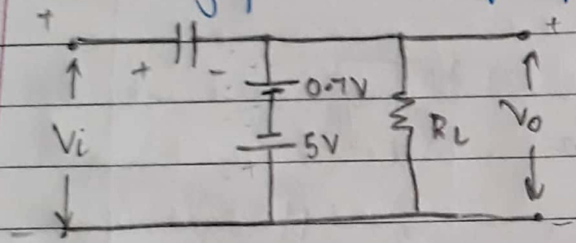
$5\tau = 5 \times 5.6ms$

$5\tau = 28ms$

ii. $T/2 = 0.5ms$

$\therefore 5\tau << T/2$

During positive Half cycle



$V_c = V_i + 4.3$

$V_c = 19.3V$

$V_o = V_i - V_c$

When $V_i = 15$

$V_o = 15 - 19.3$

$V_o = -4.3V$

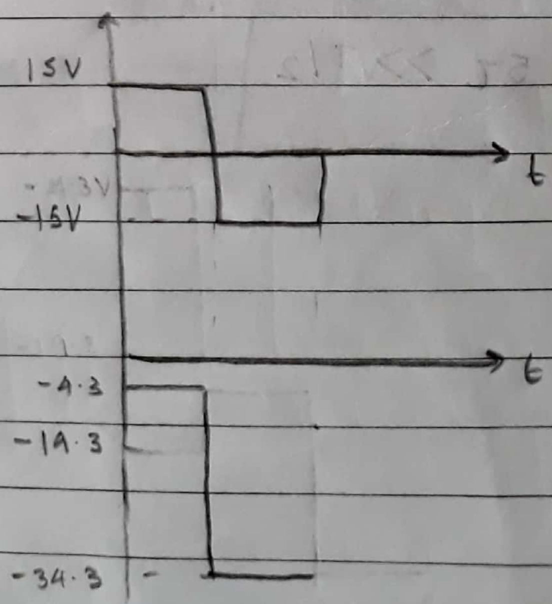
When $V_i = -15V$

$V_o = -15 - 19.3$

$V_o = -34.3V$

When $V_i = 0$

$V_o = -19.3V$



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UNIT - 4

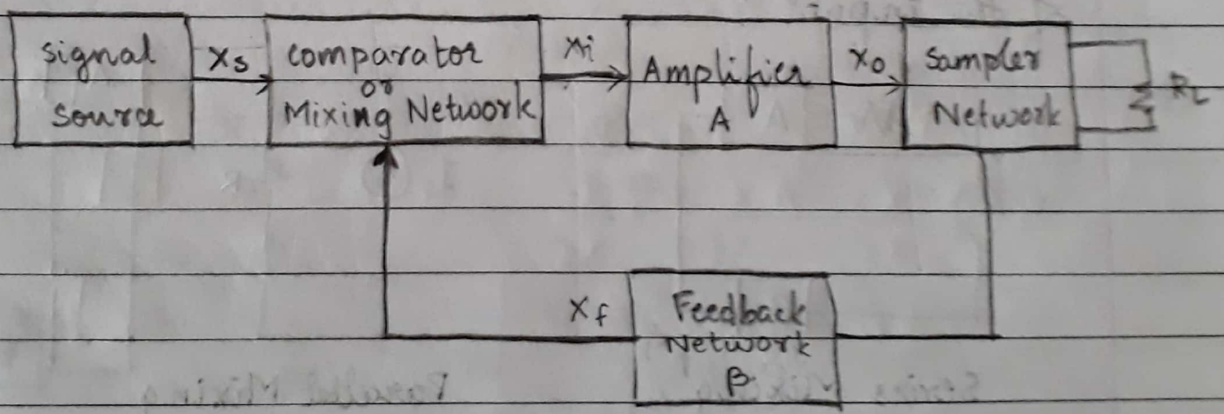
Feedback Amplifier

* **Negative feedback**
  - Increases bandwidth
  - Increases gain
  - Increases input impedence
  - Decreases output impedence
  - Decreases distortion

* **Types of Amplifier**

	INPUT	OUTPUT	GAIN
1. Voltage Amplifier	V_i	V_o	$A_v = V_o/V_i$
2. current Amplifier	I_i	I_o	$A_I = I_o/I_i$
3. Transconductance Amplifier	V_i	I_o	$G_m = I_o/V_i$
4. Transresistance Amplifier	I_i	V_o	$R_m = V_o/I_i$

* **Block Diagram of Typical Feedback Amplifier:**



$$x_i = x_s - x_f$$

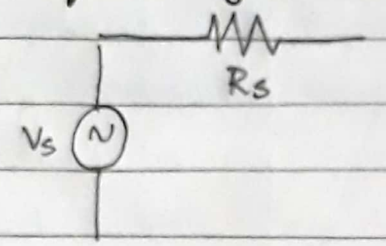
$$x_o = A x_i$$

$$\beta = \frac{x_f}{x_o}$$

* **Signal Source:**

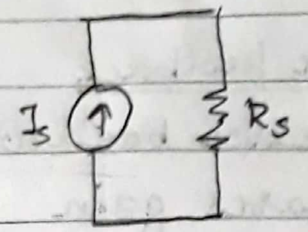
- Input canbe voltage or current.

If voltage source



Thevenin's Equivalent circuit

If current source

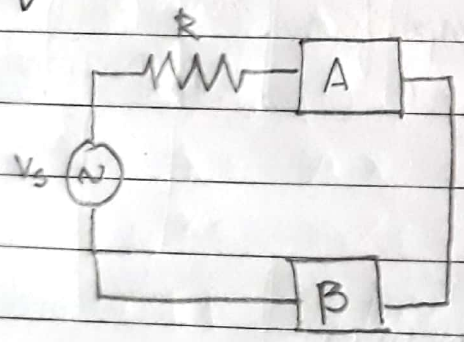


Norton's Equivalent circuit.

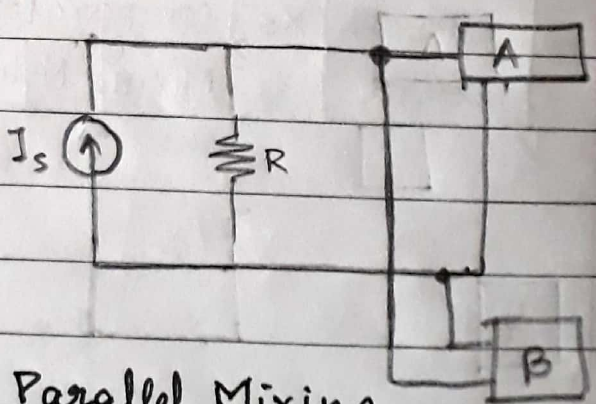
* **Comparator | Mixing Network:**

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

In transconductance and trans~~conductance~~resistance 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:

$A_V = \frac{V_o}{V_i}$ $\qquad A_I = \frac{I_o}{I_i}$

$A_{Vf} = \frac{V_o}{V_s}$ $\qquad A_{If} = \frac{I_o}{I_s}$

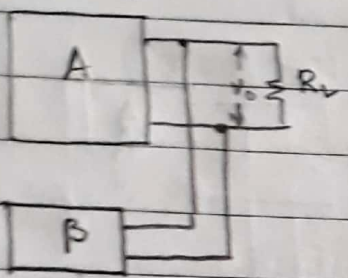
Voltage and current Amplifier gain with and without feedback.

$G_m = \frac{I_o}{V_i}$ $\quad R_m = \frac{V_o}{V_i}$ $\quad$ Transconductance and transresistance gain with and without feedback

$G_{mf} = \frac{I_o}{V_s}$ $\quad R_{mf} = \frac{V_o}{I_s}$

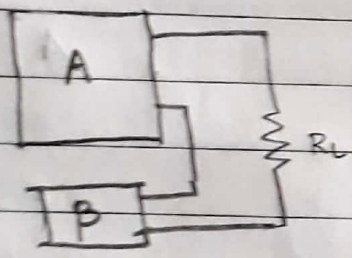
★ <u>Sampler Network</u>:

- <u>Voltage sampler</u> : Used when output of amplifier is is in terms of voltage.



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

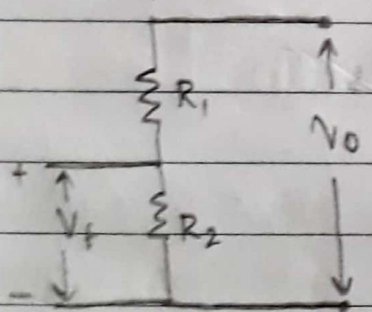
- <u>current sampler</u>: Used when output of amplifier is in terms of current.



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

★ <u>Feedback Network</u>:

The equivalent circuit for feedback network is given by



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

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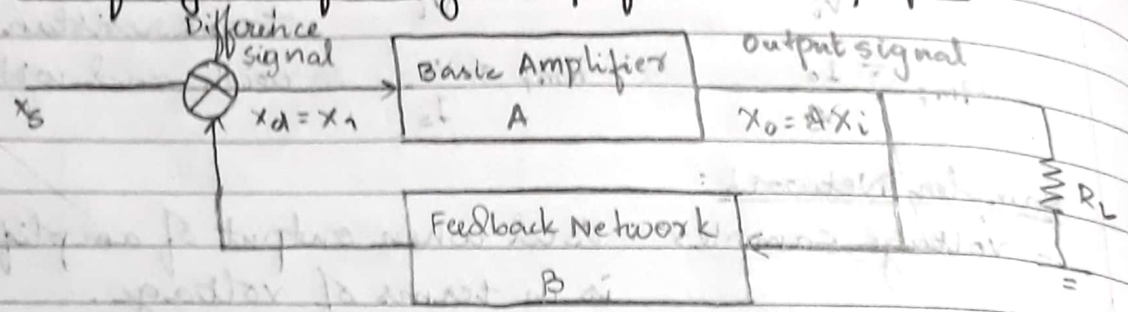
★ Transfer gain of single loop feedback amplifier:



gain without feedback (open loop gain)

$$A = \frac{x_o}{x_i}$$

$$\Rightarrow \quad x_o = Ax_i \quad \text{——— ①}$$

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

$$x_o = A(x_s - x_f)$$

wkt $x_f = \beta x_o$

$$x_o = A(x_s - \beta x_o)$$

$$x_o = Ax_s - A\beta x_o$$

dividing by x_s on both sides

$$\frac{x_o}{x_s} = A\frac{x_s}{x_s} - A\beta\frac{x_o}{x_s}$$

wkt $x_o / x_s = A_f$

$$A_f = A - A\beta A_f$$

$$A_f(1 + A\beta) = A$$

$$\boxed{A_f = \frac{A}{1 + A\beta}}$$

for $1 + A\beta < 1$

$A_f > A$

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

where $D = 1 + A\beta$

Gain in dB

$$20\log|A_f| = 20\log|A| - 20\log|D|$$

★ **Effect of negative feedback on bandwidth of an amplifier:**

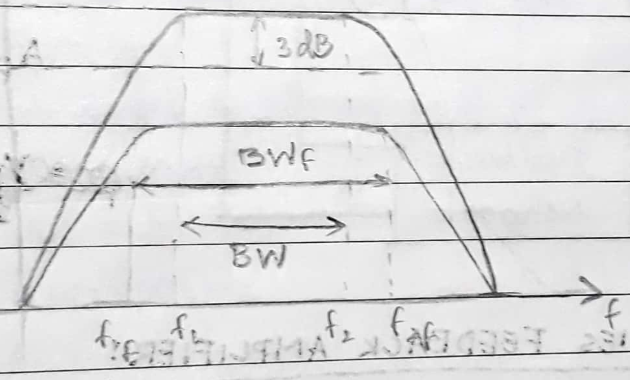
Gain Bandwidth product with feedback = Gain Bandwidth product without feedback

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

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

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

$$\boxed{BW_f = (1+A\beta)(BW)}$$



$f_2 \gg f_1$

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

$BW = f_2 - f_1$

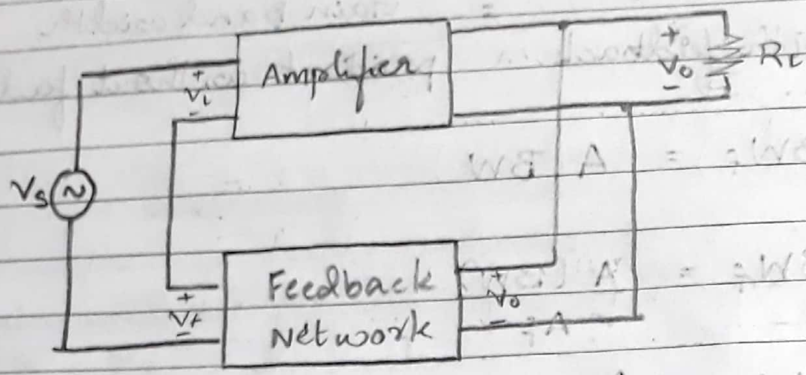
$BW_f = f_{2f} - f_{1f}$

★ **Feedback Topologies:**

sampler = A mixer

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:

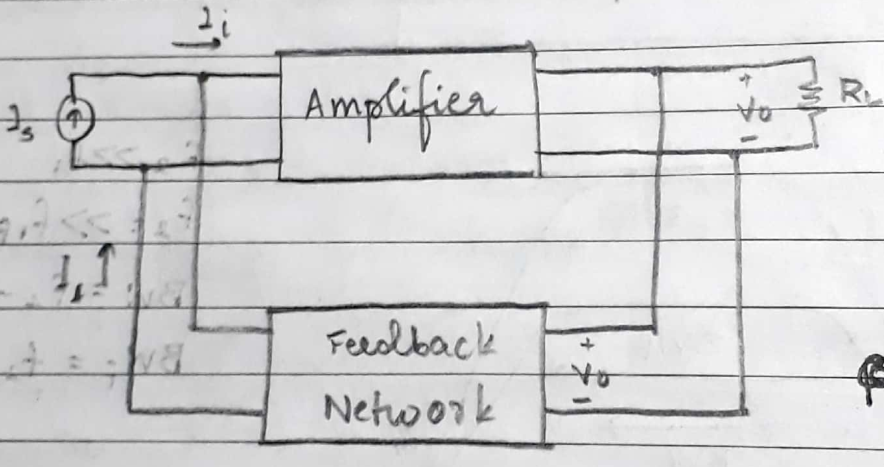


$$A = \frac{V_o}{V_i}$$

$$A_f = \frac{V_o}{V_s}$$

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

2. VOLTAGE SHUNT FEEDBACK AMPLIFIER:

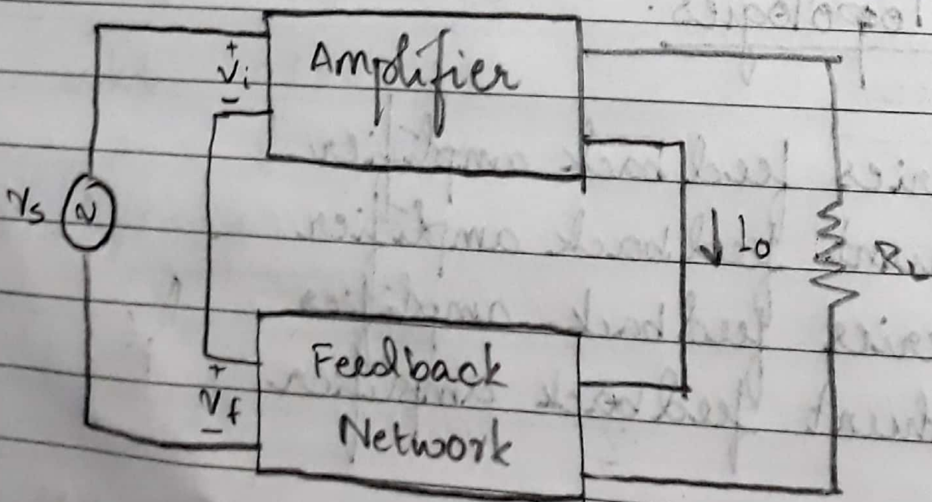


$$A = R_m = \frac{V_o}{V_i}$$

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

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

3. CURRENT SERIES FEEDBACK AMPLIFIER:



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

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

$$\beta = \frac{V_f}{I_o}$$

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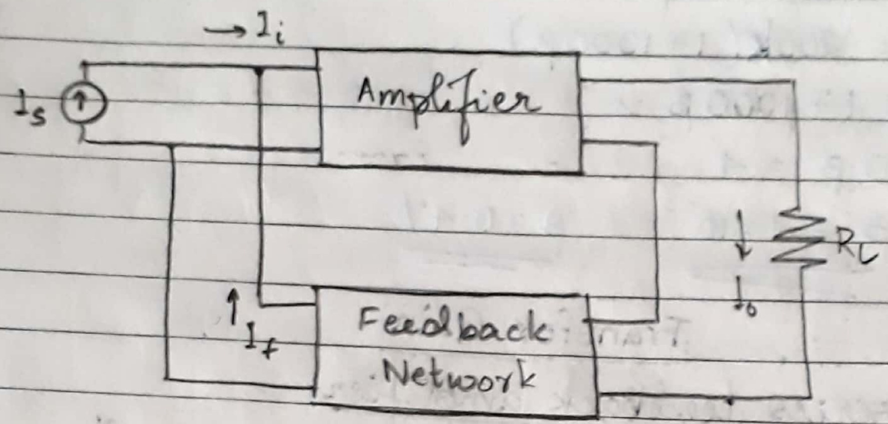
4. CURRENT SHUNT FEEDBACK AMPLIFIER:



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

$A_f = \frac{I_o}{I_s}$

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

Q1: An amplifier has a bandwidth of 200kHz 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 1MHz?

Sol: Given: $BW = 200kHz$

$A_V = 1000$

i. New bandwidth and gain

$\beta = 0.05$

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

$= (1 + 1000(0.05))(200kHz)$

$= 10.2MHz$

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

$A_f = 19.6$

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

$A_f(BW_f) = 19.6(10.2M)$

$= 199.92M$

$\approx 2 \times 10^8$

$A(BW) = 1000(200k)$

$= 2 \times 10^8$

iii. $BW_f = 1\,MHz$

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

$1M = 200k(1+1000\beta)$

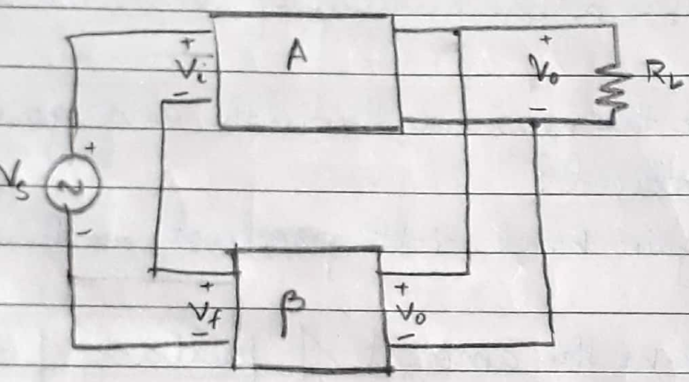
$5 = 1+1000\beta$

$1000\beta = 4$

$\beta = 4\times10^{-3}$ $\quad \beta = 0.4\%$

Transfer Gain

1. Voltage series feedback amplifier:



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

$V_o = AV_i$ —— (1)

KVL to the input

$V_s - V_i - V_f = 0$

$V_i = V_s - V_f$ —— (2)

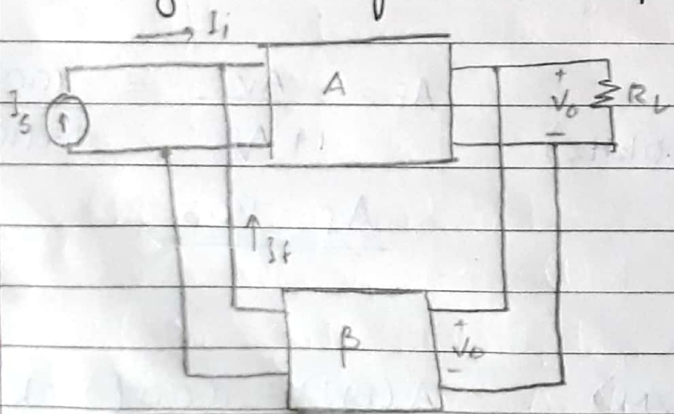
Substituting eq (2) in eq (1)

$V_o = A[V_s - V_f]$

$V_o = AV_s - A\beta V_o$

$$\boxed{A_{vf} = \frac{V_o}{V_s} = \frac{A_v}{1+A_v\beta}}$$

2. Voltage shunt feedback amplifier:



$A = \frac{V_o}{I_i}$ $\quad A_f = \frac{V_o}{I_s}$ $\quad \beta = \frac{I_f}{V_o}$

$V_o = AI_i$ —— (1)

KCL to input

$I_s - I_i - I_f = 0$

$I_i = I_s - I_f$

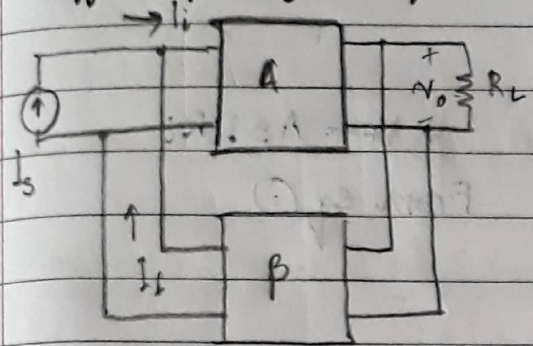
Substituting eq (2) in eq (1)

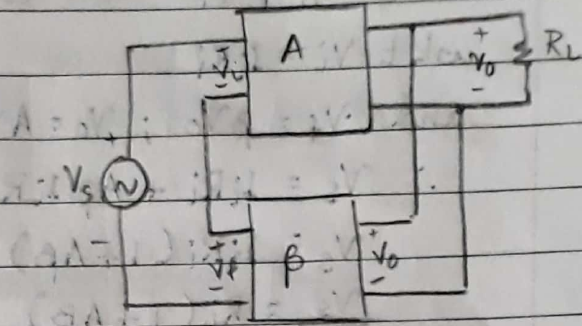
$V_o = A[I_s - I_f]$

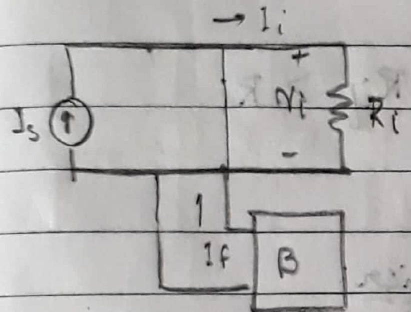
$V_o = AI_s - A\beta V_o$

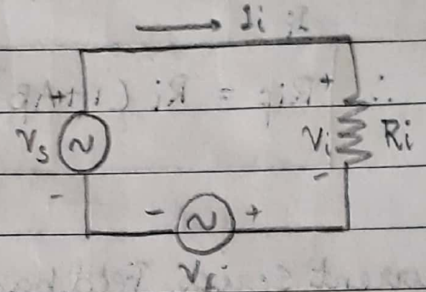
$$\boxed{R_{mf} = \frac{R_m}{1+R_m\beta}}$$

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









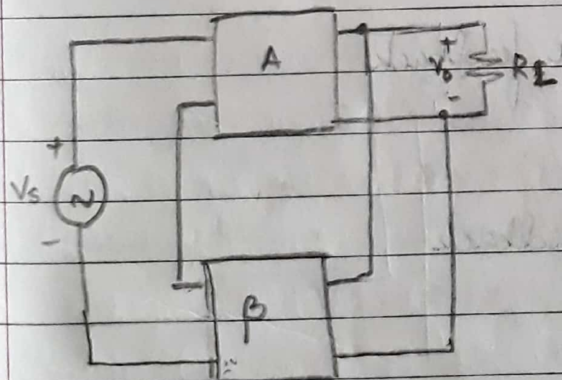
Input resistance decreases when shunt mixer is used

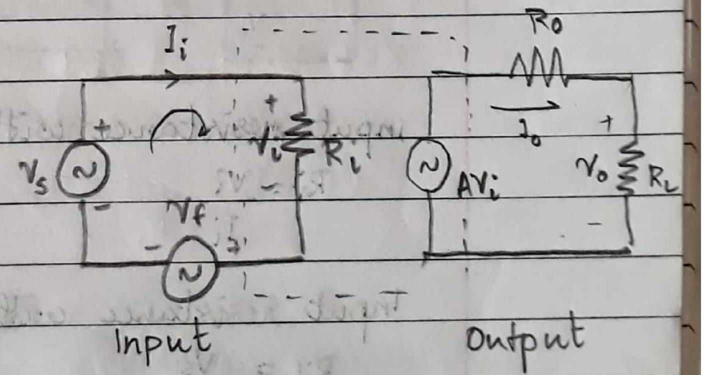
$R_i > R_{if}$

Input resistance increases when series mixer is used.

$R_i < R_{if}$

1. **Voltage Series Feedback Amplifier:**





Input resistance (without feedback)

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

Input resistance (with feedback)

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

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KVL to input circuit

$$V_s = V_i + V_f \quad \text{—— } (1)$$

wkt $V_i = I_i R_i$ $\Rightarrow V_f = A\beta I_i R_i$

and $V_f = \beta V_o$; $V_o = A V_i$

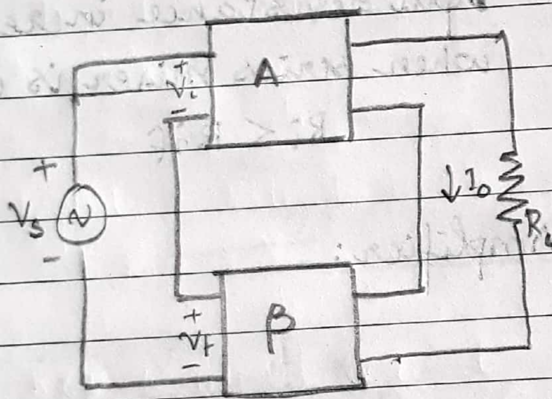
$\therefore V_s = I_i R_i + A\beta I_i R_i$ From eq (1)

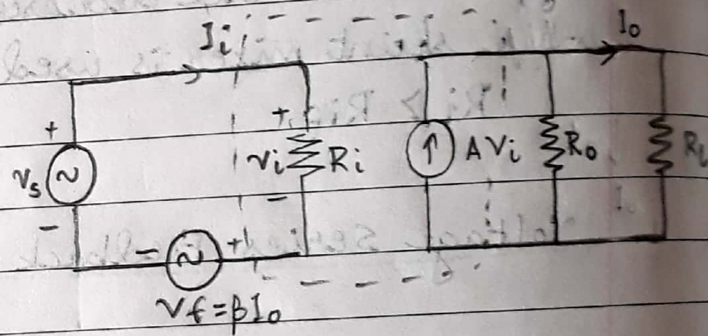
$V_s = I_i R_i (1 + A\beta)$

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

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

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

$$V_s = V_i + V_f \quad \text{—— } (1)$$

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

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

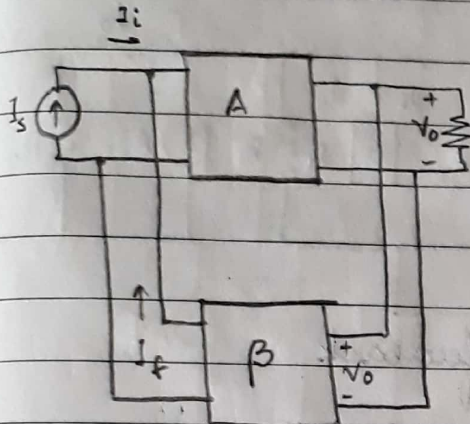
$\therefore V_s = I_i R_i + A\beta I_i R_i$ From eq (1)

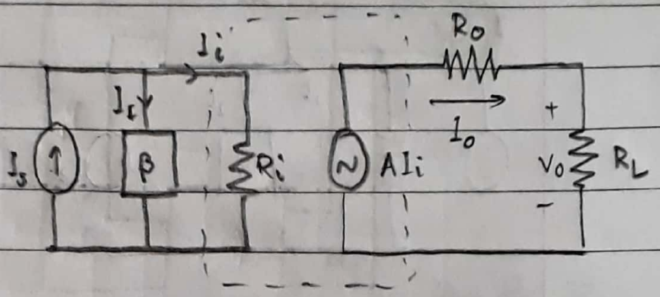
$V_s = I_i R_i (1 + A\beta)$

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

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

3. ## Voltage Shunt Feedback Amplifier:





Input resistance without feedback

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

Input resistance with feedback

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

KCL to input circuit

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

wkt $I_i = \dfrac{V_i}{R_i}$ and $I_f = \beta V_o$; $V_o = AI_i$

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

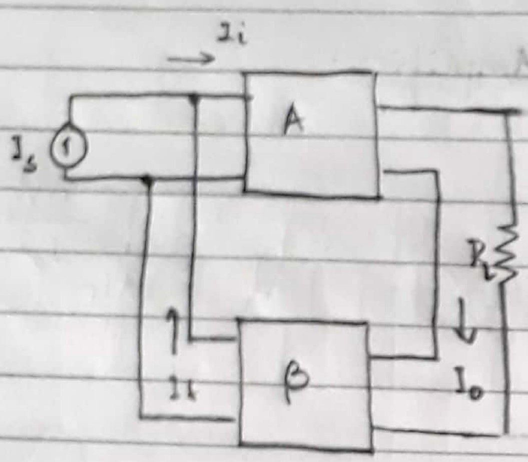
$$\therefore I_s = \frac{V_i}{R_i} + A\beta\frac{V_i}{R_i} \qquad \text{From eq (1)}$$

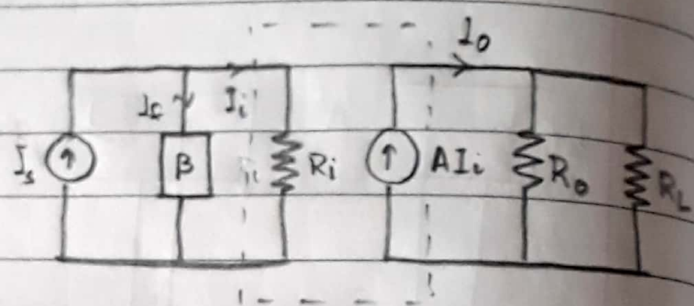
$$I_s = \frac{V_i}{R_i}(1 + A\beta)$$

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

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

4. 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 to input circuit

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

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

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

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

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

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

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

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* Effect of Negative Feedback on Output resistance:
(Dependent of type of sampler)

1. ~~Replace~~ Reduce voltage source or current source to zero.
2. Remove R_L and connect voltage source 'V'.

Output resistance decreases when voltage sampler is used.

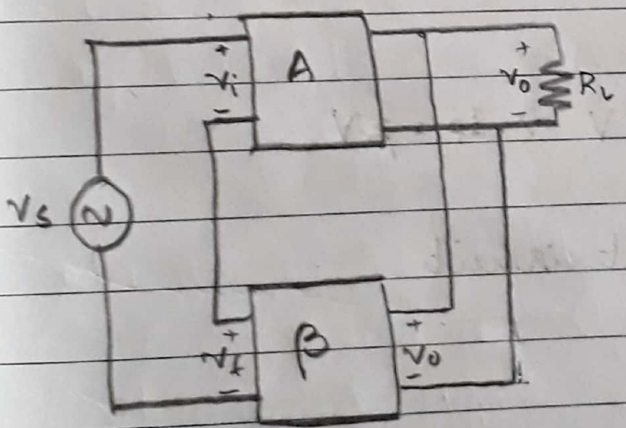
Output resistance increases when current sampler is used.

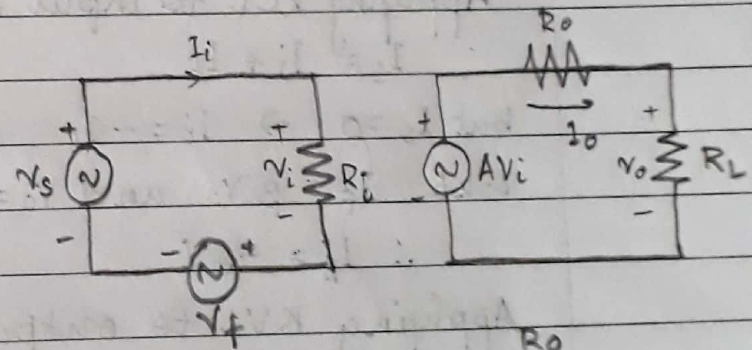
wkt

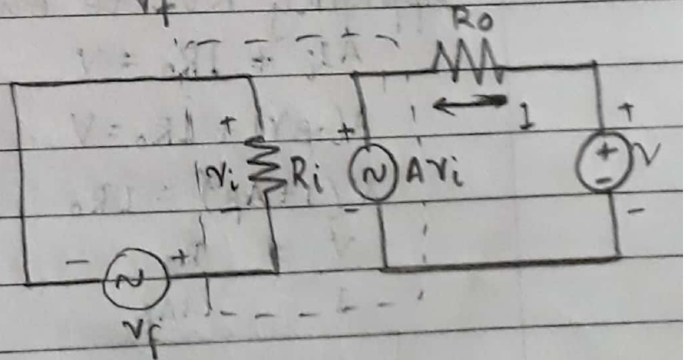
$$A_f = \frac{A}{1+A\beta} \quad \text{when } A\beta >> 1$$

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

1. Voltage series Feedback Amplifier:







Applying KVL to input circuit

- $V_i = -V_f$

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

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

Applying KVL to output circuit

$AV_i = -IR_o + V$

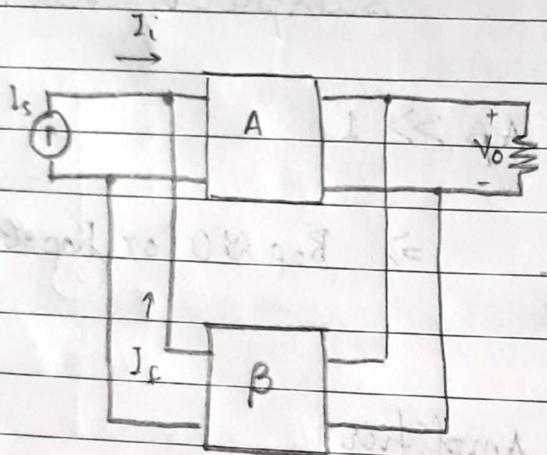
$-A\beta V = -IR_o + V$

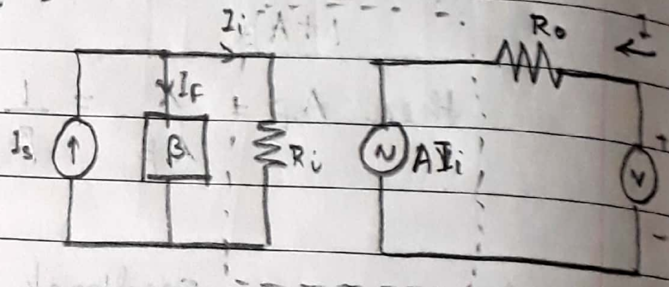
$(1+A\beta)V = I R_o$

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

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

2. Voltage Shunt Feedback Amplifier





Applying KCL to input circuit

$I_s = I_i + I_f$

but $I_s = 0 \Rightarrow I_i = -I_f$

wkt $I_f = \beta V_o$ and $V_o = V \Rightarrow I_f = \beta V$

$\therefore I_i = -\beta V$

Applying KVL to output circuit

$AI_i + IR_o = V$

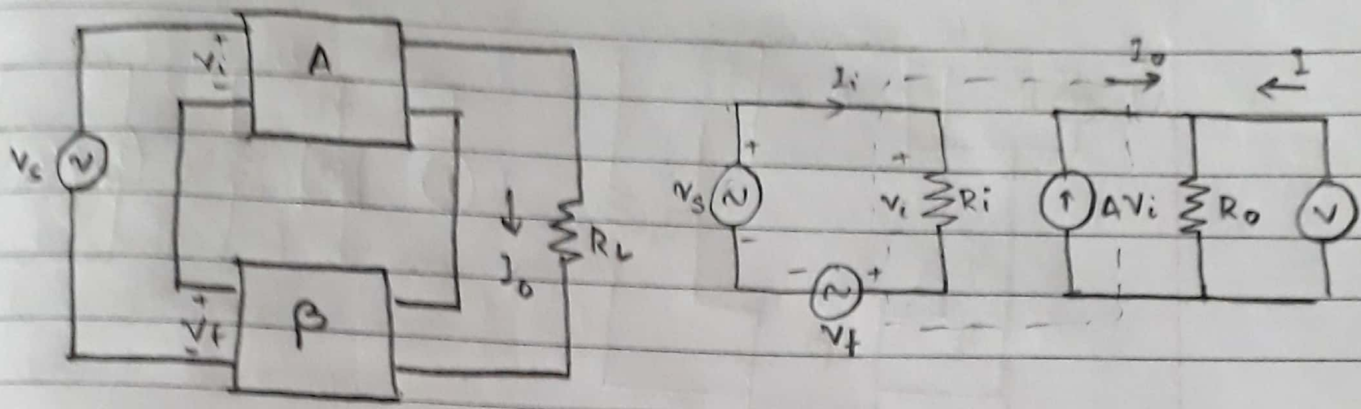
$A(-\beta V) + IR_o = V$

$V(1+A\beta) = IR_o$

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

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

3. Current Series Feedback Amplifier:



Applying KVL to input loop

$V_s = V_i + V_f$

but $V_s = 0$

$V_i = -V_f$

wkt $V_f = \beta I_o$

$\therefore V_i = -\beta I_o$

but $I_o = -I$

$\therefore V_i = \beta I$

Applying KCL to output loop

$AV_i + I = \frac{V}{R_o}$

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

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

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

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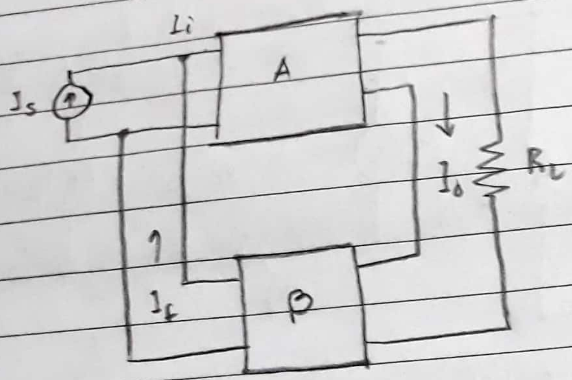
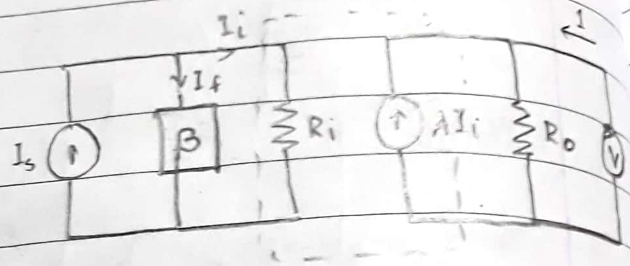
4. Current Shunt Feedback Amplifier:





Applying KCL to input loop

$I_s = I_i + I_f$

but $I_s = 0$

$\Rightarrow I_i = -I_f$

wkt $I_f = \beta I_o$

$\therefore I_i = -\beta I_o$

but $I = -I_o$

$\therefore I_i = \beta I$

Applying KCL to output loop

$AI_i + I = \dfrac{V}{R_o}$

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

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

$\therefore \boxed{R_{of} = R_o(1+A\beta)}$ $\Rightarrow R_{of} > R_o$

Page No.:

UNIT - 5

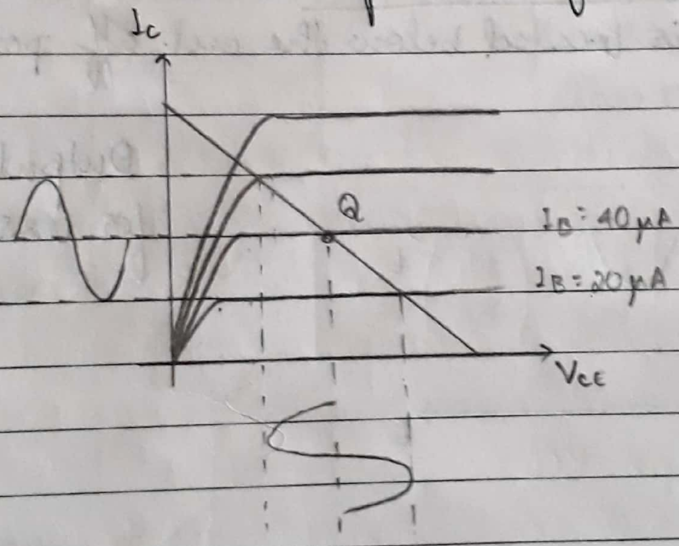
Power Amplifiers

* 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.

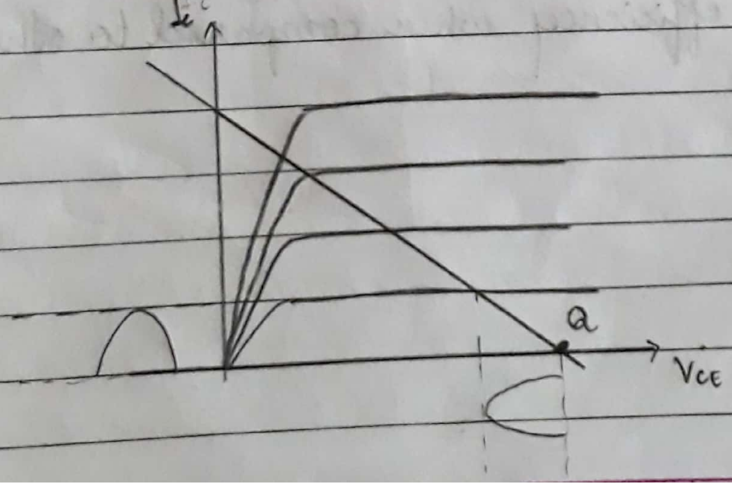
* CLASS A POWER AMPLIFIER:

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



collector current flows throughout the sine wave ($360°$)
Efficiency (25% to 50%)

* CLASS B POWER AMPLIFIER:



Q point is located at cut off region.
Distortion occurs
Efficiency (78.5%)
Collect flows for 180

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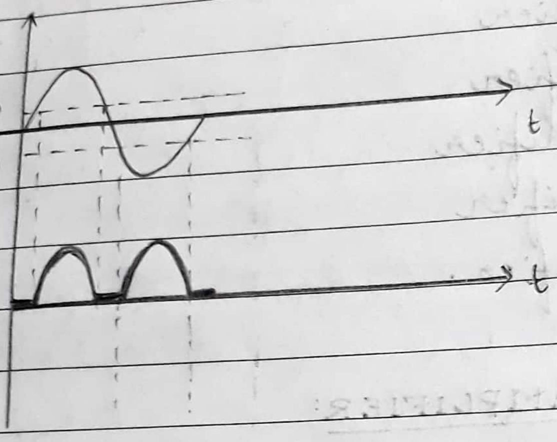
★ CLASS AB POWER AMPLIFIER:

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.



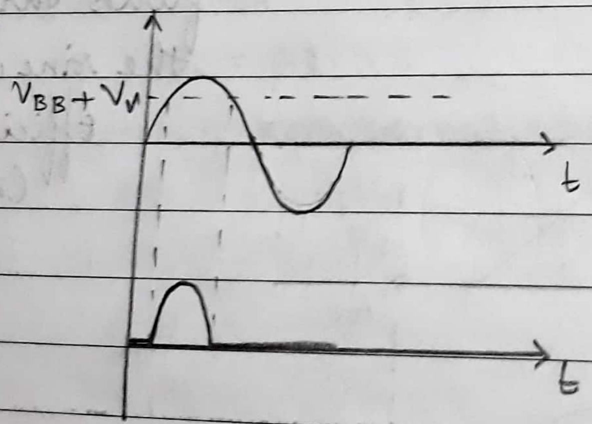
When the input voltage is less than bias voltage then the output is zero this is called crossover distortion.

~~[illegible]~~ 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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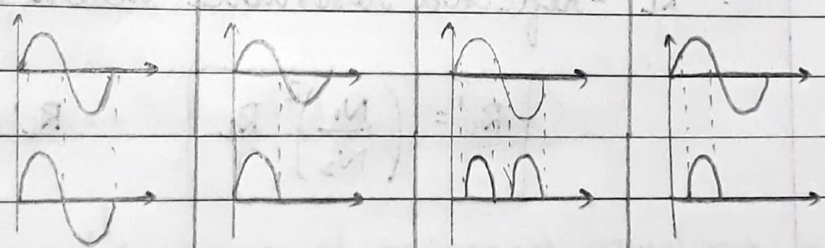
Page No.:

	CLASS	A	B	AB	C
1.	Q Point	centre	cut off Region	cut off region with bias voltage	Below the cut off region
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
5.	Input/Output waveform.				

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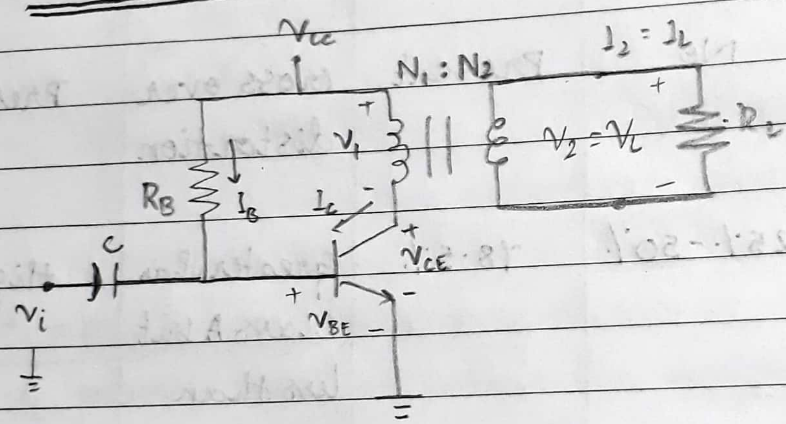
★ CLASS A POWER AMPLIFIER:

1. 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.

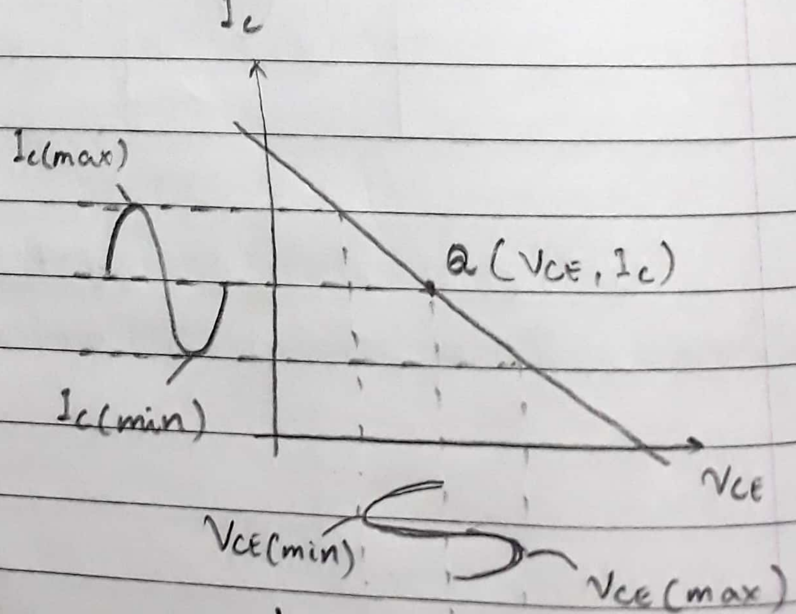
$$\boxed{R_L' = \left(\frac{N_1}{N_2}\right)^2 R_L}$$

$R_L' = R_o$

~~the~~ Applying KCL

$V_{cc} - V_{cE} = 0$

$V_{cc} = V_{CE}$



ac power

V_{1m} - peak value of primary voltage

I_{1m} - peak value of primary current.

ac power : $P_{ac} = \frac{V_{1m} \times I_{1m}}{2}$

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

$$P_{ac} = \frac{\frac{(V_{CEmax} - V_{CEmin})}{2} \times \frac{(I_{Cmax} - I_{Cmin})}{2}}{2}$$

$$P_{ac} = \frac{(V_{CEmax} - V_{CEmin})(I_{Cmax} - I_{Cmin})}{8}$$

V_{2m} - peak value of secondary voltage
I_{2m} - peak value of secondary current

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

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

$$P_{ac} = \frac{(V_{CEmax} - V_{CEmin})(I_{Cmax} - I_{Cmin})}{8}$$

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

Efficiency

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

$P_{idc} = V_{CEQ} I_{CQ}$

$$\eta = \frac{\frac{(V_{CEmax} - V_{CEmin})(I_{Cmax} - I_{Cmin})}{8}}{V_{CC} I_{CQ}}$$

$\Rightarrow P_{idc} = V_{CC} I_{CQ}$

$$\eta = \frac{\frac{(2V_{CC})(2I_{CQ})}{\cancel{8}\ 2}}{V_{CC} I_{CQ}}$$

$V_{CE\,min} = 0$

$I_{C\,min} = 0$

$V_{CEmax} = 2V_{CC}$

$I_{Cmax} = 2I_{C}$

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

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

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

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

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

$\because V_{CE(max)} = 2V_{cc}$

$V_{CE(min)} = 0$

$I_{cQ(max)} = 2I_c$

$I_{cQ(min)} = 0$

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

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

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

~~PAE~~ 11/7

Power dissipated

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

$P_d = P_{dc}$

$\boxed{P_d = V_{cc} I_{cQ}}$

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

i) Turns ratio of transformer.

ii) Calculate the power supply voltage.

Assume an ideal transformer (100% efficiency).

sol: Given: $P_{ac\,max} = 1W$ $\quad R_o = R_L' = 1000\Omega$

$R_L = 10\Omega$

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) $V_{cc} = ?$

$P_{ac\,max} = \frac{V_{cc}^2}{2R_L'}$

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

$V_{cc}^2 = 2000$

$V_{cc} = 44.72V \approx 45V$

Q2: A transformer coupled class A amplifier drives 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:

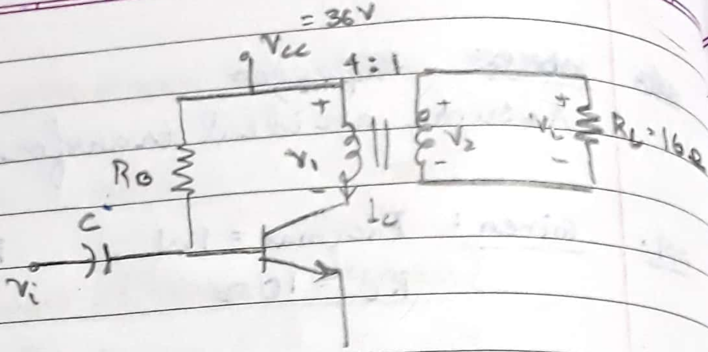
Given: $N_1 : N_2 = 4:1$

$V_{cc} = 36V$

$R_L = 16\,\Omega$

$P_{ac_{max}} = 2W$

$I_{CQ} = 150mA$



$V_2 = V_L$

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

i) ~~$R_L' = \frac{N_1}{N_2} R_L$~~

~~$R_L' = \frac{4}{1} \times 16 = 64\,\Omega$~~

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

i) $P_{pri} = P_{o(ac)} = P_L = 2W$

ii) rms voltage across load

$$P_L = \frac{V_{L(rms)}^2}{R_L}$$

$$V_{L(rms)} = \sqrt{P_L R_L} = \sqrt{2 \times 16}$$

$$V_{L(rms)} = 5.65\,V$$

iii) $$\frac{V_{1(rms)}}{V_{L(rms)}} = \frac{N_1}{N_2}$$

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

$$V_{1(rms)} = 22.6V$$

iv) $P_L = I_{L(rms)}^2 R_L$

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

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

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

$$I_{C(rms)} = \frac{\cancel{1}}{4} \times 0.353$$

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

v) $$\eta = \frac{P_{ac}}{P_{dc}} = \frac{P_{ac}}{V_{cc}\, I_{CQ}}$$

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

$$\eta = 37.03\,\%$$

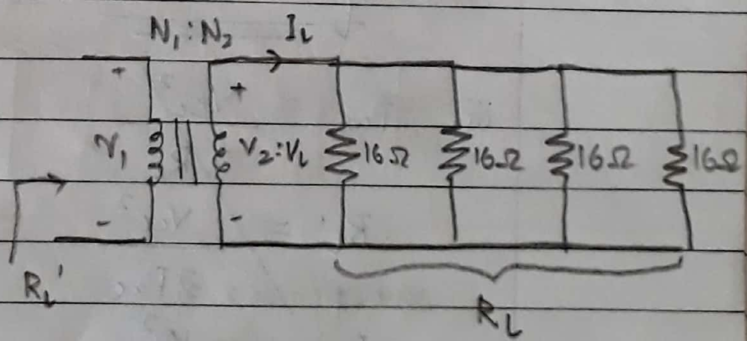
Q3: Find the turns ratio of the transformer required ~~for a~~ four parallel 16Ω loudspeakers so that they appear as an 8kΩ effective load.

Sol: $R_L' = 8k\Omega$

$R_L = 16\Omega \parallel 16\Omega \parallel 16\Omega \parallel 16\Omega$

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

$R_L = 4\Omega$



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

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

Q4: The following data is available for class A transformer coupled power amplifier.

$V_{CE(max)} = 18.5V$ $I_{C(max)} = 250mA$

$V_{CE(min)} = 1.5V$ $I_{C(min)} = 25mA$

$V_{cc} = 10V$ $I_{CQ} = 140mA$

$R_L = 8\Omega$

Find:

i. ac power delivered to the load

ii. conversion efficiency

iii. transformer turns ratio

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

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

$P_{ac} = 0.478W = 478.125mW$

ii. $\eta = \frac{P_{ac}}{P_{dc}} = \frac{P_{ac}}{V_{cc} I_{CQ}}$

$\eta = \frac{478.125m}{10(140m)} \times 100$

$\eta = 34.15\%$

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iii. $V_{CE(p)} = I_{c(p)} R_L'$

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

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

$$R_L' = 75.5\,\Omega$$

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

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

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

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

* **CLASS B POWER AMPLIFIER:**

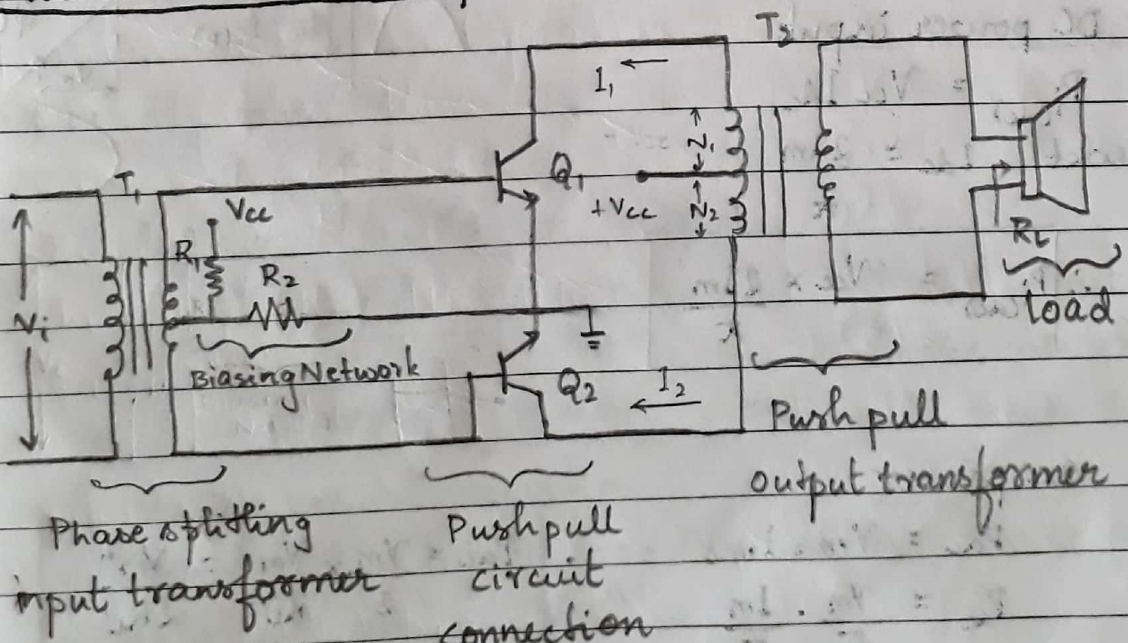
In Class B only one half of the cycle is the output. Hence by using two transistors ~~we~~ get both the half cycles as output.

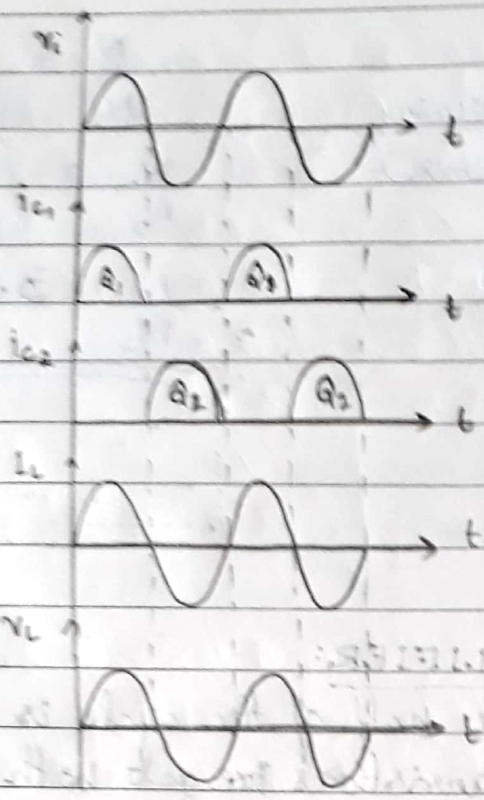
Based one the transistors used it is classified as:

i. Push Pull Power Amplifier (2n-p-n or 2p-n-p)

ii. Complementary symmetry Power Amplifier (n-p-n & p-n-p)

1. **Push Pull Power Amplifier:**





Disadvantages
- bulky, costly
- poor frequency response

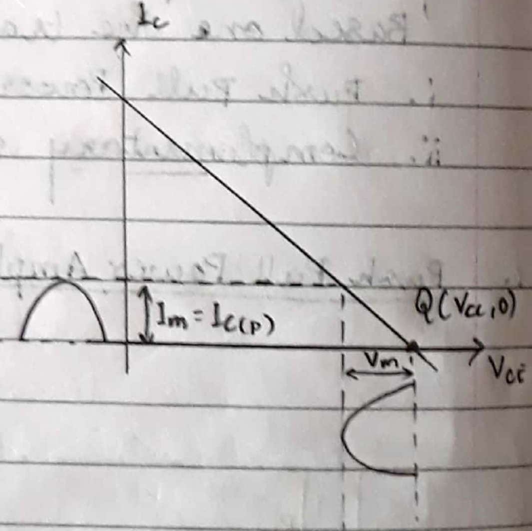
Advantages
- High efficiency

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

<u>DC operation of class B push pull power amplifier</u>

$V_{CEQ} = V_{cc} \quad I_{CQ} = 0$

$Q(V_{cc}, 0)$



<u>DC power input</u>

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

wkt $I_{dc} = \frac{2I_m}{\pi}$

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

<u>ac power</u>

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

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

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

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

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

Efficiency

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

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

Max efficiency

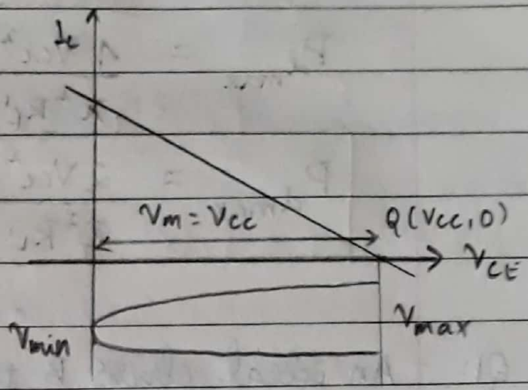
$$\eta = \frac{V_m \pi}{4V_{cc}} \times 100$$

$$V_m = V_{cc}$$

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

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

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



Power dissipation

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

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

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

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

$$\boxed{P_d = \frac{2V_{cc}V_m}{\pi R_L'} - \frac{V_m^2}{2R_L'}} \quad \text{—} \; 1$$

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

Max ~~Power~~ power dissipation.

differentiating eq 1 wrt V_m and equate it to zero.

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

$$\frac{2V_{cc}}{\pi \cancel{R_L'}} = \frac{V_m}{\cancel{R_L'}} \Rightarrow \boxed{V_m = \frac{2V_{cc}}{\pi}} \quad \text{—} \; 2$$

Substituting eq ② in eq ①

$$P_{d_{max}} = \frac{2V_{cc}}{\pi R_L'}\left(\frac{2V_{cc}}{\pi}\right) - \left(\frac{2V_{cc}}{\pi}\right)^2 \frac{1}{2R_L'}$$

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

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

$$\boxed{P_{d_{max}} = \frac{2V_{cc}^2}{\pi^2 R_L'}}$$

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

$V_{cc} = 20V = V_{CE(P)}$ $\quad h_{fe} = 20$

i) $P_{ac} = \frac{V_{cc}^2}{2R_L'}$ $\qquad R_L' = \left(\frac{N_1}{N_2}\right)^2 R_L$

$P_{ac} = \frac{(20)^2}{2(5)}$ $\qquad R_L' = \left(\frac{1}{2}\right)^2 (20)$

$P_{ac} = 40\,W$ $\qquad R_L' = 5\Omega$

iii) $P_{dc} = \frac{2V_{cc}I_m}{\pi} = \frac{2V_{cc}\cdot V_{CE(P)}}{\pi R_L'} = \frac{2V_{cc}^2}{\pi R_L'}$

$$P_{dc} = \frac{2(20)^2}{\pi \cdot 5} = 50.93\,W$$

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

ii) $P_d = P_{dc} - P_{ac}$
$P_d = 50.93 - 40$
$\underline{P_d = 10.93W}$

Power dissipation in each transistor

$\frac{P_d}{2} = \frac{10.93}{2} = \underline{5.47W}$

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).

$\Rightarrow R_L = R_L' = 8\Omega$

i. $I_{L(P)} = \frac{V_{CE(P)}}{R_L'} = \frac{22}{8} = \underline{2.75A}$

Rms load current $= \frac{I_{L(P)}}{\sqrt{2}} = \frac{2.75}{\sqrt{2}} = \underline{1.945A}$

ii. $I_{c(rms)} = I_{L(rms)}$ $\quad \because V_{L(P)} = V_{CE(P)}) \;\&\; R_L = R_L'$

$\underline{I_{c(rms)} = 1.945A}$ $\quad I_{c(P)} = I_{L(P)} = \underline{2.75A}$

iii. $I_{dc} = \frac{2Im}{\pi} = \frac{2(2.75)}{\pi} = \underline{1.75A}$ $\quad$ Each transistor: $\frac{1.75}{2} = \underline{0.875A}$

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

v. $P_{oac} = \frac{V_m I_m}{2} = \frac{22 \times 2.75}{2} = \underline{30.25W}$

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

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

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

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

Q3: For a class B push pull power amplifier with $V_{cc} = 25\,V$ driving an $8\,\Omega$ load find:

i. maximum input power.

ii. maximum output power.

iii. maximum circuit efficiency.

iv. maximum collector dissipation.

v. maximum collector dissipation in each transistor.

Sol: i. $P_{i_{dc(max)}} = \frac{2 V_{cc}^2}{\pi R_L'} = \frac{2 V_{cc}^2}{\pi R_L'} = \frac{2(25)^2}{\pi^2 (8)} = \underline{49.74\,W}$

ii. $P_{o_{ac(max)}} = \frac{V_m^2}{2 R_L'} = \frac{V_{cc}^2}{2 R_L'} = \frac{25^2}{2(8)} = \underline{\underline{39.06\,W}}$

iii. $\eta_{(max)} = \frac{P_{o_{ac(max)}}}{P_{i_{dc(max)}}} \times 100 = \frac{39.06}{49.74} \times 100 = \underline{\underline{78.5\%}}$

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

v. Each transistor $P_{d(max)} = \frac{15.83}{2} = \underline{\underline{7.91\,W}}$

Q4: Calculate the efficiency of class B push pull power amplifier for a supply voltage of $V_{cc} = 22\,V$ driving a $4\,\Omega$ load with peak voltage of

a. $V_{L(p)} = 22\,V$ b. $V_{L(p)} = 20\,V$ c. $V_{L(p)} = 4\,V$

compare and comment on the result.

Page No.:

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

Given: $V_{cc} = 22V$ $R_L = R_L' = 4\Omega$

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

$$\eta = \frac{\pi}{4} \times \frac{22}{22} \times 100 = 78.5\%$$

As $V_{L(P)}$ decreases efficiency decreases. When $V_{m(P)} = V_{CE(P)}$ efficiency is max.

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

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

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

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

Q5: In a class B power amplifier $V_{CE(min)} = 1V$ and $V_{cc} = 18V$. Calculate the collector circuit efficiency.

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

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

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

$$\eta = \frac{\pi}{4}\frac{V_m}{V_{cc}} \times 100 = \frac{\pi}{4}\frac{V_{CE(P)}}{V_{cc}} \times 100 = \frac{\pi}{4} \times \frac{17}{18} \times 100 = 74.17\%$$

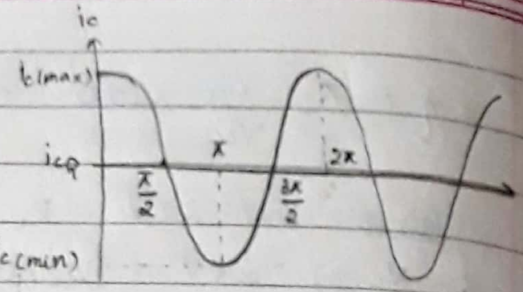
* **Distortion in Amplifiers:**

1. Frequency distortion
2. Amplitude distortion
3. Phase shift distortion
4. Harmonic distortion.

$$\%\ \text{Harmonic Distortion} = \frac{|A_n|}{|A_1|} \times 100$$ where A_n = n^{th} harmonic, A_1 - fundamental freq

Total Harmonic Distortion (THD) $= \sqrt{D_2^2 + D_3^2 + D_4^2 + \cdots D_n^2} \times 100$

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



collector current waveform

Basic equation

$i_c = i_{cq} + I_0 + I_1 \cos\omega t + I_2 \cos 2\omega t$

- i_{cq} → collector current at Q point
- I_0 → dc component
- $I_1 \cos\omega t$ → fundamental ac signal
- $I_2 \cos 2\omega t$ → second harmonic component

- At $\omega t = 0$

$i_{c(max)} = i_{cq} + I_0 + I_1 + I_2$ — (1)

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

$i_{cq} = i_{cq} + I_0 - I_2$ — (2)

- At $\omega t = \pi$

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

From eq (2) : $I_0 = I_2$

∴ From eq (1) : $i_{c(max)} = i_{cq} + 2I_0 + I_1$ — (4)

∴ From eq (3) : $i_{c(min)} = i_{cq} + 2I_0 - I_1$ — (5)

Adding eq (4) and eq (5)

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

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

Subtracting eq (4) and eq (5)

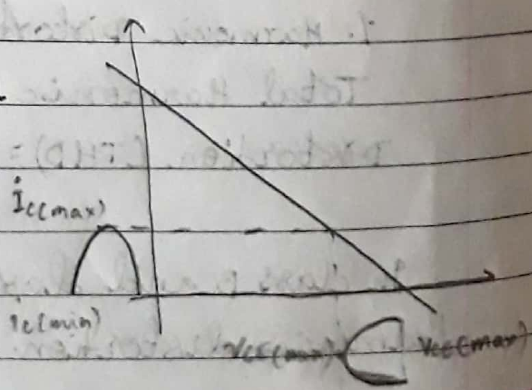
$i_{c(max)} - i_{c(min)} = 2I_1$

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

In terms of voltage

$V_0 = V_2 = \frac{V_{CE(max)} + V_{CE(min)} - 2V_{CEQ}}{4}$

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



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NOTES

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

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

$A_2 = I_0 = I_2 = \dfrac{i_{c(max)} + i_{c(min)} - 2I_{CQ}}{4}$

$HD\% = \dfrac{|A_2|}{|A_1|} \times 100 = \dfrac{\dfrac{i_{c(max)} + i_{c(min)} - 2I_{CQ}}{\cancel{4}\,2}}{\dfrac{i_{c(max)} - i_{c(min)}}{\cancel{2}}} \times 100$

$HD\% = \dfrac{1/2\left(i_{c(max)} + i_{c(min)}\right) - I_{CQ}}{i_{c(max)} - i_{c(min)}} \times 100$

$HD\% = \dfrac{1/2\left(V_{CE(max)} + V_{CE(min)}\right) - V_{CEQ}}{V_{CE(max)} - V_{CE(min)}} \times 100$

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

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

Sol: $HD\% = \dfrac{1/2\left(V_{CE(max)} + V_{CE(min)}\right) - V_{CEQ}}{V_{CE(max)} - V_{CE(min)}} \times 100$

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

$HD\% = \dfrac{1/2\left(V_{CE(max)} + V_{CE(min)}\right) - V_{CEQ}}{V_{CE(max)} - V_{CE(min)}} \times 100$

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

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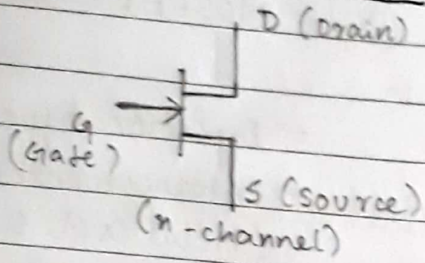
UNIT - 6

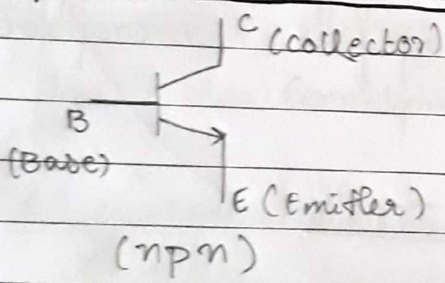
Field Effect Transistors Amplifiers (FET)

★ **Field Effect Transistor:**



→ voltage controlled device
The output (I_D) varies due to change in input voltage (V_{GS}).
→ Unipolar (majority charge carriers)
→ More stable to temperature variation
→ High input impedence (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:**

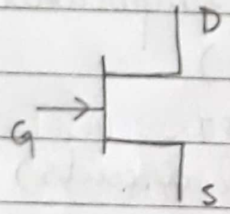


→ current controlled device (I_C controls I_B)
→ bipolar (both minority and majority charge carriers contribute)
→ less stable to temperature variation (thermal run away)
→ Input impedence is less than that of FET.
→ More noise when compared to FET.
→ Larger in size when compared to FET.
→ Types: npn 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

FET

- **JFET**
  - → n-channel
  - → p-channel



p-n junction between G and S
used in digital and linear amplifier.

- **MESFET**
  - → n-channel
  - → p-channel

Shockley Junction
(Metal Semiconductor Field Effect Transistor)
Small transit time and fast response Hence used in high frequency amplifiers (microwave amplifiers)

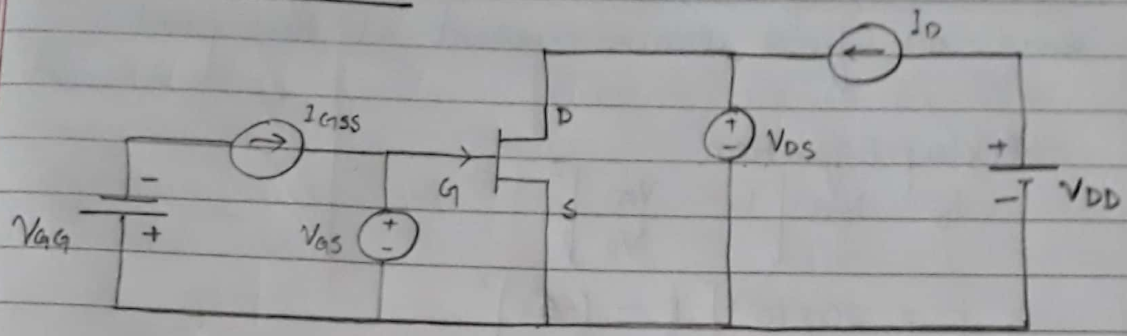
- **MOSFET**
  - → Depletion type
  - → Enhancement type

(Metal Oxide Semicon Field Effect Transisto
Input impedance is very very high, he most of VLSI design circuits use them. Memory and microprocessor

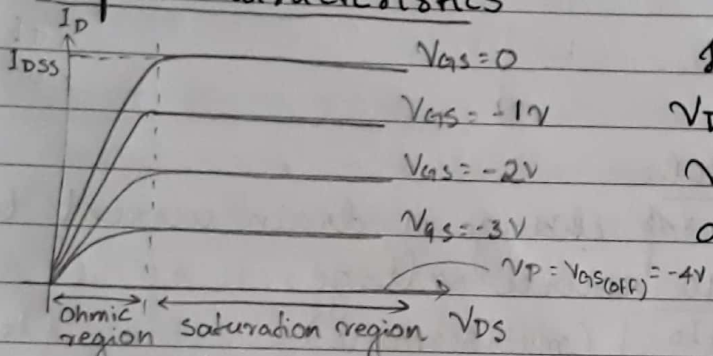
* Characteristics parameters of JFET's :

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

★ 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

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

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 $I_D = 0$

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

Sol: Shockley Equation

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

$$= 20\times10^{-3}\left[1 - \frac{(-4)}{(-5)}\right]^2$$

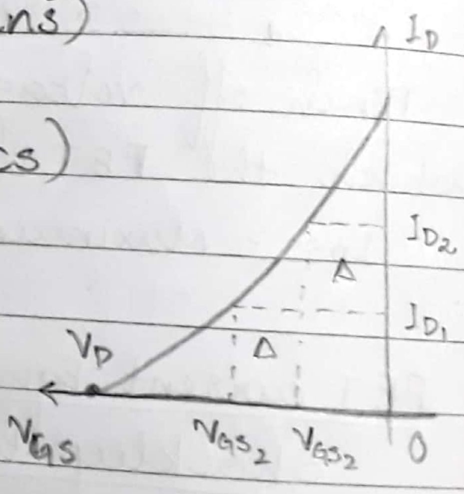
$$\underline{\underline{I_D = 0.8mA}}$$

★ **TRANSCONDUCTANCE:**

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

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

(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}

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

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

$$\boxed{g_m = g_{m_0}\left[1 - \frac{V_{GS}}{V_P}\right]}$$

where $g_{m_0} = \left[\frac{-2I_{DSS}}{V_P}\right]$

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Q: For a JFET if $I_{DSS} = 20mA$ and $V_{GS(off)} = -5V$ and $g_{mo} = 4m$ siemens. Determine the transconductance for $V_{GS} = -4V$.

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

$$= 4\times10^{-3}\left[1 - \frac{(-4)}{(-5)}\right]$$

$g_m = 0{\cdot}8mS$

★ INPUT RESISTANCE:

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

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

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

sol: $R_{in} = \left|\frac{V_{GS}}{I_{GSS}}\right| = \frac{10}{10\times10^{-9}} = 1000M\Omega$

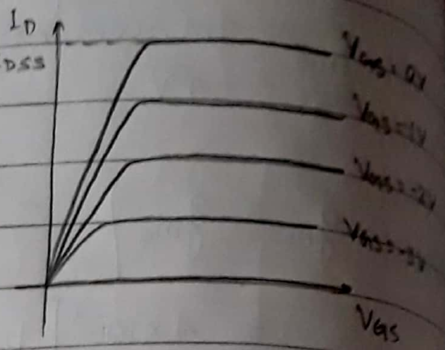
Q: Given $I_{GSS} = 1\mu A$ for $V_{GS} = 10V$ at $100°C$. Find the input resistance and compare with previous case.

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

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.



$$\boxed{r_d = \frac{\Delta V_{DS}}{\Delta I_D}}$$

r_d (50kΩ to few hundred kΩ)

impedence

Admittence : $\boxed{Y_{OS} = \frac{1}{r_d}}$

★ **AMPLIFICATION FACTOR:**

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

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

In terms of g_m and r_d

Multiplying and dividing by ΔI_D

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

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

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

★ **POWER DISSIPATION:**

Power dissipation is the product of output current to output voltage

$$\boxed{P_D = I_D V_{DS}}$$

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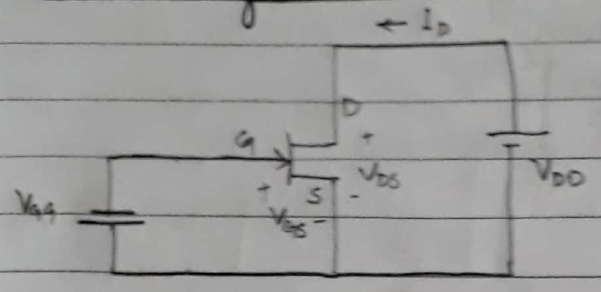
★ <u>small signal ac model</u>:



Given circuit

→ $I_D \propto V_{GS}$
(voltage controlled device)

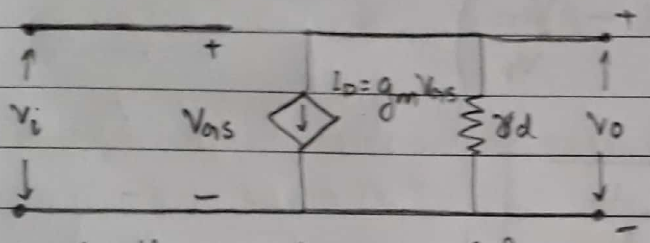
$I_D = g_m V_{GS}$

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

→ $V_{DS} \propto I_D$

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

$r_d = \frac{1}{Y_{os}}$ (output admittance)



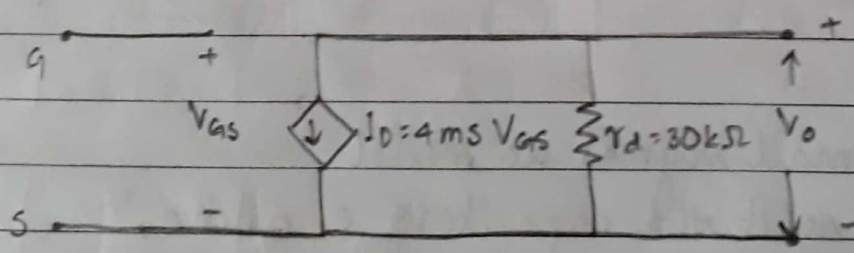
Small signal ac model

Q: A FET has $Y_{fs} = 4mS$ and $Y_{os} = 33.33\mu S$. Find
a. g_m and r_d
b. sketch the small signal ac model of FET.

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

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

b.



★ Relationship between I_D and g_m.

From shockley's equation

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

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

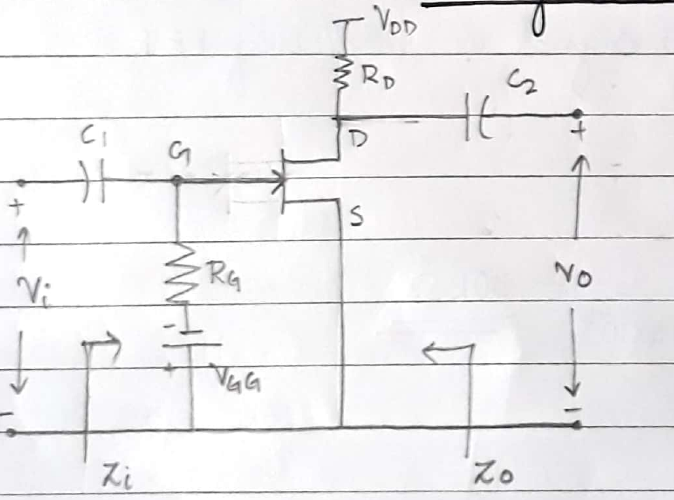
$$\sqrt{\frac{I_D}{I_{DSS}}} = 1 - \frac{V_{GS}}{V_P} \quad \text{—— (1)}$$

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

From eq (1)

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

★ JFET Common Source Amplifier using fixed Bias Configuration:



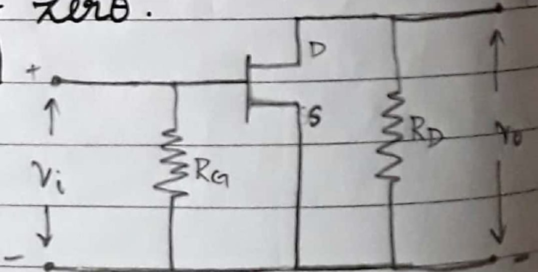
R_D and R_G are connected to avoid damage to the JFET due to large current from source.

C_1 and C_2 are the coupling capacitors.

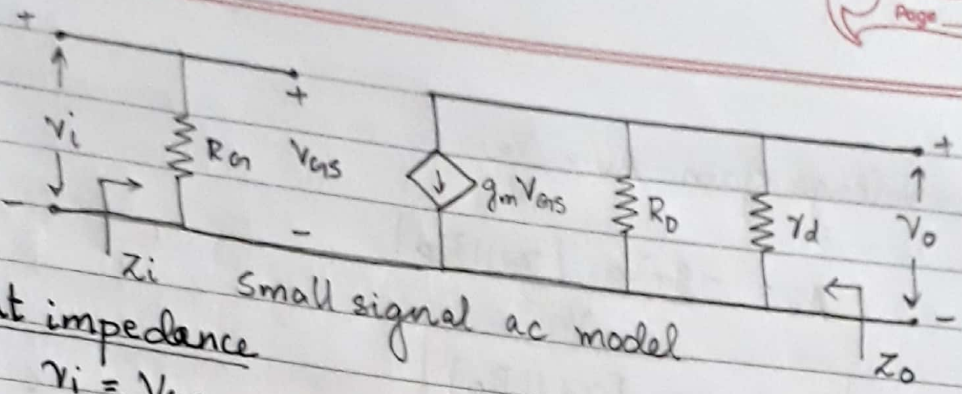
To get small signal ac model

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

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



ac equivalent circuit



Small signal ac model

Input impedance

$v_i = V_{GS}$

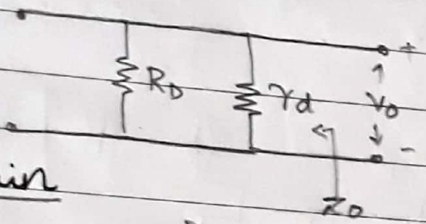
Open circuit the gate and source terminal to find the input impedance.

$\Rightarrow \boxed{Z_i = R_G}$

Output impedance

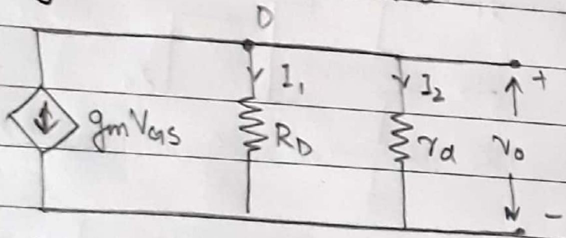
Reduce input voltage to zero to find the output impedance.

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



$\boxed{Z_o = r_d \parallel R_D}$

Voltage gain



Applying KCL to node D

$g_m V_{GS} + I_1 + I_2 = 0$

but $I_1 = \dfrac{V_o}{R_D}$, $I_2 = \dfrac{V_o}{r_d}$

$$\therefore \; g_m V_{GS} + \frac{V_o}{R_D} + \frac{V_o}{r_d} = 0$$

$$g_m V_{GS} = -V_o\left(\frac{1}{R_D} + \frac{1}{r_d}\right)$$

$$g_m V_{GS} = -V_o\left(\frac{R_D + r_d}{R_D r_d}\right)$$

$$V_o = -g_m V_{GS}\left(\frac{R_D r_d}{R_D + r_d}\right)$$

$$V_o = -g_m V_{GS}\left[r_d \parallel R_D\right]$$

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

$\therefore A_V = \frac{-g_m \cancel{V_{GS}} [r_d || R_D]}{\cancel{V_{GS}}}$

$$\boxed{A_V = -g_m [r_d || R_D]}$$

There is 180° phase shift between the input and o...

When $r_d \geq 10 R_D$

$\Rightarrow Z_o \approx R_D \quad \Rightarrow A_V = -g_m R_D$

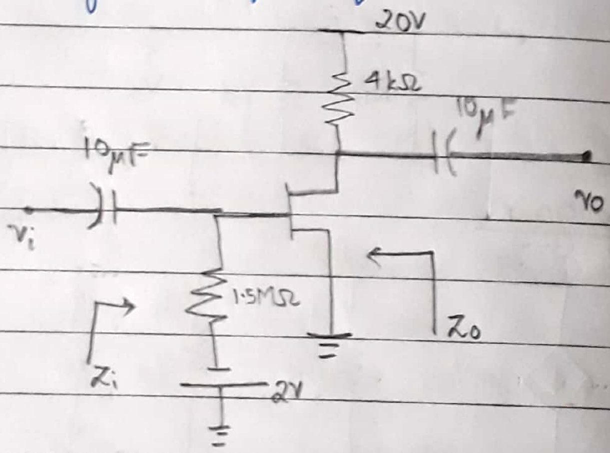
Q: For JFET amplifier shown below calculate Zi and zo, Av, ...
Zi, Zo and Av, neglecting the effect of rd and compare the re...

given:

$I_{DSS} = 15mA$

$V_P = -6V$

$Y_{os} = 25\mu S$



Sol:

$Z_i = R_G = 1.5M\Omega$

$Z_o = r_d || R_D$

$= 40k || 4k$

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

$Z_o = 3.63k\Omega$

$r_d = \frac{1}{Y_{os}} = \frac{1}{25 \times 10^{-6}} = 40k\Omega$

$A_V = -g_m [r_d || R_D]$

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

$g_{mo} = \frac{-2 I_{DSS}}{V_P} = \frac{-2(15m)}{-6}$

$g_{mo} = 5mS$

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

$g_m = 3.33mS$

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

$= -3.33 \times 10^{-3} \left[\frac{40k \times 4k}{44k} \right]$

$A_v = -12.11$

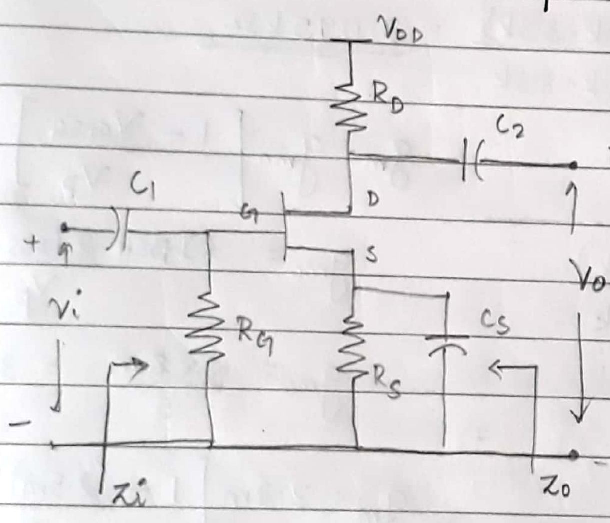
Neglecting the effect of r_d

$Z_i = R_G = 1.5 M\Omega$

$Z_o \cong R_D = 4k\Omega$

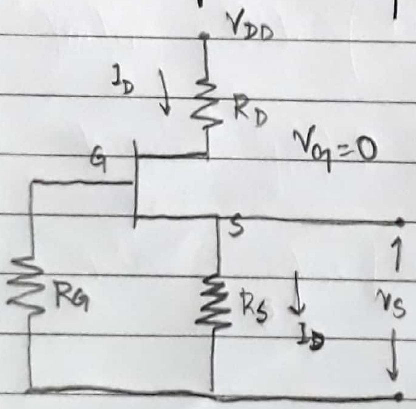
$A_v \approx -g_m R_D = -(3.33m \times 4k) = -13.32$

★ **JFET Common Source Amplifier using Self bias configuration**



C_1 and C_2 are the coupling capacitors.
C_S - by pass capacitor is used to increase gain as it ~~gives~~ 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.



$V_{GSQ} = V_G - V_S$

$V_{GSQ} = 0 - I_{DQ} R_S$

$V_{GSQ} = -I_{DQ} R_S$

Hence $Z_i = R_G$
$Z_o = R_D \| r_d$ (ac equivalent circuit)
$A_v = -g_m (R_D \| r_d)$

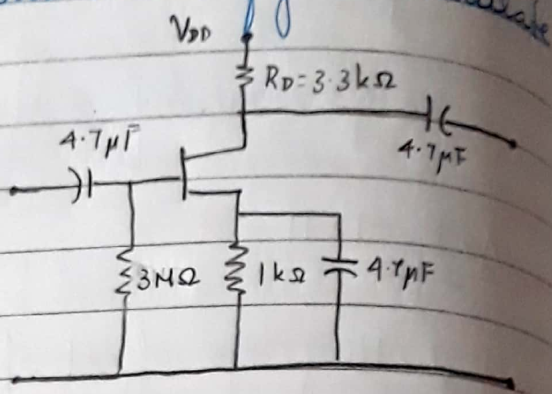
Q: For a JFET amplifier shown in the figure, calculate

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:

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

$I_{DQ} = 2.5mA$ $\quad Y_{os} = 20\mu S$.

Sol: i. $Z_i = R_G = \underline{3M\Omega}$

$$r_d = \frac{1}{Y_{os}} = \frac{1}{20\times10^{-6}} = \underline{50k\Omega}$$

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

ii. $A_V = -g_m (r_d \| R_D)$

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

$$g_{mo} = \frac{2I_{DSS}}{V_P}$$

$$g_{mo} = \frac{2\times8m}{5} = 3.2mS$$

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

$$g_m = \underline{1.6mS} \qquad V_{GSQ} = I_{DQ}\times R_S$$

$$A_V = -1.6m\frac{(50k\times3.3k)}{50k + 3.3k}$$

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

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

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

$$V_o = A_V V_i$$

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

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

iv. $Z_i = R_G = \underline{3M\Omega}$

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

$\underline{A_v = -5.28}$

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

$V_o = A_v V_i = (-5.28)(10m)$

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

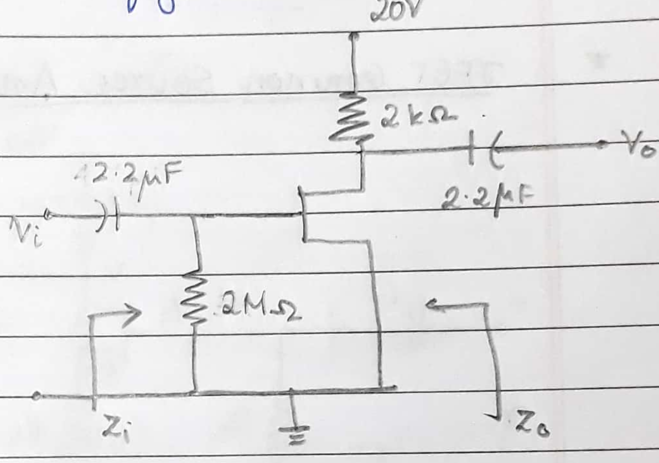
Q: For a JFET amplifier shown in the figure calculate:

i. Z_i and Z_o.

ii. A_v

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

iv. Z_i, Z_o, A_v, V_o neglecting r_d



Given:

$I_{DSS} = 5mA$

$V_p = -6V$

$Y_{os} = 40\mu S$

Sol: i. $Z_i = R_G = \underline{2M\Omega}$

$r_d = \frac{1}{Y_{os}} = \frac{1}{40\times10^{-6}} = \underline{25k\Omega}$

$Z_o = (r_d \parallel R_D) = \frac{(25k \times 2k)}{25k + 2k} = \underline{1.85k\Omega}$

ii. $A_v = -g_m (r_d \parallel R_D)$

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

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

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

$\underline{A_v = -3.09}$

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

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

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

$A_v = V_o / V_i$

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

iv. $Z_i = R_G = 2M\Omega$

$Z_o = R_D = 2k\Omega$

$A_v = -g_m R_D$

$A_v = -1.67m(2k)$

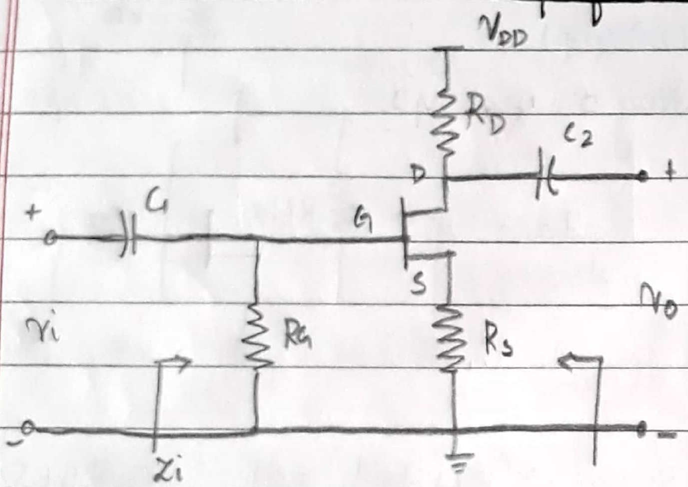
$A_v = -3.34$

$V_o = A_v V_i$

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

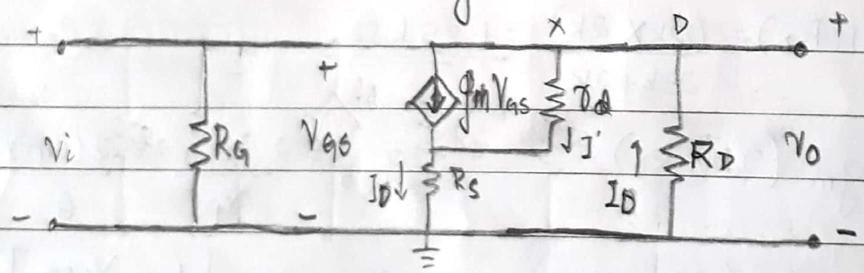
$V_o = 167mV$ (p-p)

★ JFET Common Source Amplifier with unbypassed R_s:



Here no by pass capacitor C_s is used.

ac small signal circuit



Input impedance

$\boxed{Z_i = R_G}$ — (1)

Gain

$A_v = \frac{V_o}{V_i}$ — (2)

$V_o = -I_D R_D$ — (3)

Apply KCL at node X

$$I_D = I' + g_m V_{gs} \quad —④$$

Apply KVL

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

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

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

Substituting eq ⑤ in eq ④

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

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

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

$$V_{gs} = V_i - I_D R_S \quad —⑦$$

Substitute eq ⑦ in eq ⑥

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

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

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

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

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

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

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Effect of unbypassed R_S on voltage gain

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

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

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

$$\boxed{A_V = -g_m (r_d \parallel R_D)}$$

Expression of A_V neglecting the effect of r_d

$r_d \geq 10(R_D + R_S)$

then $\boxed{A_V \approx \frac{-g_m R_D}{1 + g_m R_S}}$

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: Given: $R_G = 2M\Omega$

$R_S = 1k\Omega$

$R_D = 3.3k\Omega$

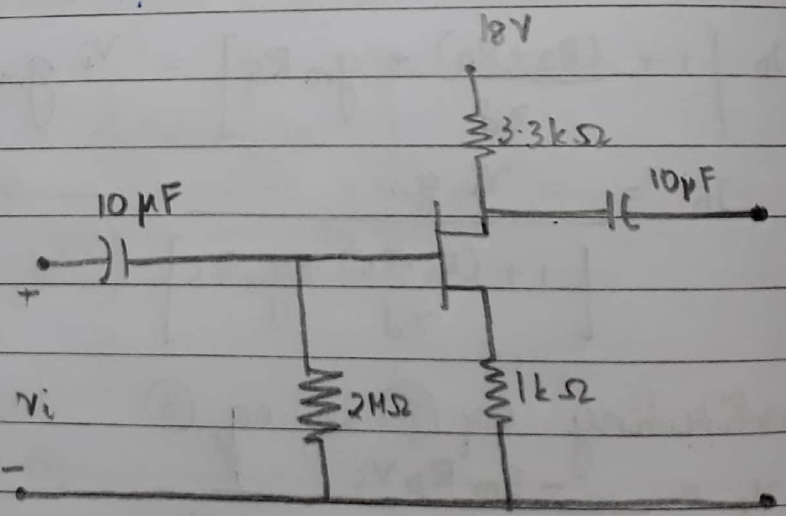
$V_{DD} = 18V$

$I_{DSS} = 8mA$

$V_P = -6V$

$I_{DSQ} = 2.5mA$

$Y_{os} = 25\mu S$



i. $z_i = R_G = 2M\Omega$

ii. $A_V = \frac{-g_m R_D}{1 + \frac{(R_D+R_S)}{r_d} + g_m R_S}$

$g_{m0} = \frac{-2I_{DSS}}{V_P} = \frac{-2(8m)}{-6} = 2.67m$

$r_d = \frac{1}{Y_{os}} = \frac{1}{25\mu S} = 40k\Omega$

$g_m = g_{m0}\sqrt{\frac{I_{DSQ}}{I_{DSS}}} = 1.55mS$

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$$A_v = \frac{-1.55\times10^{-3}(3.3\times10^{3})}{1+\frac{(3.3k+1k)}{40k}+(1.55\times10^{-3}\times1\times10^{3})} = \frac{-5.115}{2.66}$$

$$\underline{\underline{A_v = -1.92}}$$

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

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

$$V_o = \frac{-(1.55m)(3.3k)(50m)}{\left[1+\frac{(3.3k+1k)}{40k}+(1.55m\times1k)\right]}$$

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

iv. Neglecting effect of r_d

$$Z_i = R_G = 2M\Omega$$

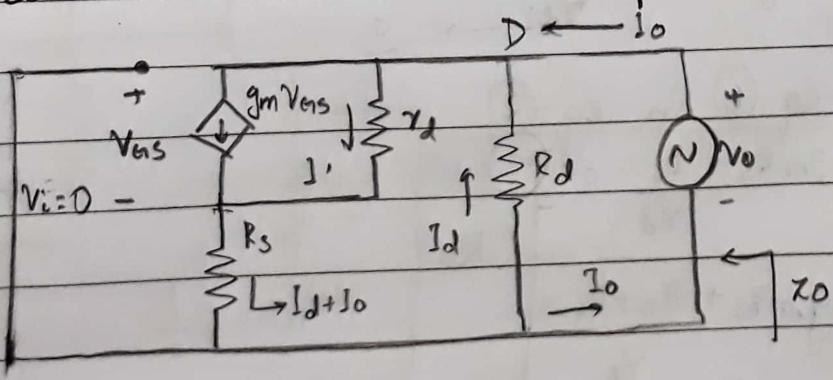
$$A_v = \frac{-g_m R_D}{1+g_m R_S} = \frac{-(1.55m)(3.3k)}{1+(1.55m)(1k)} = \underline{\underline{-2.0}}$$

$$V_o = \frac{-g_m R_D V_i}{1+g_m R_S} = \frac{-(1.55m)(3.3k)(50m)}{1+(1.55m)(1k)}$$

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

* Output Impedance

1. $V_i = 0$
2. connect V_o (source) at the output side of the circuit.



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$$Z_o = \frac{V_o}{I_o} \quad \text{——} \; (1)$$

$$V_o = -I_D R_D$$

Subtituting in eq (1)

$$Z_o = -\frac{I_D R_D}{I_o} \quad \text{——} \; (2)$$

At node D applying KCL

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

Applying KVL across r_d, R_D, R_S

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

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

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

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

Applying KVL at the input side of the circuit

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

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

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

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

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

$$\frac{-I_D}{I_o} = \frac{1 + g_m R_S + \frac{R_S}{r_d}}{1 + g_m R_S + \frac{R_D + R_S}{r_d}} \quad \text{——} \; (6)$$

Substituting eq (6) in eq (2)

$$\boxed{Z_o = \left[\frac{1 + g_m R_S + \frac{R_S}{r_d}}{1 + g_m R_S + \frac{R_D + R_S}{r_d}}\right] R_D}$$

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Neglecting the effect of r_d

$$\boxed{Z_o \approx R_D}$$

Q1: continued.

i. Z_o ii. Z_o neglecting the effect of r_d

Sol: i. $$Z_o = \left[\frac{1 + g_m R_S + \frac{R_S}{r_d}}{1 + g_m R_S + \frac{R_D + R_S}{r_d}}\right] R_D$$

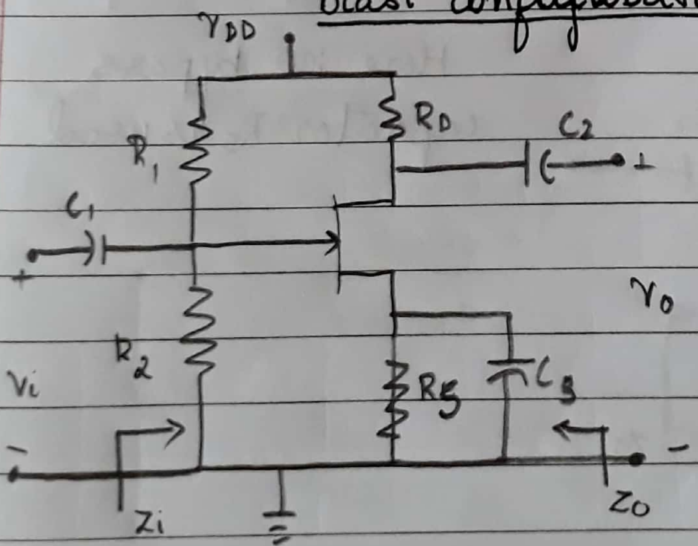
$$Z_o = \left[\frac{1 + (1.55m)(1k) + \frac{1k}{40k}}{1 + (1.55m)(1k) + \frac{3.3k + 1k}{40k}}\right] 3.3k$$

$$Z_o = \frac{8.4975k}{2.6575}$$

$$Z_o = 3.197k\Omega$$

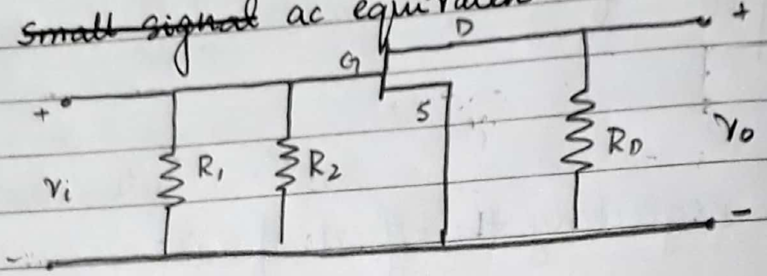
ii. $Z_o \approx R_D = 3.3k\Omega$ (neglecting the effect of r_d).

* JFET common source amplifier using voltage divider bias configuration:

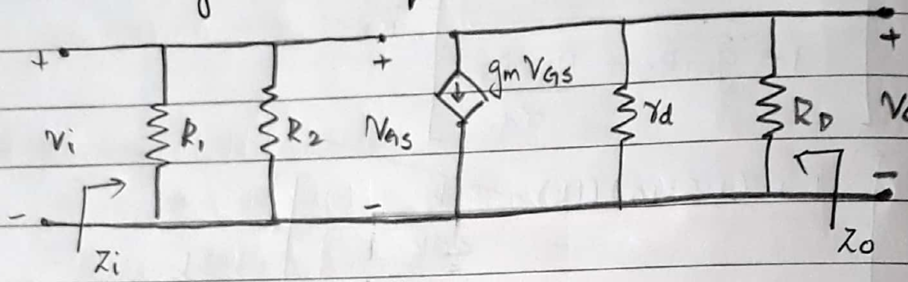


R_1 and R_2 are biasing resistors. C_1 and C_2 are the coupling capacitors. C_S - bypass capacitor.

~~Small signal~~ ac equivalent circuit



small signal ac equivalent circuit.



Input impedance

$\boxed{Z_i = R_1 \| R_2}$

Output impedance

$\boxed{Z_o = r_d \| R_D}$

Gain

$\boxed{A_V = -g_m [r_d \| R_D]}$

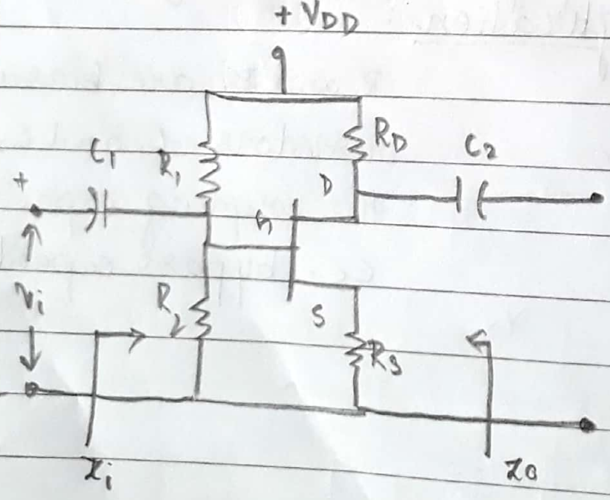
Neglecting the effect of r_d

$Z_i = R_1 \| R_2$

$Z_o = R_D$

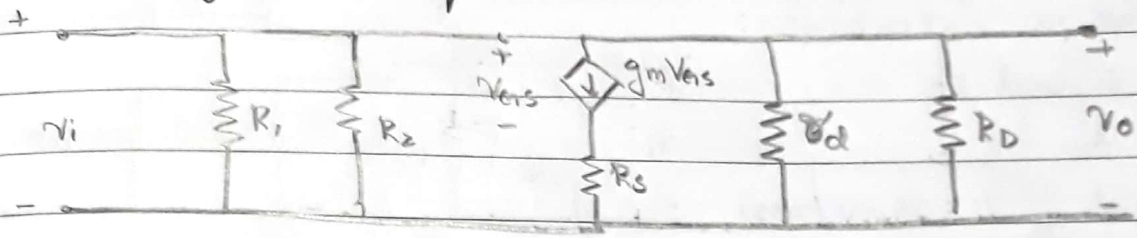
$A_V = -g_m R_D$

Without unbypassed R_S



Here no bypass capacitor R_S is used.

small signal ac equivalent circuit



Input impedance

$$\boxed{Z_i = R_1 \| R_2}$$

output impedance

$$\boxed{Z_o = \left[\frac{1 + g_m R_S + \frac{R_S}{r_d}}{1 + g_m R_S + \frac{R_D + R_S}{r_d}}\right] R_D}$$

Gain

$$\boxed{A_v = \frac{-g_m R_D}{1 + \frac{(R_D + R_S)}{r_d} + g_m R_S}}$$

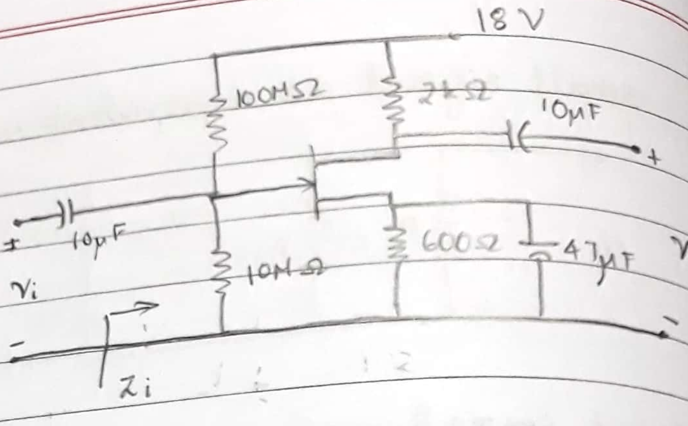
Neglecting the effect of r_d

$$Z_i = R_1 \| R_2$$

$$Z_o \approx R_D$$

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

Q1: For a JFET amplifier shown, calculate
i. Z_i and Z_o
ii. A_v
iii. V_o if $V_i = 25mV$ (rms)



Given:
$Y_{os} = 10\mu S$ $\quad V_{GSQ} = -1V$
$I_{DSS} = 12mA$ $\quad V_P = -3V$

Sol:
i. $Z_i = R_1 \| R_2$

$$Z_i = \frac{100M \times 10M}{(100+10)M} = \underline{9.09M\Omega}$$

$$r_d = \frac{1}{Y_{os}} = \frac{1}{10\mu S} = 100k\Omega$$

$Z_o = r_d \| R_D$

$$Z_o = \frac{100k \times 2k}{(100+2)k} = \underline{1.96k\Omega}$$

ii. $A_v = -g_m [r_d \| R_D]$

$$g_{mo} = \frac{2I_{DSS}}{V_P} = \frac{2(12m)}{3}$$

$$g_{mo} = 8mS$$

$$A_v = -5.33m\left[\frac{100k \times 2k}{102k}\right]$$

$$\underline{A_v = -10.45}$$

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

$$g_m = 8m\left[1 - \frac{1}{3}\right] = 5.33mS$$

5.36

iii. $V_o = A_v V_i$

$= -10.45(25m)$

$\underline{V_o = -261 mV \text{ (rms)}}$

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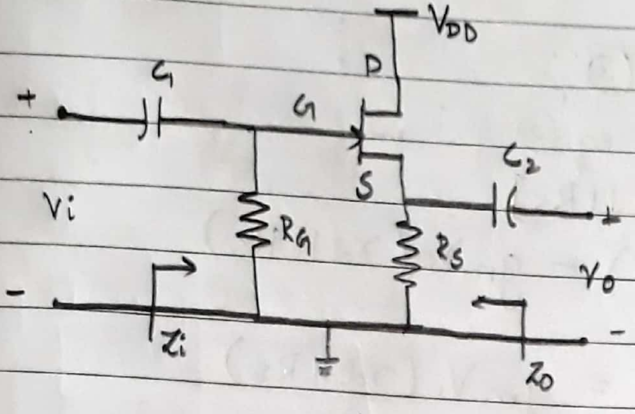
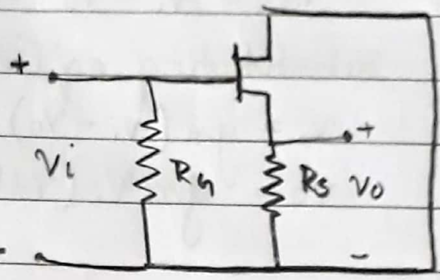
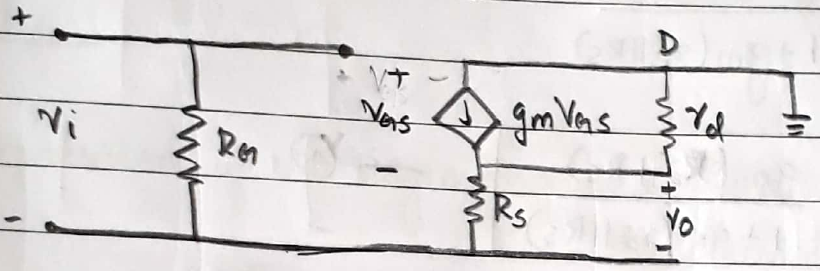
* JFET Source Follower [Common Drain Configuration]

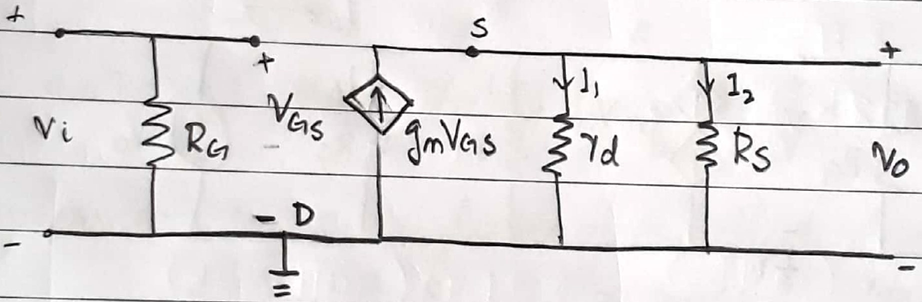




ac equivalent circuit



small signal ac model



Input impedance

$$\boxed{Z_i = R_G} \quad \text{--- (1)}$$

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.

$v_i - V_{gs} - v_o = 0$

$V_{gs} = v_i - v_o$ —— ③

Substituting eq ③ in eq ②

$v_o = g_m (v_i - v_o) [r_d \parallel R_s]$

$v_o = g_m v_i (r_d \parallel R_s) - g_m v_o (r_d \parallel R_s)$

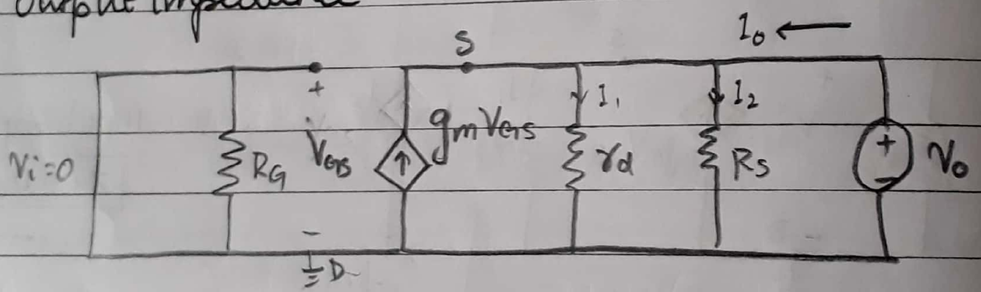
$v_o (1 + g_m [r_d \parallel R_s]) = g_m v_i (r_d \parallel R_s)$

$$\frac{v_o}{v_i} = \frac{g_m (r_d \parallel R_s)}{1 + g_m (r_d \parallel R_s)}$$

Gain:

$$\therefore \boxed{A_v = \frac{g_m (r_d \parallel R_s)}{1 + g_m (r_d \parallel R_s)}} \quad —— ④$$

Output impedance:



$$z_o = \frac{V_o}{I_o} \quad —— ⑤$$

Apply KCL at node S.

$I_o + g_m V_{gs} = I_1 + I_2$

$$I_o + g_m V_{gs} = \frac{V_o}{r_d} + \frac{V_o}{R_s}$$

$$I_o + g_m V_{gs} = V_o \left[\frac{1}{r_d} + \frac{1}{R_s} \right] \quad —— ⑥$$

Applying KVL at the input loop.

$V_i - V_{gs} - V_o = 0$

Since $V_i = 0$ $\quad V_{gs} = -V_o$ —— ⑦

substituting eq (7) in eq (6)

$$I_o - g_m v_o = v_o\left[\frac{1}{r_d} + \frac{1}{R_s}\right]$$

$$v_o\left[g_m + \frac{1}{r_d} + \frac{1}{R_s}\right] = I_o$$

$$\frac{V_o}{I_o} = \frac{1}{g_m + \frac{1}{r_d} + \frac{1}{R_s}}$$

$$\boxed{Z_o = \frac{1}{g_m} \,||\, r_d \,||\, R_s}$$

- Expression of A_v neglecting the effect of r_d.

$r_d \geq 10R_s \quad \therefore R_s || r_d \approx R_s$

$$A_v = \frac{g_m R_s}{1 + g_m R_s}$$

If $g_m R_s \gg 1$ then $A_v = 1$ (unity)

- Expression for Z_o neglecting the effect of r_d

$r_d \geq 10R_s \quad \therefore r_d || R_s \approx R_s$

$$Z_o = \frac{1}{g_m} \,||\, R_s$$

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.

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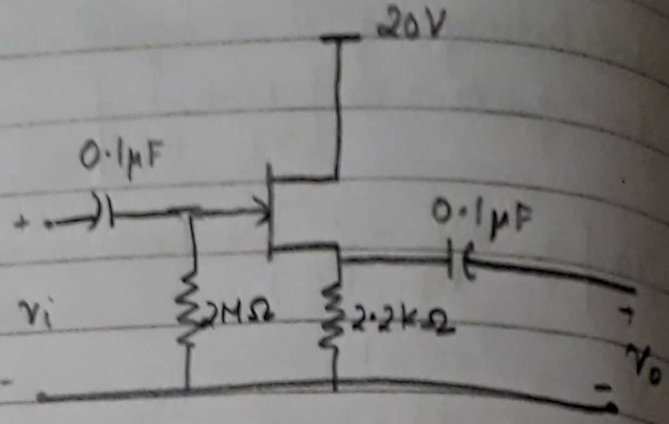
Given:

$I_{DSS} = 10\,mA$

$V_P = -5V$

$r_d = 40k\Omega$

$V_{GSQ} = -2.85V$



Sol: a. $Z_i = R_G = 2M\Omega$ //

$g_{m0} = \frac{2I_{DSS}}{V_P} = \frac{2(10m)}{5} = 4m$

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

$g_m = 4m\left[1 - \frac{2.85}{5}\right] = 1.72$

$\frac{1}{g_m} = 0.58\,k\Omega$

$Z_o = \frac{1}{g_m} \| r_d \| R_s$

$Z_o = 0.58k \| 40k \| 2.2k$

$= 0.57k \| 2.2k$

$= \frac{0.57k \times 2.2k}{2.77k}$

$Z_o = 0.452\,k\Omega$

b. $A_V = \frac{g_m(r_d \| R_s)}{1 + g_m(r_d \| R_s)} = \frac{1.72(40k \| 2.2k)}{1 + 1.72(40k \| 2.2k)}$

$A_V = \frac{3.586}{4.586} = 0.7818$ //

c. V_o if $V_i = 20\,mV_{(p-p)}$

$V_o = A_V V_i$

$= 0.7818(20m)$

$V_o = 15.64\,mV_{(p-p)}$

d. Neglecting effect of r_d

$Z_i = R_G = 2M\Omega$ //

$Z_o = \frac{1}{g_m} \| R_s = \frac{0.58k \times 2.2k}{2.78k} = 0.458\,k\Omega$

$$A_v = \frac{g_m R_s}{1+g_m R_s} = \frac{1.72m(2.2k)}{1+1.72m(2.2k)} = 0.79$$

$$v_o = A_v V_i = 0.79(20m) = 15.8\,mV_{(pp)}$$

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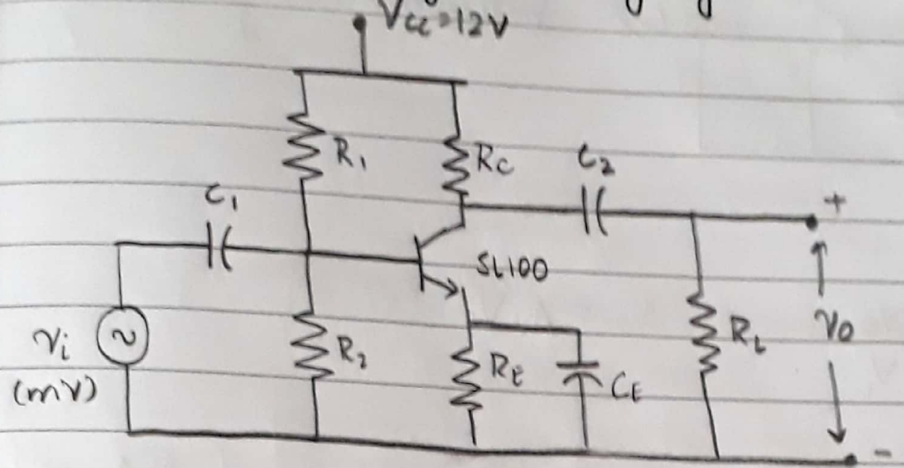
UNIT - 3

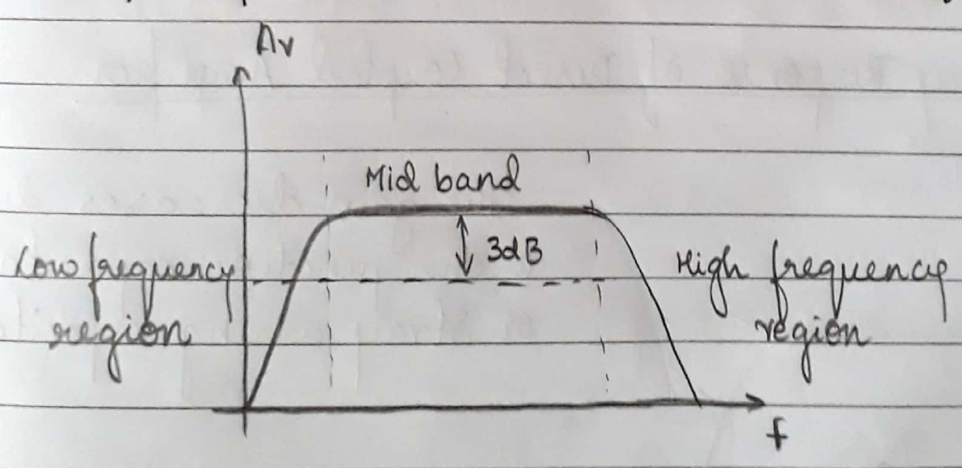
RC Coupled Amplifier



Single stage 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 ~~transi~~ junction capacitor

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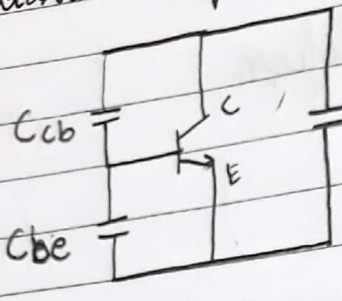
or parasitic capacitor or stray wiring capacitor.

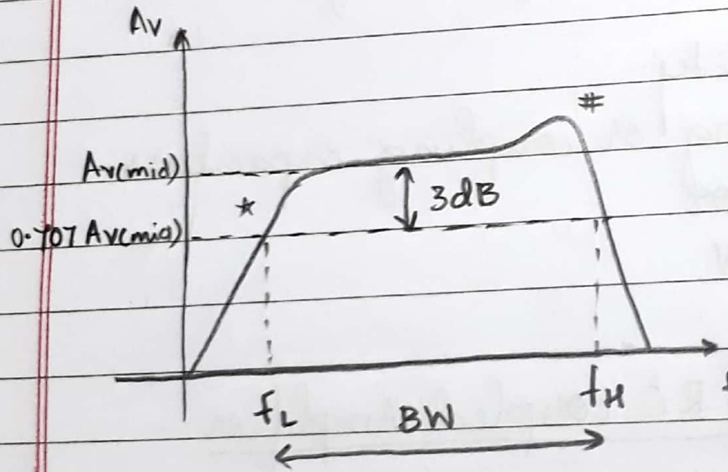


Internal capacitance between the junctions.

Gain:

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

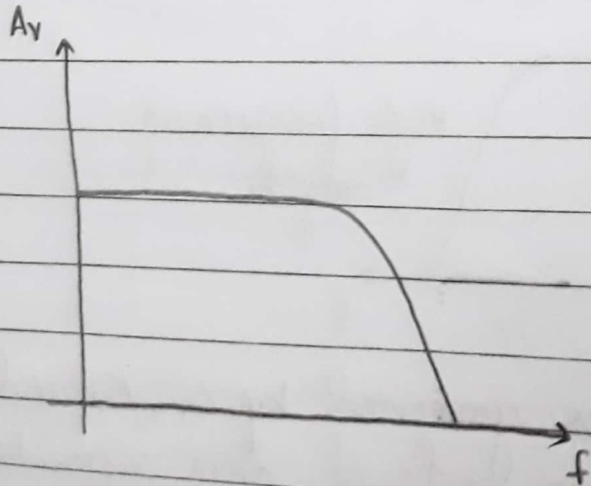
★ Frequency Response of Transformer Coupled Amplifier:



* Gain keeps increasing as due to $X_L = 2\pi f L$ of the transformer, Av 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

$$\boxed{BW = f_2 - f_1}$$

Gain

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

The output voltage at mid band frequency region

$$|V_o| = |A_{v(mid)}||V_i| \quad \text{—— (1)}$$

The output power at mid band frequency region

$$P_{o(mid)} = \frac{V_o^2}{R} \quad \text{—— (2)}$$

Substituting eq (1) in eq (2)

$$P_{o(mid)} = \frac{(|A_{v(mid)}||V_i|)^2}{R}$$

The output voltage at cut off frequency region

$$|V_o| = |0.707 A_{v(mid)}||V_i| \quad \text{—— (3)}$$

The output power at cut off frequency region

$$P_{o(cut\,off)} = \frac{V_o^2}{R} \quad \text{—— (4)}$$

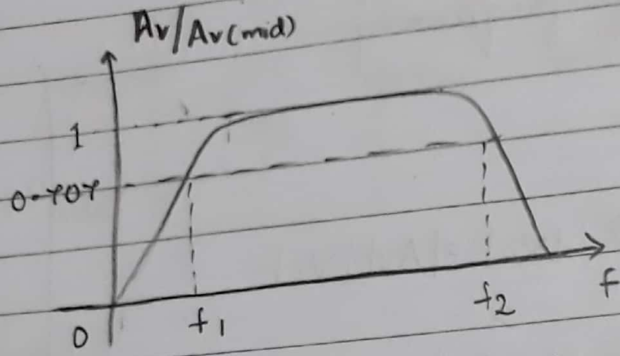
Substituting eq (3) in eq (4)

$$P_{o(cut\,off)} = \frac{(|0.707 A_{v(mid)}||V_i|)^2}{R}$$

$$P_{o(cut\,off)} = \frac{0.5\,(|A_{v(mid)}||V_i|)^2}{R}$$

$$\boxed{P_{o(cut\,off)} = 0.5\,P_{o(mid)}}$$

* Normalised Gain versus Frequency Plot:



Normalised Gain = $\frac{A_v}{A_{v(mid)}}$

Normalised Midband Gain = $\frac{A_{v(mid)}}{A_{v(mid)}} = 1$

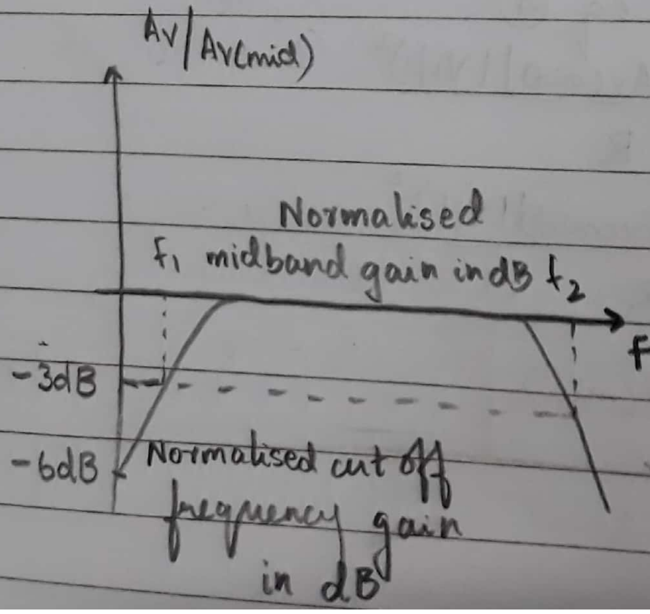
Normalised Gain at cut off frequency = $\frac{0.707 A_{v(mid)}}{A_{v(mid)}} = 0.707$

* Normalised decibel voltage gain versus frequency:

Normalised gain in dB = $\left(\frac{A_v}{A_{v(mid)}}\right)_{dB} = 20 \log_{10}\left(\frac{A_v}{A_{v(mid)}}\right)$

Normalised Midband Gain in dB = $20 \log_{10}(1) = 0$

Normalised Gain at cut off frequency in dB = $20 \log_{10}(0.707) = -3dB$



Low Frequency Analysis:

High Pass RC circuit

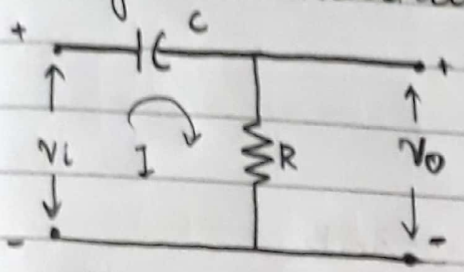
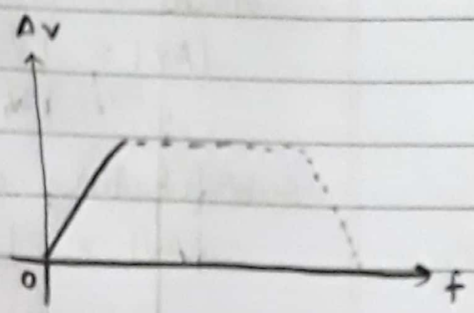


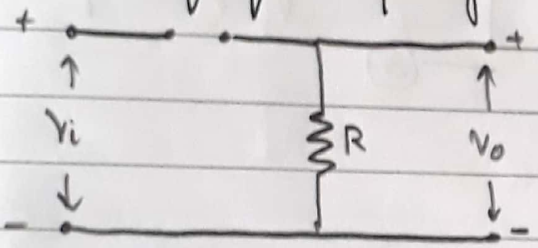
fig 1



The reactance of the capacitor

$$X_c = \frac{1}{2\pi f C}$$

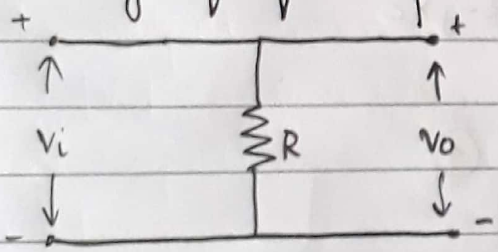
At low frequency region capacitor acts as open circuit.



$V_o = 0$

fig 2

At high frequency region capacitor acts as short circuit.



$V_o = V_i$

$X_c \approx 0$

fig 3

Applying voltage divider rule for fig 1

$$V_o = IR$$

$$I = \frac{V_i}{R - jX_c}$$

$$\therefore V_o = \frac{V_i R}{R - jX_c}$$

Magnitude of V_o

$$V_o = \frac{V_i R}{\sqrt{R^2 + X_c^2}} \quad \text{— (1)}$$

if $X_c = R$

$$V_o = \frac{V_i R}{\sqrt{2}\, R}$$

$$V_o = \frac{V_i}{\sqrt{2}} \quad \text{— (2)}$$

gain

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

Substituting eq ②

$$|A_v| = \frac{|V_i/\sqrt{2}|}{|V_i|}$$

$$|A_v| = 0.707 \qquad |A_v|_{dB} = -3dB$$

when $X_c = R$

$$\frac{1}{2\pi f C} = R$$

$$\boxed{f_1 = \frac{1}{2\pi RC}}$$ Break frequency. —— ③

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

Substituting eq ①

$$A_v = \frac{\frac{\cancel{V_i} R}{R - jX_c}}{\cancel{V_i}} \qquad A_v = \frac{R}{R - jX_c}$$

$$\boxed{A_v = \frac{1}{1 - j(X_c/R)}} \quad —— ④$$

$$A_v = \frac{1}{1 - j\left(\frac{1}{2\pi f C R}\right)}$$

From eq ③

$$A_v = \frac{1}{1 - j\left(\frac{f_1}{f}\right)}$$

Magnitude

$$|A_v| = \frac{1}{\sqrt{1 + \left(\frac{f_1}{f}\right)^2}}$$

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In dB : $|A_v|_{dB} = 20 \log_{10}\left(\frac{1}{\sqrt{1+(f_1/f)^2}}\right)$

$$|A_v|_{dB} = -20 \log_{10}\left[1 + \left(\frac{f_1}{f}\right)^2\right]^{1/2}$$

$$|A_v|_{dB} = -10 \log_{10}\left[1 + \left(\frac{f_1}{f}\right)^2\right]$$

If $f \ll f_1$

then $\left(\frac{f_1}{f}\right)^2 \gg 1$

$$\therefore |A_v|_{dB} = -10 \log_{10}\left[\frac{f_1}{f}\right]^2$$

$$\boxed{|A_v|_{dB} = -20 \log_{10}\left[\frac{f_1}{f}\right]}$$

Q: Calculate the gain for frequencies for

i. $f = f_1$ iii. $f = f_1/4$

ii. $f = f_1/2$ iv. $f = f_1/10$

Sol: i. When $f = f_1$

$$|A_v|_{dB} = -20 \log_{10}\left[\frac{f_1}{f}\right] = -20 \log_{10} 1 = 0$$

ii. When $f = f_1/2$

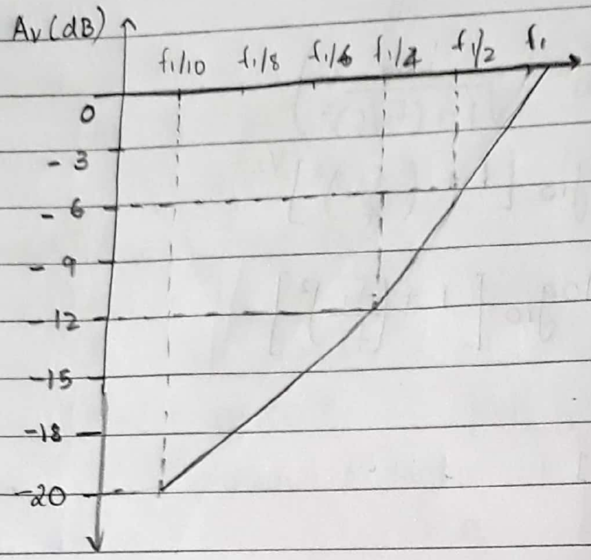
$$|A_v|_{dB} = -20 \log_{10}\left[\frac{f_1}{f_1/2}\right] = -20 \log_{10} 2 = -6.02\ dB$$

iii. When $f = f_1/4$

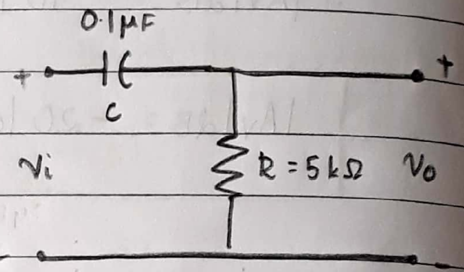
$$|A_v|_{dB} = -20 \log_{10}\left[\frac{f_1}{f_1/4}\right] = -20 \log_{10} 4 = -12.04\ dB$$

iv. When $f = f_1/10$

$$|A_v|_{dB} = -20 \log_{10}\left[\frac{f_1}{f_1/10}\right] = -20 \log_{10} 10 = -20\ dB$$



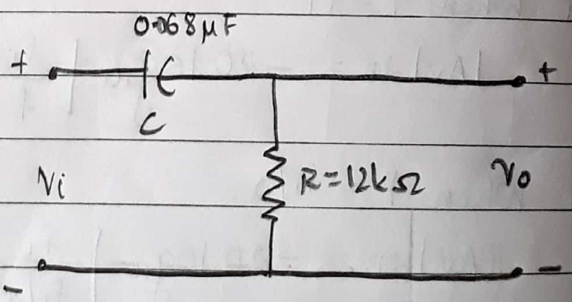
Q: For the network shown in the figure, determine the break frequency.



Sol: Break frequency

$$f_1 = \frac{1}{2\pi RC} = \frac{1}{2\pi(5k)(0.1\mu)} = 318.3 Hz$$

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 10 Hz, 100 Hz, 1 kHz, 2 kHz, 5 kHz, 10kHz

iv. Sketch the frequency response of $\frac{|V_o|}{|V_i|}$

v. construct the Bode Magnitude plot.

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vi. sketch the actual frequency response.
vii. compare the results obtained in iv and v.

i. $|A_v| = \frac{|V_o|}{|V_i|} = \left[\frac{1}{\sqrt{1+(f_1/f)^2}}\right]$

ii. Break frequency

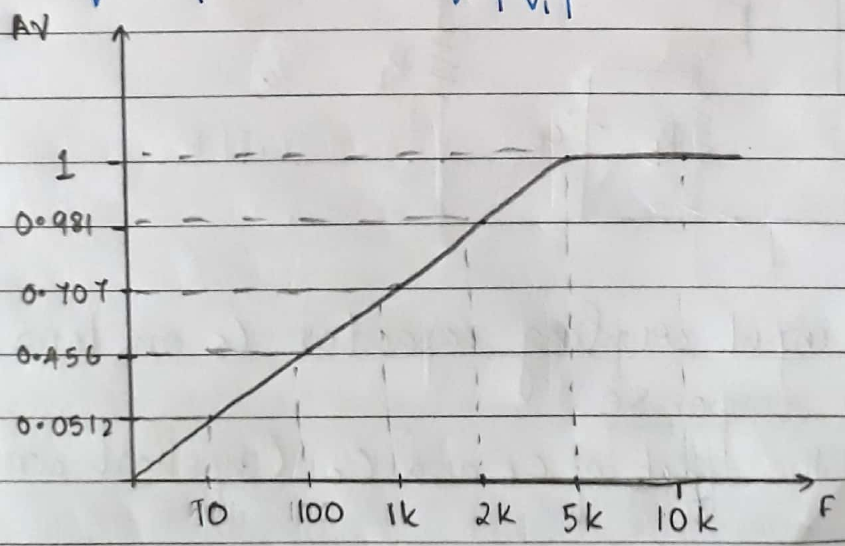
$f_1 = \frac{1}{2\pi RC} = \frac{1}{2\pi(12k)(0.068\mu)} = 195\,Hz$

iii. at 10 Hz, 100 Hz, 1 kHz, 2 kHz, 5 kHz, 10 kHz

$\left|\frac{V_o}{V_i}\right| = ?$

f	f_1/f	$\|A_v\| = \|V_o\|/\|V_i\|$	$\|A_v\|_{dB} = 20\log_{10}(A_v)$
10	19.5	0.0512	-25.815
100	1.95	0.456	-6.82
1k	195m	0.707	-3
2k	97.5m	0.981	-0.166
5k	39m	0.999	0
10k	19.5m	1	0
			0

iv. Frequency response of $\frac{|V_o|}{|V_i|}$



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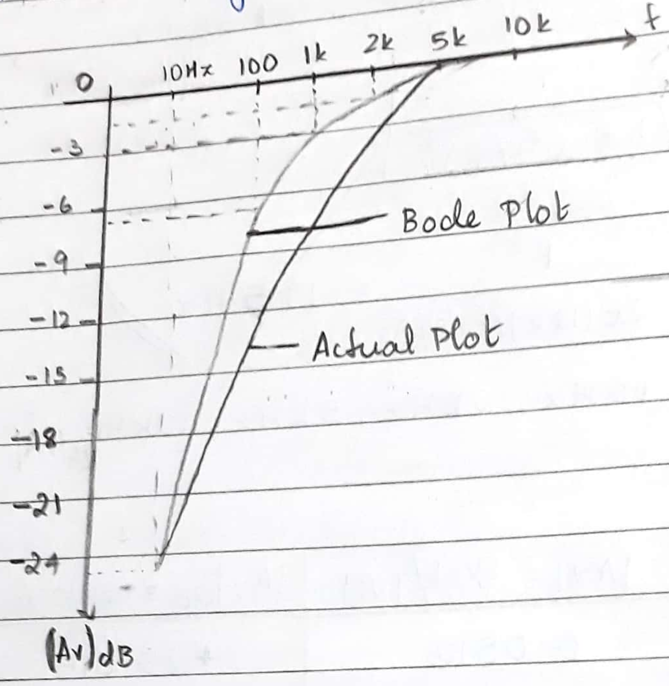
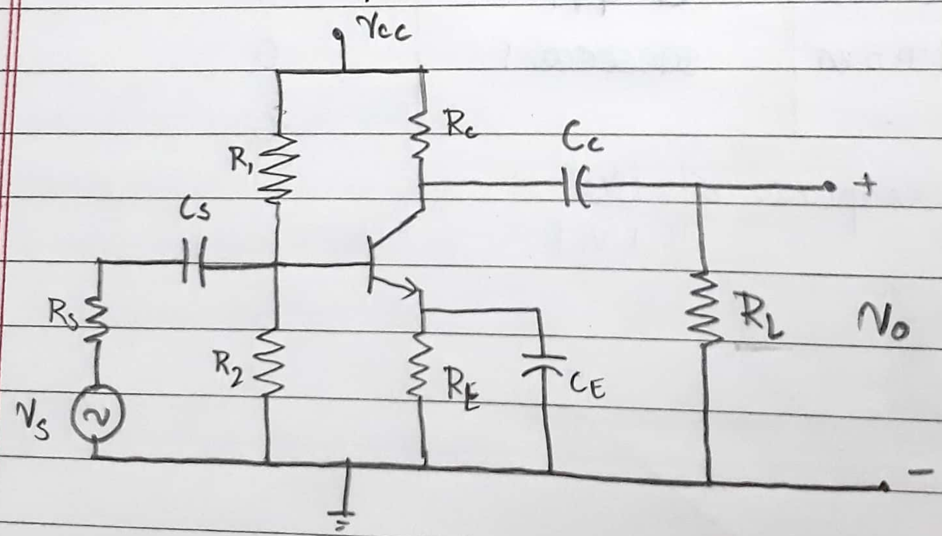
v. Bode Magnitude Plot



★ **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)

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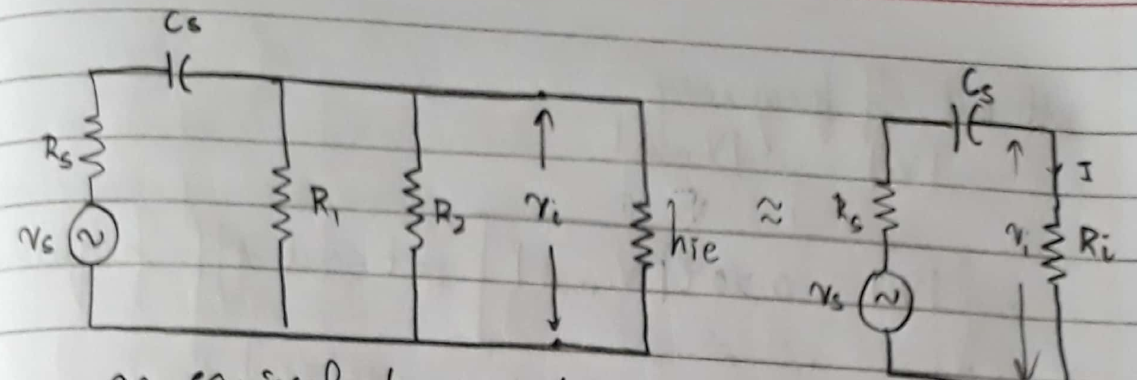


ac equivalent circuit

$R_i = R_1 || R_2 || h_{ie}$

$$\boxed{R_i = R_1 || R_2 || h_{ie}}$$

$$\boxed{h_{ie} = \beta r_e}$$

$v_i = I R_i$ —— (1)

$$I = \frac{v_s}{R_i + R_s - jX_{cs}} \quad \text{—— (2)}$$

substituting eq (2) in eq (1)

$$v_i = \frac{v_s R_i}{R_i + R_s - jX_{cs}}$$

$$v_i = \frac{v_s R_i}{(R_i + R_s)\left[1 - jX_{cs}/(R_i + R_s)\right]}$$

dividing by $R_s + R_i$

$$v_i = \frac{\dfrac{v_s R_i}{R_s + R_i}}{\left[1 - j\dfrac{X_{cs}}{R_s + R_i}\right]}$$

$$|v_i| = \frac{|v_s| \dfrac{R_i}{R_s + R_i}}{\sqrt{1 + \left(\dfrac{X_{cs}}{R_s + R_i}\right)^2}}$$

In mid band frequency, f is sufficiently large as a result $X_{cs} = 0$.

$$\therefore \boxed{v_i = \frac{v_s R_i}{R_s + R_i}} \text{ at mid band.}$$

At cut off frequency

$$|V_i| = \frac{|V_{imid}|}{\sqrt{2}}$$

$$\boxed{|V_i| = 0.707\,|V_{imid}|}$$ at cut off frequency

when $X_{cs} = R_s + R_i$ because $1 + \left[\frac{[X_{cs}]}{R_s + R_i}\right]^2 = 2$

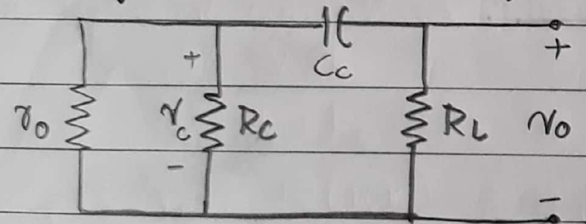
$$\frac{X_{cs}}{R_s+R_i} = 1 \Rightarrow X_{cs} = R_s + R_i$$

$$\frac{1}{2\pi f_{LS} C_s} = R_s + R_i$$

$$\therefore \boxed{f_{LS} = \frac{1}{2\pi C_s (R_s + R_i)}}$$

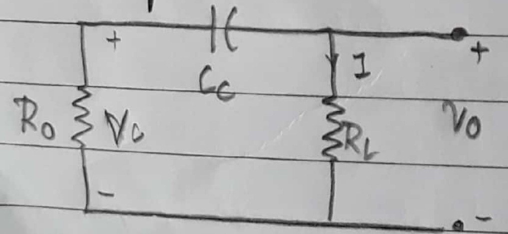
Effect of output coupling capacitor C_c on low frequency response.

Neglect the effect of C_s and C_E. (by short circuiting



R_E is by passed when C_E is short circuited.

ac equivalent circuit



$$\boxed{R_o = r_o \,||\, R_c}$$

$$V_o = I R_L \quad \text{—— (1)}$$

$$I = \frac{V_c}{R_o + R_L - jX_{c_c}} \quad \text{—— (2)}$$

Substituting eq (2) in eq (1)

$$V_o = \frac{V_c R_L}{(R_o + R_L) - jX_{c_c}}$$

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$$v_o = \frac{v_C R_L}{(R_o+R_L)\left[1-j\,X_C/(R_o+R_L)\right]}$$

dividing by (R_o+R_L)

$$v_o = \frac{\dfrac{V_C R_L}{R_o+R_L}}{\left[1-j\dfrac{X_{Cc}}{R_o+R_L}\right]}$$

$$|v_o| = \frac{\dfrac{|V_c|\,R_L}{R_o+R_L}}{\sqrt{1+\left(\dfrac{X_{Cc}}{R_o+R_L}\right)^2}}$$

In mid band frequency, f is sufficiently large

$\therefore X_{Cc} = 0$

$$\therefore \boxed{|v_o| = \frac{|V_c|R_L}{R_o+R_L}} \text{ at mid band}$$

at cut off frequency

$$|v_o| = \frac{|v_{o\,mid}|}{\sqrt{2}}$$

$$\boxed{|v_o| = 0.707\,|v_{o\,mid}|} \text{ at cut off frequency}$$

when $X_{Cc} = R_o+R_L$

$$\frac{1}{2\pi f_{Lc} C_c} = R_o+R_L$$

$$\therefore \boxed{f_{Lc} = \frac{1}{2\pi C_c(R_o+R_L)}}$$

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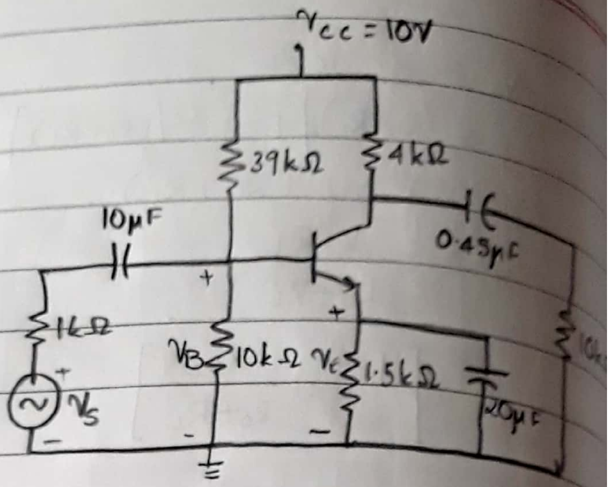
Q: For the circuit shown:
Calculate the following:
i. r_e
ii. input resistance
iii. mid band voltage gain

$A_v = \frac{V_o}{V_i}$ $A_{V_S} = \frac{V_o}{V_s}$



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 biase circuit

$$\beta R_E \geq 10 R_2$$

$$100(1.5k) \geq 10(10k)$$

This condition is valid, hence approximate analysis is considered.

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

$$V_B = \frac{10(10k)}{39k + 10k} = 2.04V$$

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

$$V_E = 2.04 - 0.7 = 1.34V$$

$$I_E = \frac{V_E}{R_E} \qquad I_E = \frac{1.34}{1.5k} = 0.893mA$$

$$r_e = \frac{26mV}{I_E}$$

$$r_e = \frac{26m}{0.893m} = 29.1\Omega$$

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ii. Input resistance

$R_i = R_1 || R_2 || h_{ie}$

$h_{ie} = \beta r_e$

$R_i = 39k || 10k || 2.91k$

$h_{ie} = 100(29.1)$

$R_i = 7.96k || 2.91k$

$h_{ie} = 2.91 k\Omega$

$R_i = 2.13 k\Omega$

iii. Midband voltage gain.

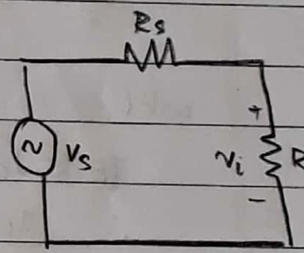
$$A_v = \frac{v_o}{v_i} = \frac{-R_o || R_L}{r_e}$$

$R_o = r_o || R_c \quad \therefore R_o = R_c = 4k$

$$A_v = \frac{-4k || 10k}{29.1} = -98.183$$

$$A_{vs} = \frac{v_o}{v_s} = \frac{v_o}{v_i} \times \frac{v_i}{v_s} = \frac{A_v v_i}{v_s}$$

$$\therefore A_{vs} = \frac{A_v v_i}{v_s}$$



$$v_i = \frac{v_s R_i}{R_i + R_s} \Rightarrow \frac{v_i}{v_s} = \frac{R_i}{R_i + R_s}$$

$$\therefore A_{vs} = A_v \frac{R_i}{R_i + R_s}$$

$$A_{vs} = (-98.183)\left[\frac{2.13k}{1k + 2.13k}\right] = -66.81$$

iv. lower cut off frequency due to C_s

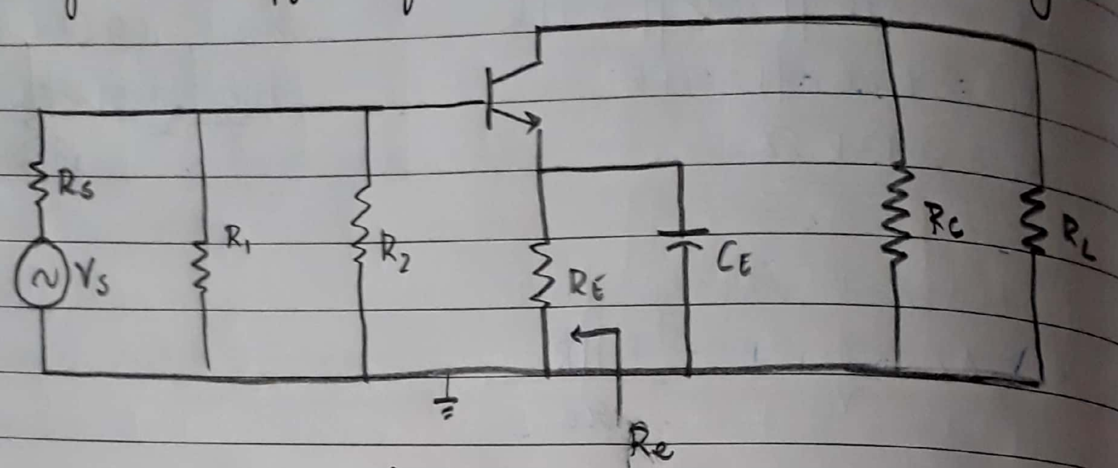
$$f_{Ls} = \frac{1}{2\pi C_s (R_i + R_s)} = \frac{1}{2\pi (10\mu)(2.13k + 1k)} = 5.1 Hz$$

v. lower cut off frequency due to C_c

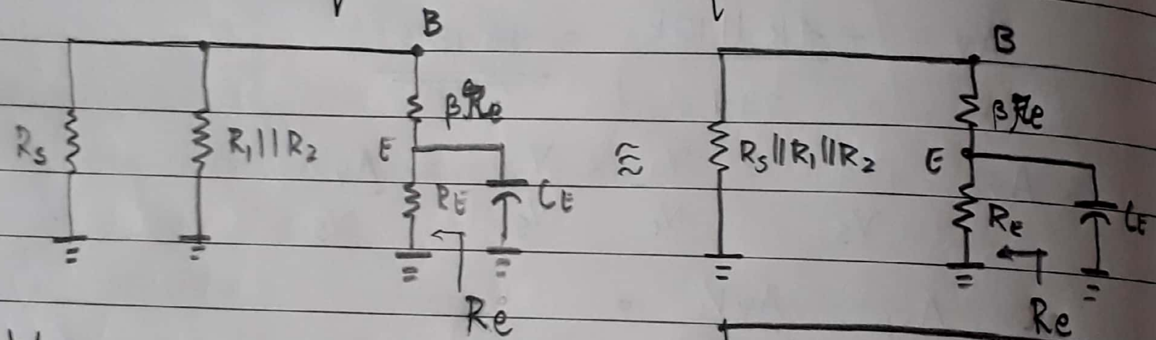
$$f_{Lc} = \frac{1}{2\pi C_c (R_o + R_L)} = \frac{1}{2\pi (0.45\mu)(4k + 10k)} = 25.26 Hz$$

Effect of by pass 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



$$\boxed{R_s' = R_s || R_1 || R_2}$$

wkt

$$I_E \approx I_c = \beta I_B$$

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

$$\frac{R's + \beta R_e}{\beta} = I_B$$

$$\therefore \frac{R's}{\beta} + R_e = R_E$$

$$\therefore \boxed{R_e = R_E || \left[\frac{R's}{\beta} + r_e\right]}$$

$$\boxed{f_{LE} = \frac{1}{2\pi r_e C_E}}$$

continued.

Q: vi. lower cut off frequency due to C_e

sol: $R_s' = R_s || R_1 || R_2$

$R_s' = 1k || 39k || 10k$

$R_s' = 0.88k\Omega$

$R_e = R_E || \left[\frac{R'_s}{\beta} + r_e \right]$

$= 1.5k || \left[\frac{0.88k}{100} + 29.1 \right]$

$= 1.5k || 37.9$

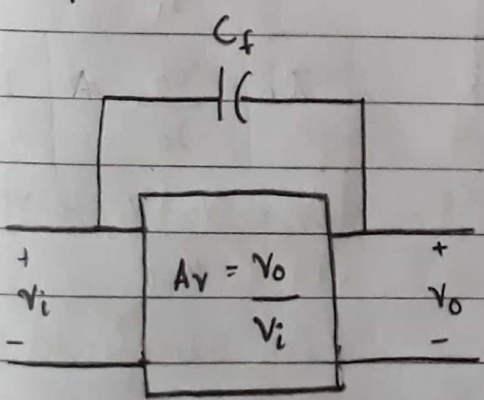
$R_e = 37\Omega$

$f_{LE} = \frac{1}{2\pi r_e C_E}$

$f_{LE} = \frac{1}{2\pi (29.1)(20\mu)} = 215 Hz$

★ Miller Effect Capacitance:

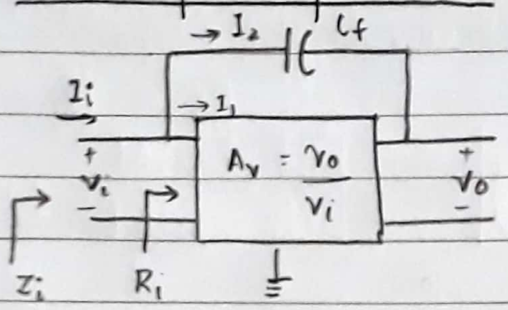
Inverting amplifiers with capacitance between input and output nodes.



To find the Miller input capacitance and Miller output capacitance where C_{mi} and C_{mo} are input and output capacitance respectively.

Junction capacitance reduces gain, hence to overcome this Miller capacitance is used.

Miller Input capacitance



$R_i = \frac{V_i}{I_1} \Rightarrow I_1 = \frac{V_i}{R_i}$

$Z_i = \frac{V_i}{I_i} \Rightarrow I_i = \frac{V_i}{Z_i}$

$I_2 = \frac{V_i - V_o}{X_{cf}} = \frac{V_i(1-A_v)}{X_{cf}}$

because $V_o = A_v V_i$

By KCL

$I_i = I_1 + I_2$

Substituting I_i and I_1 and I_2

$$\frac{V_i}{Z_i} = \frac{V_i}{R_i} + \frac{V_i(1-A_v)}{X_{cf}}$$

$$\frac{1}{Z_i} = \frac{1}{R_i} + \frac{1-A_v}{X_{cf}}$$

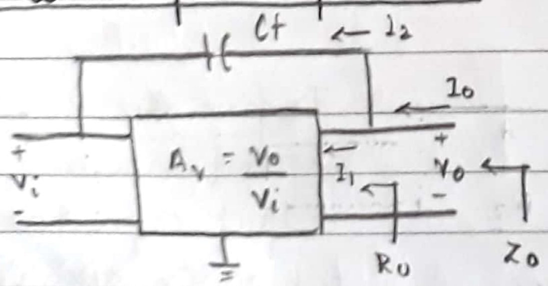
Here $\frac{X_{cf}}{1-A_v} = X_{C_{mi}}$

$$1/2\pi f C_f = (1-A_v)/2\pi f C_{mi}$$

$$\boxed{C_{mi} = (1-A_v) C_f}$$

$X_{C_{mi}} = \frac{1}{2\pi f C_{mi}}$

Miller Output capacitance



$R_o = \frac{V_o}{I_1} \Rightarrow I_1 = \frac{V_o}{R_o}$

$Z_o = \frac{V_o}{I_o} \Rightarrow I_o = \frac{V_o}{Z_o}$

$I_2 = \frac{V_o - V_i}{X_{cf}} = \frac{V_o(1 - 1/A_v)}{X_{cf}}$

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

By KCL

$I_o = I_1 + I_2$

Substituting I_1, I_2 and I_o

$$\frac{V_o}{Z_o} = \frac{V_o}{R_o} + \frac{V_o(1 - 1/A_v)}{X_{cf}}$$

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$$\frac{1}{Z_o} = \frac{1}{R_o} + \frac{(1 - 1/A_v)}{X_{cf}} \quad \text{—— (1)}$$

Here $$\frac{X_{cf}}{1 - 1/A_v} = X_{cmo}$$

$$\frac{1}{2\pi f C_f} = \left(1 - \frac{1}{A_v}\right)\frac{1}{2\pi f C_{mo}}$$

$$\boxed{C_{mo} = \left(1 - \frac{1}{A_v}\right) C_f}$$

R_o is large so neglecting $\frac{V_o}{R_o}$ in eq (1)

$$Z_o = \frac{X_{cf}}{1 - 1/A_v}$$

$$Z_o = \frac{1}{2\pi f[1 - 1/A_v]C_f}$$

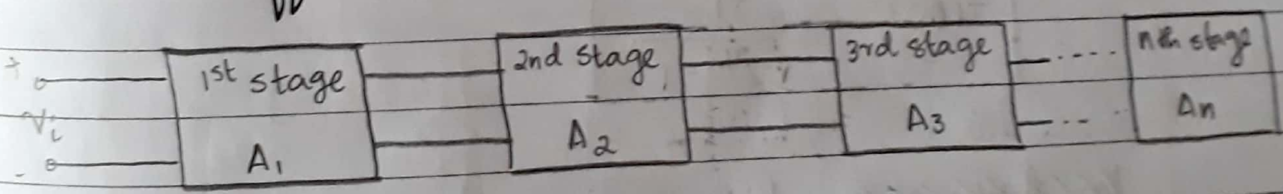
$$\boxed{Z_o = \frac{1}{2\pi f C_{mo}}}$$

For a non inverting amplifier

$$C_{mi} = (1 + A_v) C_f$$

$$C_{mo} = \left(1 + \frac{1}{A_v}\right) C_f$$

* **Cascaded Effect:**



For low frequency region

$$A_{v(low)\,overall} = A_{v_1(low)}\, A_{v_2(low)}\, A_{v_3(low)} \cdots A_{v_n(low)}$$

wkt $$A_{v(low)} = \frac{|A_{v(mid)}|}{\sqrt{1 + (f_1/f)^2}}$$

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$$\therefore \frac{A_{V(low)}}{A_{V(mid)}} = \frac{1}{\sqrt{1+(f_1/f)^2}}$$ (For single stage)

For n stages

$$\left.\frac{|A_{V(low)}|}{|A_{V(mid)}|}\right|_n = \left[\frac{1}{\sqrt{1+(f_1/f)^2}}\right]^n \quad \text{—— (1)}$$

~~When~~ for $f = f_{L(n)}$ - lower cut off frequency

$$\left.\frac{|A_{V(low)}|}{|A_{V(mid)}|}\right|_n^{f=f_{L(n)}} = \frac{1}{\sqrt{2}} \quad \text{—— (2)}$$

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

$$2 = \left[1+\left(\frac{f_1}{f_{L(n)}}\right)^2\right]^n$$

$$2^{1/n} = 1+\left(\frac{f_1}{f_{L(n)}}\right)^2$$

$$\frac{f_1}{f_{L(n)}} = \sqrt{2^{1/n}-1}$$

$$\boxed{f_{L(n)} = \frac{f_1}{\sqrt{2^{1/n}-1}}}$$

~~for n stages~~ wkt $A_{V(high)} = \frac{|A_{V(mid)}|}{\sqrt{1+(f/f_2)^2}}$

~~for~~

$$\therefore \frac{A_{V(high)}}{A_{V(mid)}} = \frac{1}{\sqrt{1+(f/f_2)^2}}$$ (For single stage)

~~For n stages~~

For n stages

$$\left.\frac{|Av(high)|}{|Av(mid)|}\right|_n = \left[\frac{1}{\sqrt{1+(f/f_2)^2}}\right]^n \quad \text{——— ③}$$

for $f = f_{H(n)}$ - higher cut off frequency

$$\left.\frac{|Av(high)|}{|Av(mid)|}\right|_n^{f=f_{H(n)}} = \frac{1}{\sqrt{2}} \quad \text{——— ④}$$

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

$$2 = \left[1+\left(\frac{f_{H(n)}}{f_2}\right)^2\right]^n$$

$$2^{1/n} = 1+\left(\frac{f_{H(n)}}{f_2}\right)^2$$

$$\boxed{f_{H(n)} = f_2\sqrt{2^{1/n}-1}}$$

Q: An amplifier consistists of 3 identical amplifiers cascaded. The bandwidth of overall amplifier extends from 20Hz to 20kHz. Calculate the bandwidth of individual stage.

Sol: Given: $n = 3$

$f_{L(n)} = 20Hz$

$f_{H(n)} = 20kHz$

$$f_{L(n)} = \frac{f_1}{\sqrt{2^{1/n}-1}} \Rightarrow f_1 = f_{L(n)}\sqrt{2^{1/n}-1}$$

$$f_1 = 20\left(\sqrt{2^{1/3}-1}\right)$$

$$f_1 = 10.196\,Hz$$

$$f_{H(n)} = f_2\sqrt{2^{1/n}-1}$$

$$\therefore f_2 = \frac{f_{H(n)}}{\sqrt{2^{1/n}-1}}$$

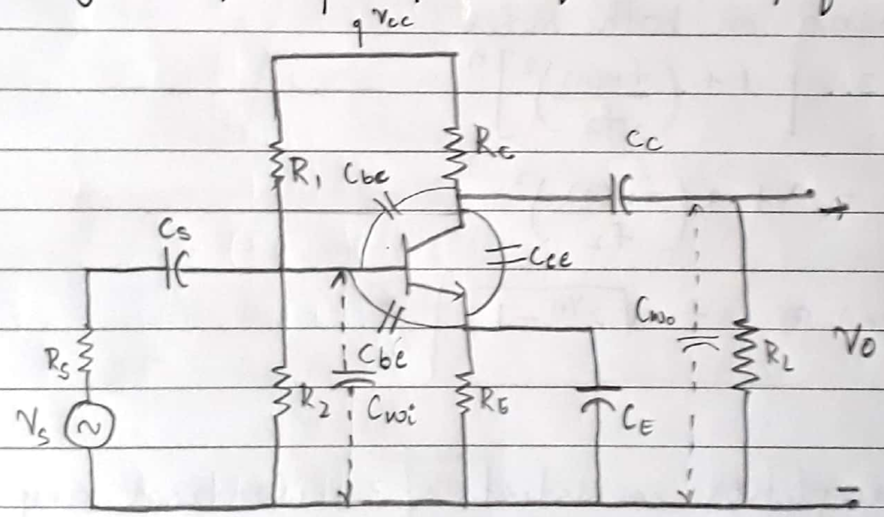
$$f_2 = \frac{20\times10^3}{\sqrt{2^{1/3}-1}}$$

$$f_2 = 39.23\,kHz$$

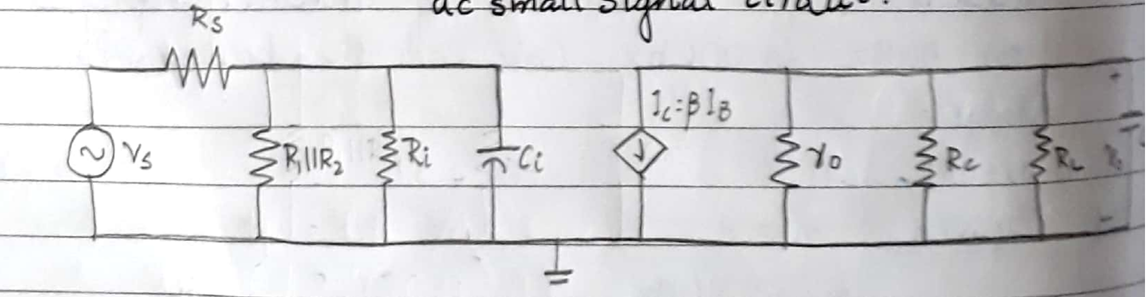
$$BW = 39.23kHz - 10.196Hz$$

$$BW = 39.22\,kHz$$

★ **High Frequency Response of BJT Amplifier:**



ac small signal circuit.



$$C_i = C_{wi} + C_{be} + C_{mi}$$

$$C_o = C_{wo} + C_{ce} + C_{mo}$$

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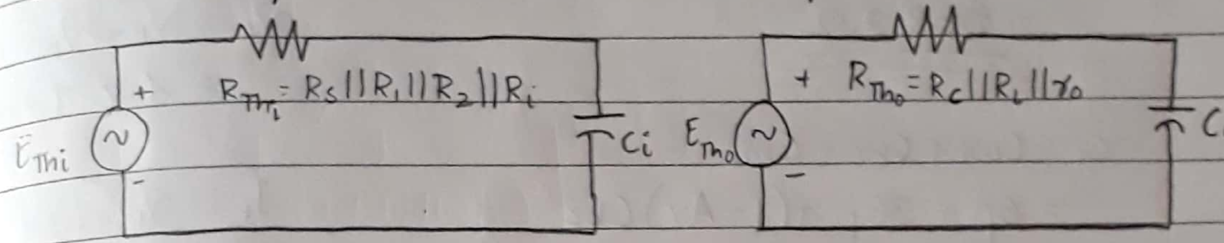
wkt $C_{mi} = [1 - A_v] C_f$

Here $C_f = C_{bc}$ $\therefore C_{mi} = [1 - A_v] C_{bc}$

wkt $C_{mo} = [1 - 1/A_v] C_f$

Here $C_f = C_{bc}$ $\therefore C_{mo} = [1 - 1/A_v] C_{bc}$

Thevenin's Equivalent input and output circuit.



$R_{Thi} = R_S || R_1 || R_2 || R_i$

$R_{Tho} = R_C || R_L || r_o$

$$\boxed{f_{Hi} = \frac{1}{2\pi R_{Thi} C_i}} \qquad \boxed{f_{Ho} = \frac{1}{2\pi R_{Tho} C_o}}$$

Q: Determine the lower cut off frequency for the network given $\beta = 100$, $r_o = \infty$. ~~Deter~~

Determine mid band gain if $C_{be} = 36\,pF$ and $C_{bc} = 4\,pF$ and $C_{wi} = 6\,pF$ and $C_{wo} = 8\,pF$.

Determine f_{Hi} and f_{Ho} and sketch the frequency response for low and high frequency region using the results.

Assume $C_c = 1\,pF$

Sol: Given: $\beta = 100$

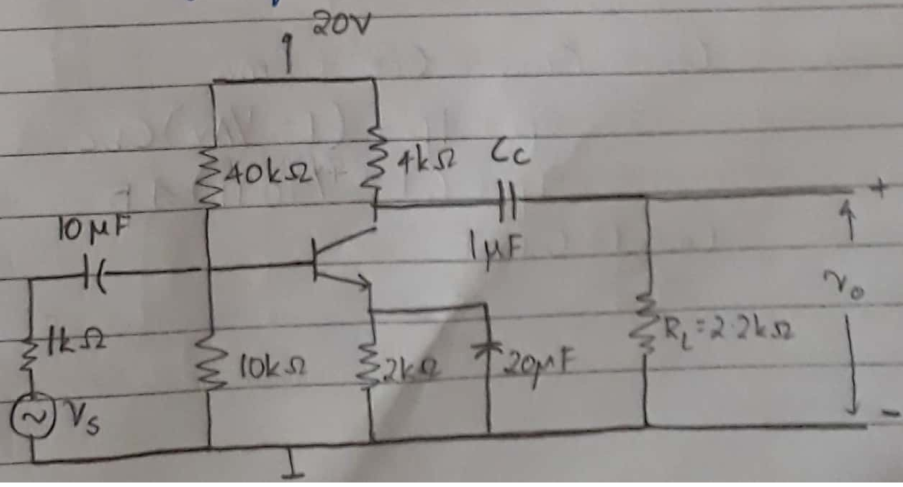
$r_o = \infty$

$C_{be} = 36\,pF$

$C_{bc} = 4\,pF$

$C_{wi} = 6\,pF$

$C_{wo} = 8\,pF$



$R_i = \beta r_e$

$R_i = 100(15.75)$

$R_i = 1.575k\,\Omega$

$r_e = \frac{26mV}{I_E}$

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

$V_B = \frac{10k(20)}{10k+40k} = 4V$

$V_E = V_B - V_{BE}$

$= 4 - 0.7 = 3.3V$

$I_E = \frac{V_E}{R_E} = \frac{3.3}{2k} = 1.65mA$

$r_e = \frac{26m}{1.65m} = 15.75\Omega$

$A_V = \frac{-R_C || R_L}{r_e}$

$A_V = -\frac{4k || 2.2k}{15.75}$

$A_V = -90.11$

$R_{Thi} = R_S || R_1 || R_2 || R_i$

$R_{Thi} = 1k || 40k || 10k || 1.575k$

$= 568.2\Omega$

$C_i = C_{wi} + C_{be} + C_{mi}$

$= 6p + 36p + (1 - A_V) C_{bc}$

$= 42p + (1 + 90.11) 4p$

$C_i = 406pF$

$f_{Hi} = \frac{1}{2\pi R_{Thi} C_i}$

$= \frac{1}{2\pi (568.2)(406p)}$

$f_{Hi} = 689.91\text{ kHz}$

$R_{Tho} = R_C || R_L || r_o$

$R_{Tho} = 4k || 2.2k || \infty$

$= 1.4193k\Omega$

$C_o = C_{wo} + C_{ce} + C_{mo}$

$= 8p + 1p + (1 - 1/A_V) C_{bc}$

$= 9p + (1 + 1/90.11) 4p$

$C_o = 13.04pF$

$f_{Ho} = \frac{1}{2\pi R_{Tho} C_o}$

$= \frac{1}{2\pi (1.4193k)(13.04p)}$

$= 8.599\text{ MHz}$

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$$f_{LS} = \frac{1}{2\pi[R_S + R_i)C_S} = \cancel{\frac{1}{2\pi(1k + 1.575k)10\mu}} = \cancel{6.18 Hz}$$

$$= \frac{1}{2\pi(1k+1.316k)10\mu}$$

$R_i = R_1 || R_2 || \beta r_e$

$= 40k || 10k || 100(15.75)$

$= 1.316 k\Omega$

$$\underline{f_{LS} = 6.87 Hz}$$

$$f_{LC} = \frac{1}{2\pi[R_O + R_L)C_C}$$

$R_O = r_o || R_C$

$R_O = \infty || 4k$

$= 4k\Omega$

$$= \frac{1}{2\pi(4k + 2.2k)1\mu}$$

$$\underline{f_{LC} = 25.67 Hz}$$

$$R_e = R_E || \left[\frac{R_s'}{\beta} + r_e\right]$$

$$f_{LE} = \frac{1}{2\pi R_e C_E}$$

$R_s' = R_S || R_1 || R_2$

$= 1k || 40k || 10k$

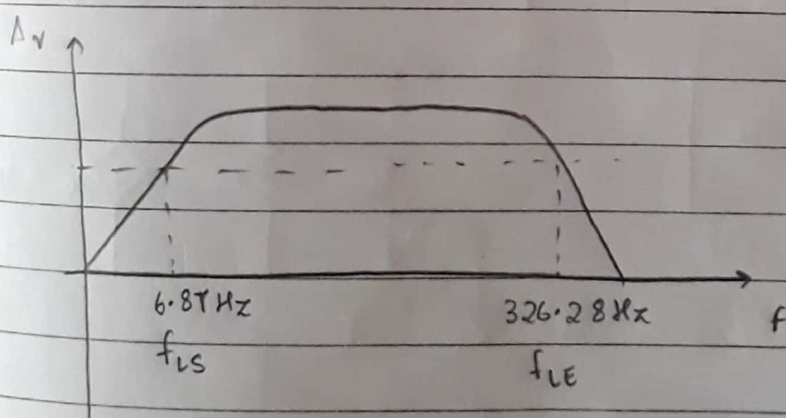
$= 888.9\Omega$

$$= \frac{1}{2\pi(24.3)20\mu}$$

$$\underline{f_{LE} = 327.48 Hz}$$

$$R_e = 2k || \left[\frac{888.9}{100} + 15.75\right]$$

$$\underline{R_e = 24.3\Omega}$$

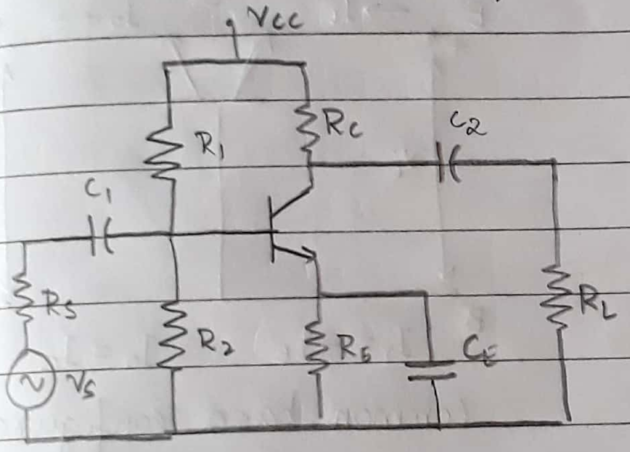


UNIT - 2

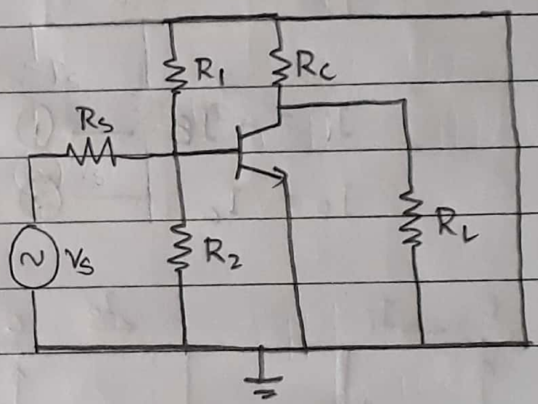
Transistor as Amplifier

AC 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.



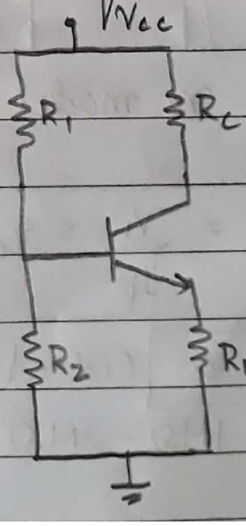
ac equivalent circuit



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. r_e model
2. hybrid mode
3. hybrid π model

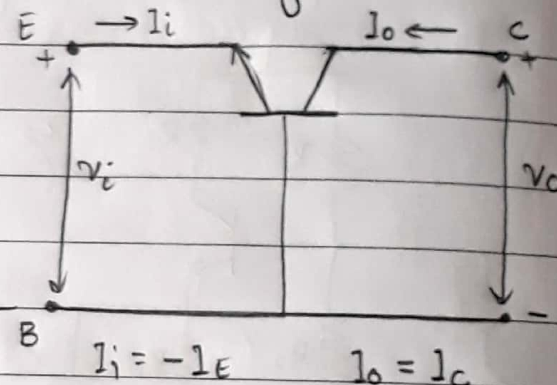
(1–2: low frequency analysis; 3: high frequency analysis (SLE))

★ r_e Model:

a. r_e model of a transistor in common Base configuration

ac resistance of transistor in active region

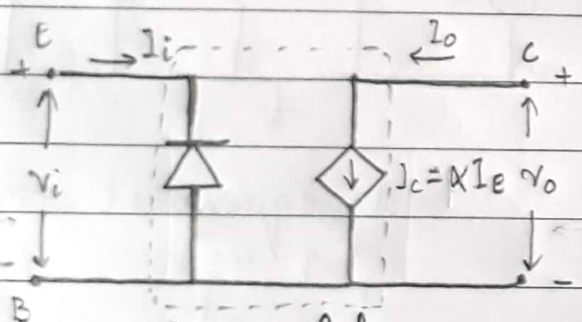
$$\boxed{r_e = \frac{26mV}{I_E}}$$



common base configuration

$$I_i = -I_e \quad \text{— ①}$$

$$I_o = I_c \quad \text{— ②}$$



r_e model

current gain

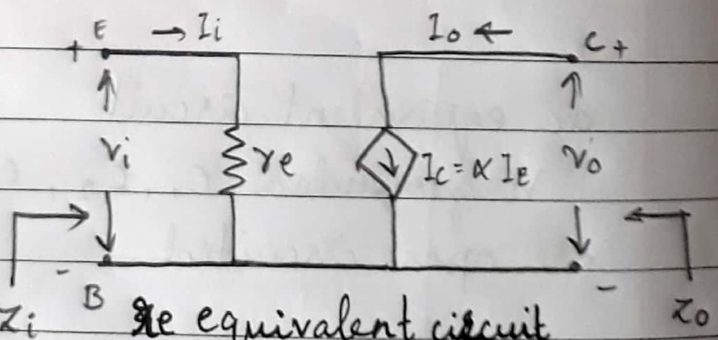
$$\alpha = \frac{I_c}{I_e}$$

$$I_c = \alpha I_e$$

$$\boxed{Z_i = \frac{V_i}{I_i} = r_e}$$

$\boxed{Z_o = \infty}$ (ideal)

$Z_o = 1M\Omega - 2M\Omega$ (practical)



r_e equivalent circuit

$$\boxed{A_v = \frac{v_o}{v_i} = \frac{\alpha R_L}{r_e}}$$

$$\boxed{A_i = \frac{I_o}{I_i} = \frac{-I_e}{I_c} = -\alpha}$$

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Date ______
Page ______

Q: For a common base configuration $I_e = 4mA$ 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.

Sol: i. $r_e = \dfrac{26mV}{I_e} = \dfrac{26mV}{4mV} = \underline{\underline{6.5\Omega}}$

$Z_i = r_e = \underline{\underline{6.5\Omega}}$

ii. $A_v = \dfrac{\alpha R_L}{r_e} = \dfrac{0.991(610)}{6.5} = \underline{\underline{93}}$

$A_i = -\alpha = \underline{\underline{-0.991}}$

iii. $V_o = A_v V_i = 93(3m) = \underline{\underline{279mV}}$

$I_i = \dfrac{V_i}{Z_i} = \dfrac{3m}{6.5} = \underline{\underline{461.5\mu A}}$

$I_o = A_i I_i = (-0.991)(461.5\mu) = \underline{\underline{-457.34\mu A}}$

iv. $Z_o = r_o = \infty$ //

$I_i = -I_e \Rightarrow I_e = -461.5\mu A$ //

$I_o = I_c \Rightarrow I_c = -457.34\mu A$ //

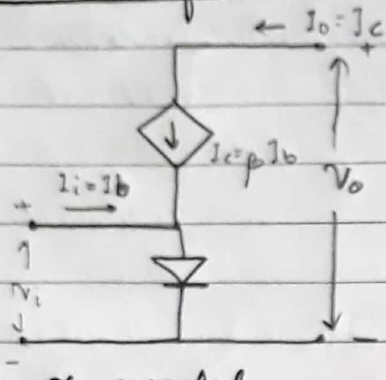
$I_e = I_c + I_b$

$I_b = I_e - I_c = -461.5\mu - (-457.34\mu)$

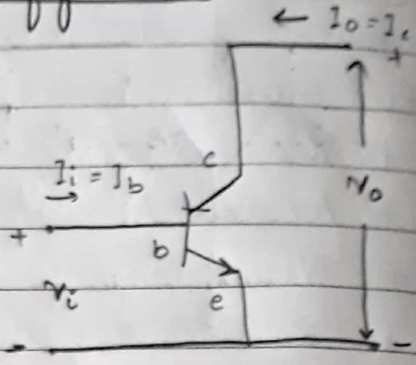
$I_b = \underline{\underline{-4.15\mu A}}$

Scanned by CamScanner

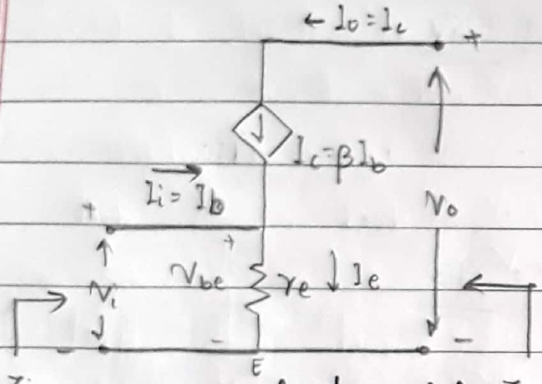
b. r_e model for common Emitter configuration:



r_e model



Common emitter configuration



r_e equivalent model

$V_i = V_{be} = I_e r_e$

$I_e = I_b + I_c$

$I_e = I_b + \beta I_b$

$I_e = I_b(1+\beta)$

$I_e \approx \beta I_b$

$$Z_i = \frac{V_i}{I_i} = \frac{\beta \cancel{I_b} r_e}{\cancel{I_b}}$$

$$Z_o = 40k \text{ to } 50k\,\Omega$$

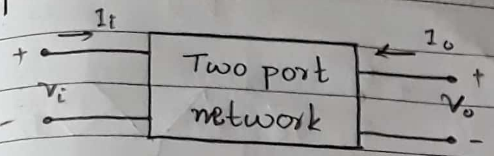
$$\boxed{Z_i = \beta r_e}$$

$$\boxed{A_v = \frac{-R_L}{r_e}}$$

$$A_i = \frac{I_o}{I_i} = \frac{I_c}{I_b} = \frac{\beta I_b}{I_b}$$

$$\boxed{A_i = \beta}$$

Hybrid model:



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 parameter

$V_i = h_{11} I_i + h_{12} V_o$

$I_o = h_{21} I_i + h_{22} V_o$

$h_{11} = \left.\dfrac{V_i}{I_i}\right|_{V_o=0}$ ohms $\qquad h_{12} = \left.\dfrac{V_i}{V_o}\right|_{I_i=0}$

$h_{21} = \left.\dfrac{I_o}{I_i}\right|_{V_o=0} \qquad h_{22} = \left.\dfrac{I_o}{V_o}\right|_{I_i=0}$ mho

$V_i = h_i I_i + h_r V_o$

$I_o = h_f I_i + h_o V_o$

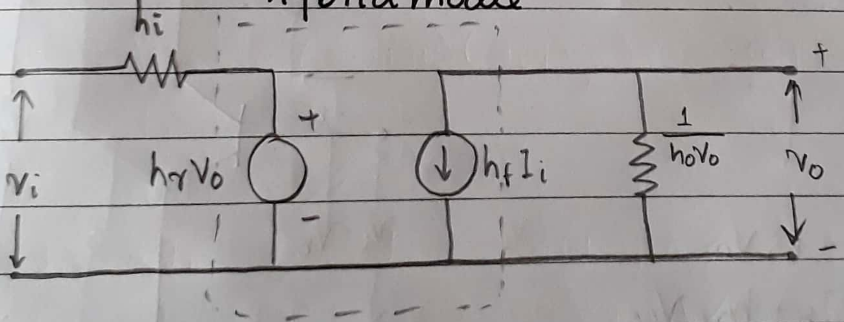
$h_{11} = h_i \Rightarrow$ voltage drop across impedance $(h_i I_i)$

$h_{12} = h_r \Rightarrow$ 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 model



Hybrid parameter nomenclature for transistors:

h parameter	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}

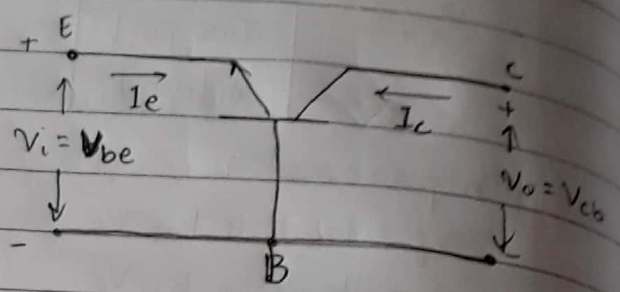
a. ## Hybrid model for common base configuration:

$V_i = V_{be}$

$I_i = I_e$

$V_o = V_{cb}$

$I_o = I_c$

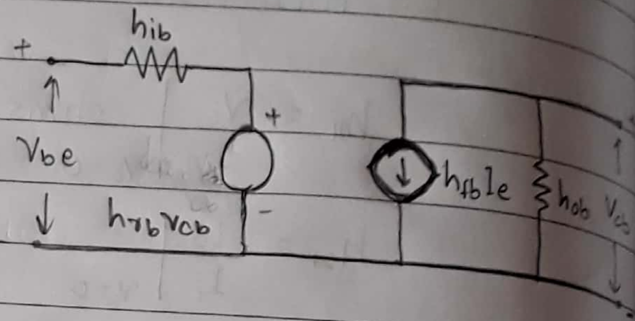


wkt $V_i = h_i I_i + h_r V_o$

$$V_{be} = h_{ib} I_e + h_{rb} V_{cb}$$

wkt $I_o = h_f I_i + h_o V_o$

$$I_c = h_{fb} I_e + h_{ob} V_{cb}$$



$$h_{ib} = \frac{V_{be}}{I_e}, \quad h_{rb} = \frac{V_{be}}{V_{cb}}$$

$$h_{fb} = \frac{I_c}{I_e}, \quad h_{ob} = \frac{I_c}{V_{cb}}$$

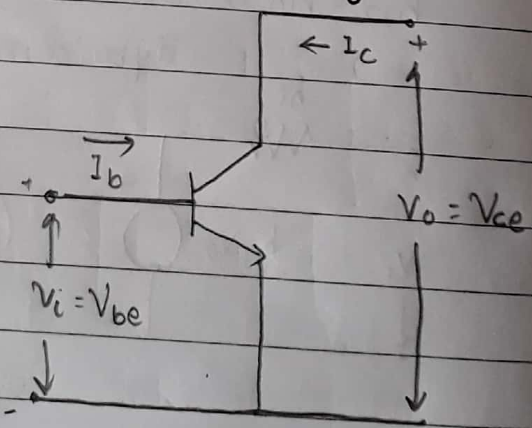
b. ## Hybrid model for common Emitter configuration:

$V_i = V_{be}$

$I_i = I_b$

$V_o = V_{ce}$

$I_o = I_c$

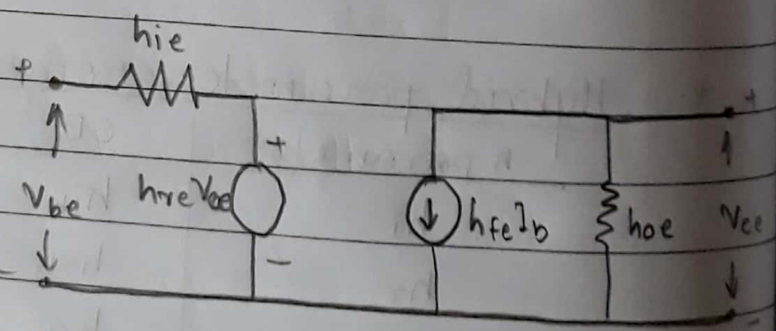


wkt $V_i = h_i I_i + h_r V_o$

$$V_{be} = h_{ie} I_b + h_{re} V_{ce}$$

wkt $I_o = h_f I_i + h_o V_o$

$$I_c = h_{fe} I_b + h_{oe} V_{ce}$$



$$h_{ie} = \frac{V_{be}}{I_b}, \quad h_{re} = \frac{V_{be}}{V_{ce}}$$

$$h_{fe} = \frac{I_c}{I_b}, \quad h_{oe} = \frac{I_c}{V_{ce}}$$

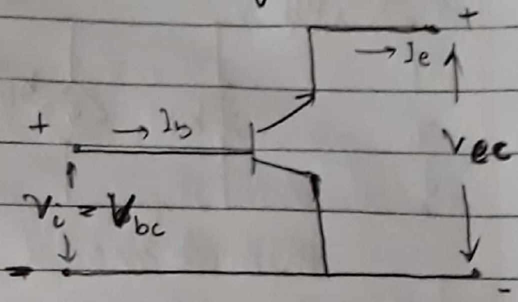
Hybrid model for common collector configuration:

$v_i = V_{bc}$

$I_i = I_b$

$V_o = V_{ec}$

$I_o = I_e$

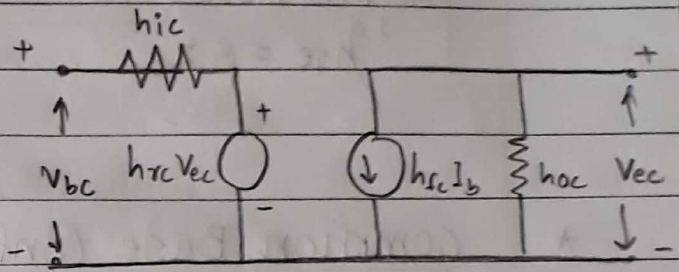


wkt $V_i = h_i I_i + h_r V_o$

$V_{bc} = h_{ic} I_b + h_{rc} V_{ec}$

wkt $I_o = h_f I_i + h_o V_o$

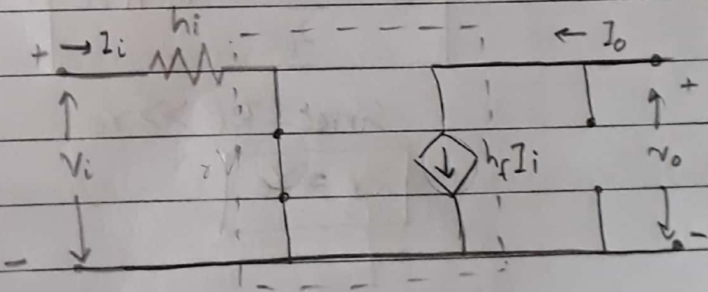
$I_e = h_{fc} I_b + h_{oc} V_{ec}$



$h_{ic} = \frac{V_{bc}}{I_b}$, $h_{rc} = \frac{V_{be}}{V_{ec}}$

$h_{fc} = \frac{I_e}{I_b}$, $h_{oc} = \frac{I_e}{V_{ec}}$

* Approximate Hybrid Equivalent circuit:



$h_r = 0.25m$

h_r is very low, hence it is short circuited.

$h_o = 40k\Omega - M\Omega$

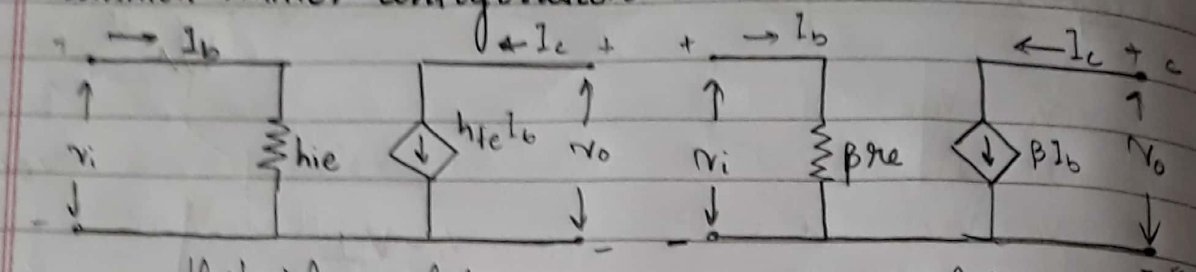
when h_o parallel with R_L

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.

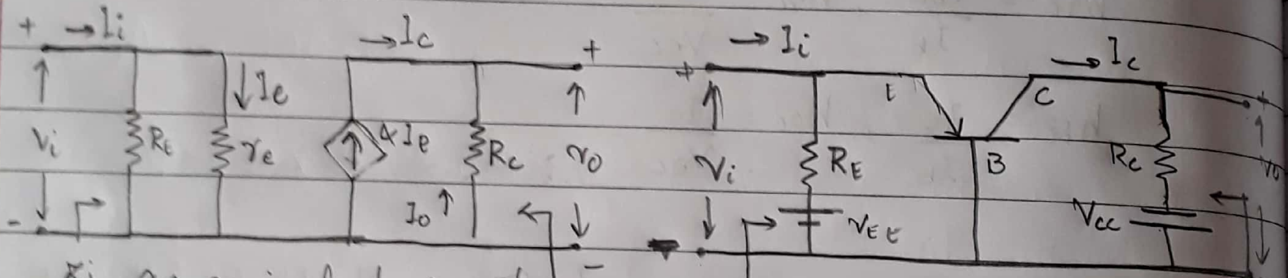
- Common Emitter configuration



Hybrid model $\qquad\qquad$ r_e model

$h_{ie} = \beta r_e \qquad\qquad h_{fe} = \beta$

★ Common Base Configuration:



ac equivalent circuit

$$\boxed{Z_i = \frac{V_i}{I_i} = R_E \parallel r_e}$$

Since $R_E >> r_e$

$$\boxed{Z_i \approx r_e}$$

For Z_o

$V_i = 0 \Rightarrow I_i = 0 \Rightarrow I_e = 0$

then $I_c = 0 \quad \because I_c = \alpha I_e = 0$ (open circuit).

$$\boxed{Z_o = R_C}$$

Gain

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

$\Rightarrow V_o = -I_o R_C$

Since $I_o = -I_c$

$V_o = I_c R_C$

$\Rightarrow V_i = I_i (R_E \parallel r_e)$

$V_i = I_i r_e$

Since $I_i = I_e$

$V_i = I_e r_e$

$V_i = \frac{I_c r_e}{\alpha} \quad (\because I_c = \alpha I_e)$

$$A_v = \frac{I_c R_C}{\frac{I_c r_e}{\alpha}}$$

$$\boxed{A_v = \frac{\alpha R_C}{r_e}}$$

If $\alpha = 1$ $\quad A_v = \frac{R_C}{r_e}$

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~~As~~ Since $r_e >> R_E$

$\Rightarrow I_e \approx I_i$ $\qquad I_o = -I_c$

$$A_I = \frac{I_o}{I_i} = \frac{-I_c}{I_e} = \frac{-\alpha I_e}{I_e}$$

$$\boxed{A_i = -\alpha}$$

Important characteristics of common base configuration.

- Input impedance
  $Z_i = r_e$ $\Rightarrow$ Low input impedance.
- Gain
  $A_V = \frac{R_C}{r_e}$ $\Rightarrow$ High voltage gain
- current Gain
  $A_i = -\alpha$ $\Rightarrow$ Approximately unity
- Output impedance
  $Z_o = R_C$ $\Rightarrow$ 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

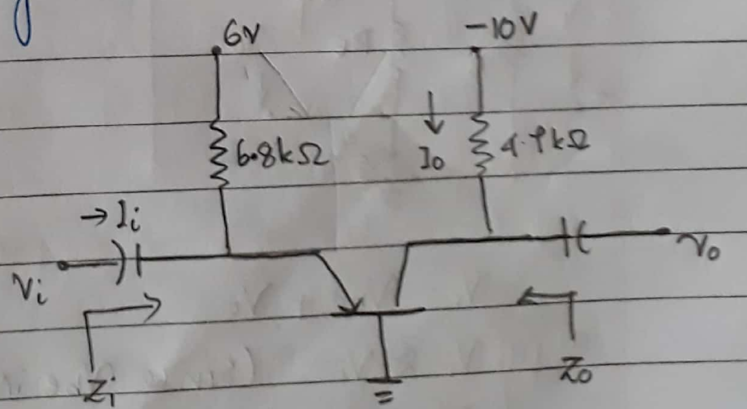
a. r_e

b. Z_i and Z_o

c. A_V and A_i

Take $\beta = 499$

and $r_o = 1M\Omega$



Sol: $V_{EE} = 6V$

$V_{CC} = -10V$

$I_E = \frac{V_{EE} - V_{BE}}{R_E} = \frac{6-0.7}{6.8k} = 0.78mA$

i. $r_e = \frac{26mV}{I_E} = \frac{26m}{0.78m} = 33.33\Omega$

ii. $Z_i = R_E || r_e$

$= 6.8k || 33.33$

$Z_i = 33.17\Omega$

$Z_o = R_C$

$Z_o = 4.7k\Omega$

iii. $A_v = \frac{\alpha R_C}{r_e}$

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

$A_v = \frac{(0.998)(4.7k)}{33.33}$

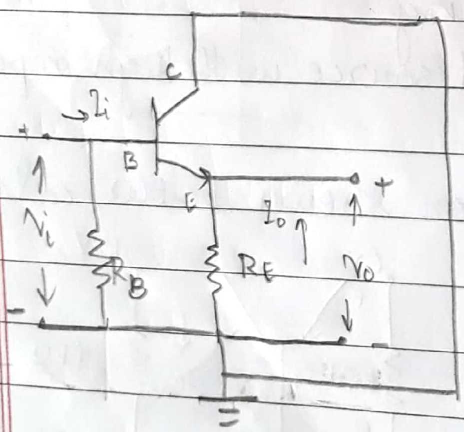
$\alpha = \frac{499}{499+1} = 0.998$

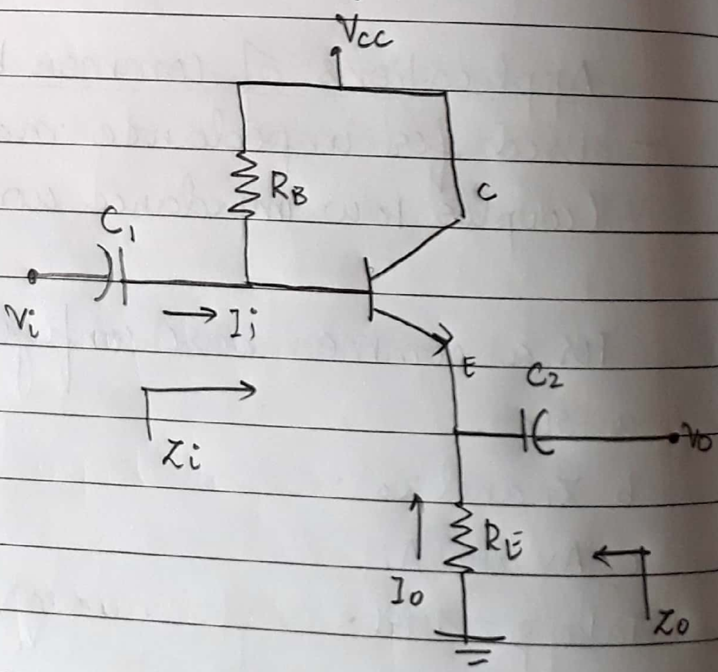
$A_v = 140.73$

$A_i = -\alpha = -0.998$

* Emitter Follower Configuration (using re model):

ac equivalent circuit





$V_i = V_{be} + V_E$

$V_i \approx V_E$ (since V_{be} is small)

$V_i \approx V_o$

$\boxed{A_v = \frac{V_o}{V_i} = 1}$

- Input impedance

Applying KVL to input side

$v_i = I_b \beta r_e + I_e R_E$

$v_i = I_b \beta r_e + I_b(1+\beta)R_E$

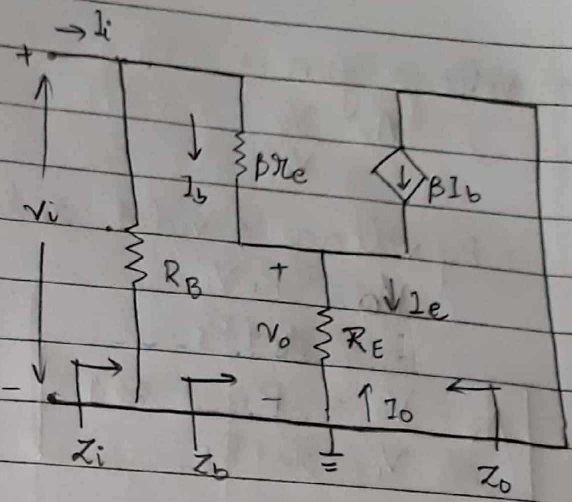
$\frac{v_i}{I_b} = \beta r_e + \beta R_E$

$(1+\beta \approx \beta)$

$$\boxed{Z_b = \beta(r_e + R_E)}$$

$Z_b \approx \beta R_E$

$$\boxed{Z_i = \frac{V_i}{I_i} = R_B \| Z_b}$$



re model

- Output impedance

$Z_b = \frac{V_i}{I_b} \Rightarrow I_b = \frac{v_i}{Z_b}$

$I_b = \frac{I_e}{1+\beta}$

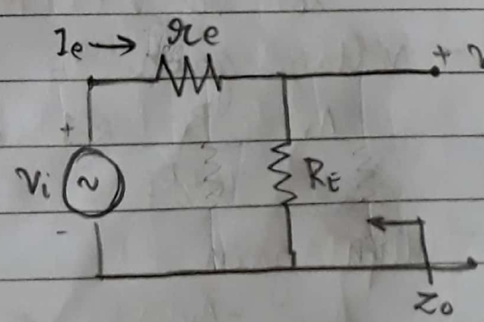
$\therefore \frac{I_e}{1+\beta} = \frac{v_i}{Z_b} \Rightarrow I_e = \frac{(1+\beta)v_i}{Z_b}$

Substituting for Z_b

$I_e = \frac{(1+\beta)V_i}{\beta(r_e+R_E)}$

$I_e = \frac{\beta V_i}{\beta(r_e+R_E)}$ $\quad 1+\beta \approx \beta$

$I_e = \frac{V_i}{r_e+R_E}$



$\Rightarrow v_i = I_e r_e + I_e R_E$

For Z_o : $V_i = 0$

$$\boxed{Z_o = r_e \| R_E}$$

$$\boxed{Z_o = r_e}$$

- voltage gain

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

By voltage divider rule

$$V_o = \frac{R_E V_i}{r_e + R_E}$$

$$\boxed{A_v = \frac{V_o}{V_i} = \frac{R_E}{r_e + R_E} \approx 1}$$

- Current gain

$$V_o = I_e R_E = -I_o R_E$$

$$\Rightarrow I_o = \frac{-V_o}{R_E}$$

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

$$A_i = \frac{I_o}{I_i} = \frac{-V_o}{R_E} \times \frac{Z_i}{V_i}$$

$$\boxed{A_i = -\frac{A_v Z_i}{R_E}}$$

Important characteristics :

- Input impedance

$Z_i = R_B \| Z_b$ ⇒ high input impedance

- Output impedance

$Z_o = r_e$ ⇒ low input impedance

- voltage gain

$A_v = \frac{R_E}{r_e + R_E} \approx 1$ ⇒ approximately unity

- Current gain

$A_i = \frac{-A_v Z_i}{R_E}$ ⇒ high current gain

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Applications :

used as buffer

Q: For emitter follower circuit, calculate:

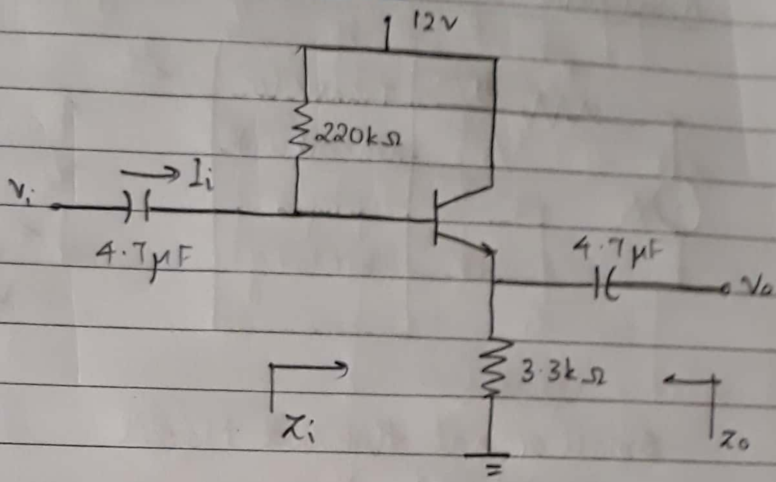
a. r_e

b. Z_i and Z_o

c. A_v and A_i

$\beta = 100$

$r_o = \infty$



Sol: a. $r_e = \dfrac{26mV}{I_E}$

$I_E = (1+\beta) I_B$

$I_E = (1+100) 20.42\mu$

$I_E = 2.063mA$

$I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (1+\beta)R_E}$ (Fixed bias)

$I_B = \dfrac{12 - 0.7}{220k + (1+\beta)3.3k} = 20.42\mu A$

$r_e = \dfrac{26m}{2.063m} = 12.6\Omega$

b. $Z_0 = r_e = 12.6\Omega$

$Z_i = R_B \parallel Z_b$

$Z_i = 220k \parallel 334.56k$

$Z_i = 132.72 k\Omega$

$Z_b = \beta r_e + (1+\beta)R_E$

$Z_b = 100(12.6) + (1+100)3.3k$

$Z_b = 334.56 k\Omega$

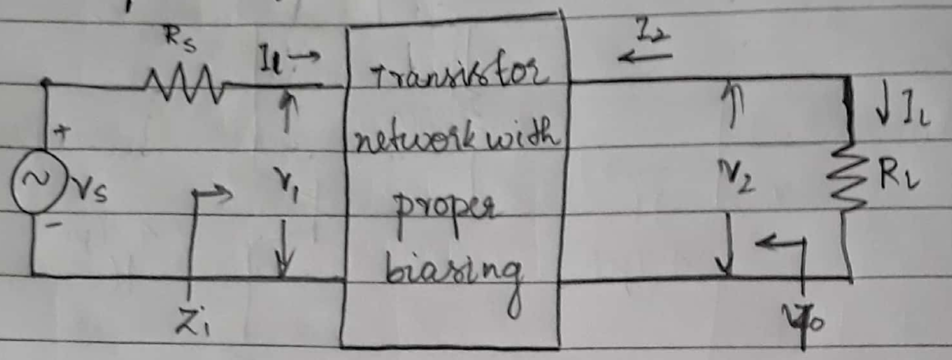
c. $A_V = \dfrac{R_E}{r_e + R_E} = \dfrac{3.3k}{12.6 + 3.3k} = 0.996$

$A_i = \dfrac{-A_V Z_i}{R_E} = -\dfrac{(0.996)(132.72k)}{3.3k} = -40.06$

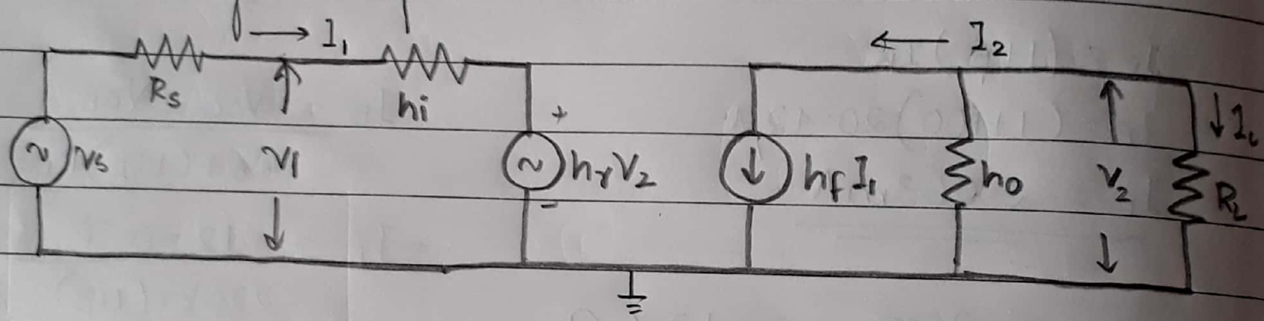
NOTE:

Emitter follower using voltage divider biasing circuit
Replace R_B by $R_1 || R_2$

★ Analysis of BJT single stage Amplifier by hybrid model.



Small signal Hybrid Model



- Current gain:

$$A_i = \frac{I_L}{I_1} = \frac{-I_2}{I_1} \quad \text{——— } (1)$$

wkt $I_2 = h_f I_1 + h_o V_2$

here $V_2 = I_L R_L = -I_2 R_L$

$\therefore I_2 = h_f I_1 - h_o I_2 R_L$

$h_f I_1 = I_2 + h_o I_2 R_L$

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

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

Substituting in eq (1)

$$\boxed{A_i = \frac{-h_f}{1 + h_o R_L}} \quad \text{——— } (a)$$

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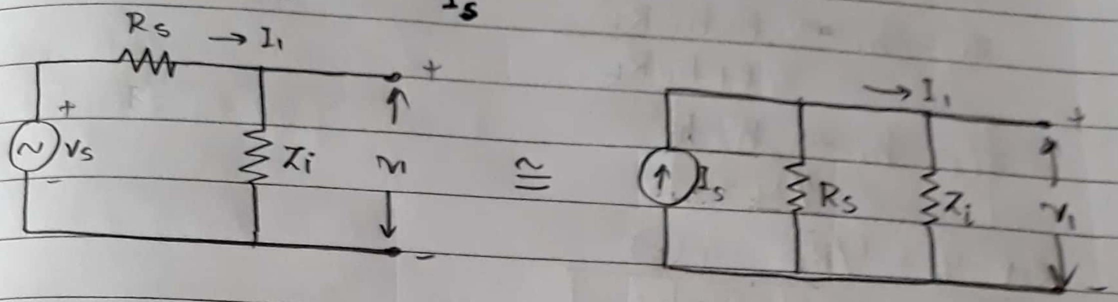
- **Current gain (wrt source):**

$$A_{is} = \frac{I_L}{I_s} = \frac{-I_2}{I_s}$$



$$A_{is} = \frac{-I_2}{I_1} \times \frac{I_1}{I_s}$$

$$A_{is} = A_i \frac{I_1}{I_s} \quad \text{——— (2)} \qquad \text{(From eq (1))}$$

$$I_1 = \frac{I_s R_s}{R_s + Z_i} \Rightarrow \frac{I_1}{I_s} = \frac{R_s}{R_s + Z_i}$$

Substituting in eq (2)

$$\boxed{A_{is} = \frac{A_i R_s}{R_s + Z_i}}$$

- **Input Impedance:**

$$Z_i = \frac{V_1}{I_1} \quad \text{——— (3)}$$

wkt $V_1 = h_i I_1 + h_r V_2$

Substituting in eq (3)

$$Z_i = \frac{h_i I_1 + h_r V_2}{I_1}$$

$$Z_i = h_i + \frac{h_r V_2}{I_1} \qquad \text{wkt } V_2 = -I_2 R_L$$

$$Z_i = h_i - \frac{h_r I_2 R_L}{I_1} \qquad \text{(From eq (1))}$$

$$Z_i = h_i + A_i h_r R_L \qquad \text{(From eq (a))}$$

$$Z_i = h_i + \left(\frac{-h_f}{1+h_o R_L}\right) R_L h_r$$

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

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

Let $Y_L = 1/R_L$

$$\boxed{Z_i = h_i - \frac{h_r h_f}{Y_L + h_o}}$$

– Voltage gain

$$A_V = \frac{V_o}{V_i} = \frac{V_2}{V_1} \quad \text{—— (4)}$$

$V_2 = -I_2 R_L$

$V_2 = A_i I_1 R_L \quad (\because -I_2 = A_i I_1)$

$$A_V = \frac{A_i I_1 R_L}{V_1} \qquad \left(\frac{V_1}{I_1} = Z_i\right)$$

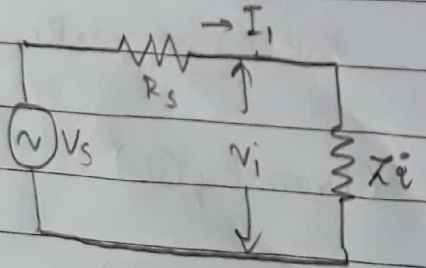
$$\boxed{A_V = \frac{A_i R_L}{Z_i}} \quad \text{—— (6)}$$

– Voltage gain (wrt source)

$$A_{VS} = \frac{V_2}{V_S}$$

$$A_{VS} = \frac{V_2}{V_1} \times \frac{V_1}{V_S}$$

$$A_{VS} = A_V \frac{V_1}{V_S} \quad \text{—— (5)} \qquad (\text{From eq } (4))$$



Voltage divider rule

$$V_1 = \frac{Z_i V_s}{R_s + Z_i}$$

$$\frac{V_1}{V_s} = \frac{Z_i}{R_s + Z_i}$$

substituting in eq (5)

$$A_{vs} = \frac{A_v Z_i}{R_s + Z_i}$$

substituting eq (6)

$$\boxed{A_{vs} = \frac{A_i R_L}{R_s + Z_i}}$$

- 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)

$$Y_o = h_f\left(\frac{-h_r}{R_s + h_i}\right) + h_o$$

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

- Power gain:

$$A_p = \frac{P_2}{P_1} \quad \text{—— (7)}$$

$$P_2 = V_2 I_L = -V_2 I_2$$

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$P_1 = V_1 I_1$

Substituting in eq 1

$$\therefore A_p = \frac{-V_2 I_2}{V_1 I_1}$$

$$\boxed{A_p = A_v A_i}$$

From eq 1 and eq 4

Substituting eq 6

$$A_p = \frac{A_i R_L}{Z_i} A_i$$

$$\boxed{A_p = \frac{A_i^2 R_L}{Z_i}}$$

Important formulae

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

$$A_{is} = \frac{A_i R_s}{Z_i + R_s}$$

$$Z_i = h_i + h_r A_i R_L = h_i - \frac{h_r h_f}{Y_L + h_o}$$

$$A_v = \frac{A_i R_L}{Z_i}$$

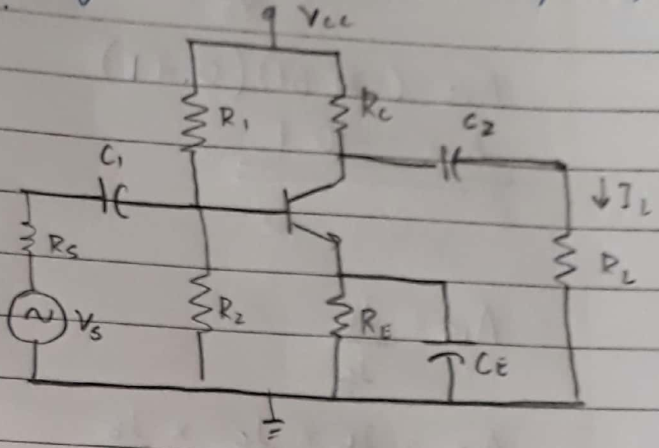
$$A_{vs} = \frac{A_v R_i}{R_i + Z_i} = \frac{A_i R_L}{Z_i + R_s} = \frac{A_{is} R_L}{R_s}$$

$$Y_o = h_o - \frac{h_f h_r}{h_i + R_s} = \frac{1}{Z_o}$$

$$A_p = A_v A_i$$

$$A_p = \frac{A_i^2 R_L}{Z_i}$$

Q: Consider a single stage CE amplifier with $R_s = 1k\Omega$, $R_1 = 50k\Omega$, $R_2 = 2k\Omega$, $R_C = 1k\Omega$, $R_L = 1.2k\Omega$, $h_{fe} = 50$, $h_{ie} = 1.1k\Omega$, $h_{oe} = 25\mu A/V$, $h_{re} = 2.5 \times 10^{-4}$, as shown in the figure. Find: A_i, $R_i(z_i)$, A_v, $A_{is} = \frac{I_L}{I_s}$, $A_{vs} = \frac{V_o}{V_s}$ and R_o.



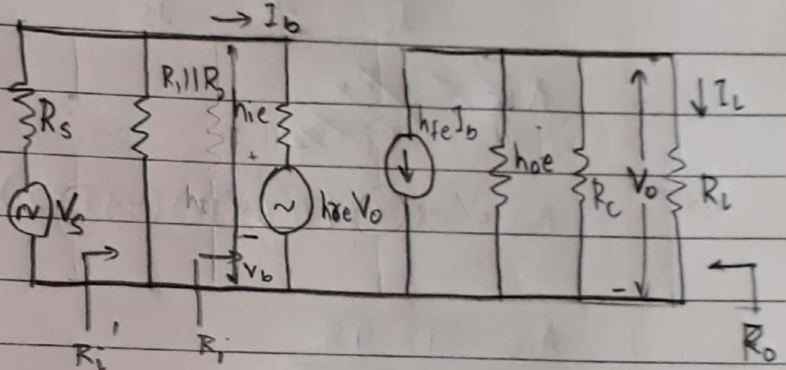
Sol:

$\cancel{A_i = \frac{1 - h_{fe}}{1 + h_{oe} R_L'}}$

$\cancel{A_i = \frac{1 + 50}{1 + 25\mu(1.2k)}}$

$\cancel{A_i = 48.754}$

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



$R_L' = R_C || R_L$

$R_L' = 1k || 1.2k$

$R_L' = 545.45\Omega$

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

$A_i = \frac{-50}{1 + 25\mu(545.45)} = -49.32$

$R_i = h_{ie} + h_{re} A_i R_L'$

$= 1.1k + (0.25m)(-49.32)(545.45)$

$R_i = 1.093k\Omega$

$A_v = \frac{A_i R_L'}{R_i} = \frac{(-49.32)(545.45)}{1.093k} = -24.61$

$\cancel{A_{is} = \frac{I_L}{I_s} = \frac{A_i R_s}{Z_i + R_s}}$

$R_i' = R_i || R_1 || R_2$

$= (1.093k || 50k || 2k) = 696.9\Omega$

$$A_{vs} = \frac{V_c}{V_s} = \frac{V_c}{V_b} \times \frac{V_b}{V_s}$$

$$A_{vs} = A_v \left(\frac{V_b}{V_s} \right)$$

$$A_{vs} = (-24.61)(0.41)$$

$$\underline{A_{vs} = -10.1}$$

$$V_b = \frac{V_s R_i'}{R_s + R_i'}$$

$$\frac{V_b}{V_s} = \frac{R_i'}{R_s + R_i'} = \frac{6969}{(1k + 6969)}$$

$$\frac{V_b}{V_s} = 0.41$$

$$\frac{V_c}{V_b} = A_v = -24.61$$

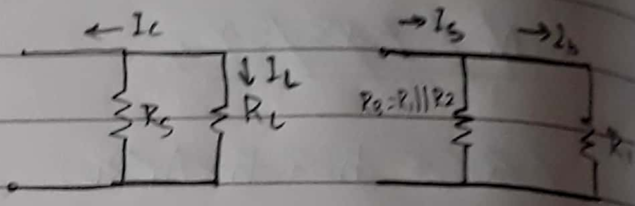
$$A_{is} = \frac{I_L}{I_s}$$

$$A_{is} = \frac{I_L}{I_c} \times \frac{I_c}{I_b} \times \frac{I_b}{I_s}$$

$$\cancel{A_{is} = \frac{-R_c}{R_c + R_L}}$$

$$A_{is} = -0.45(0.637k)(-49.32)$$

$$\underline{A_{is} = 13.98}$$



$$I_L = \frac{-I_c R_c}{R_c + R_L}$$

$$\frac{I_L}{I_c} = \frac{-R_c}{R_c + R_L}$$

$$\frac{I_L}{I_c} = \frac{-1k}{1k + 1.2k} = -0.45$$

$$I_b = \frac{I_s R_B}{R_B + R_i}$$

$$\frac{I_b}{I_s} = \frac{R_B}{R_B + R_i} = \frac{1.923k}{(1.923k + 1.093k)}$$

$$\frac{I_b}{I_s} = 0.637$$

$$\frac{I_c}{I_b} = -49.32$$