ElCoM
ELECTRICAL COMPUTER MECHATRONICS

تقدم لجنة ElCoM الاكاديمية

دفتر لمادة:

الكترونيات (2)

من شرح:

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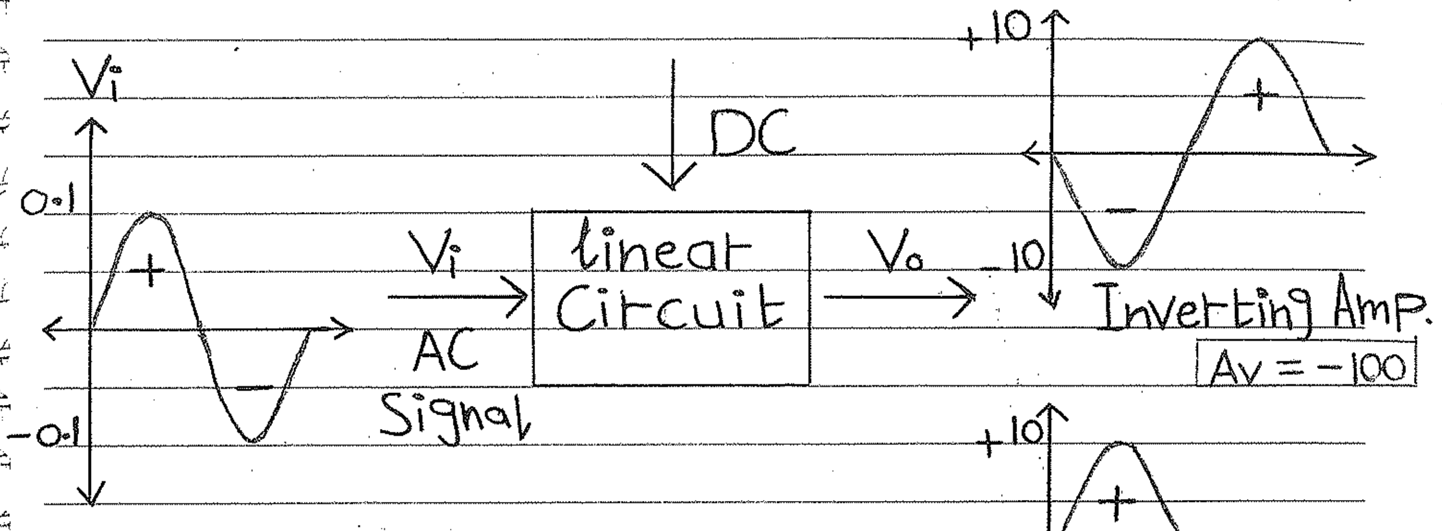
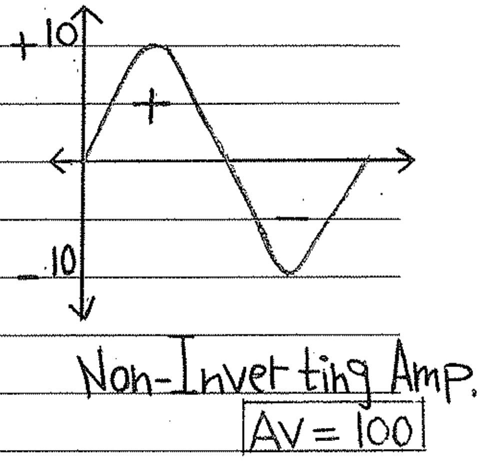
جزيل الشكر للطالب:

عدنان حوراني

Chapter(6): Basic (BJT) Amplifiers :-





$$\boxed{V_o = A_v \cdot V_i}$$

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

$$\boxed{V_o = A_v \cdot V_i}$$

Amplifier : Linear electronic Circuit

Contains :

- Active devices : (BJT, MosFET, JFET, op-Amp), to Amplify the AC i/p Signal.
- DC Sources : Biasing Active Devices in the required mode.

- Resistors : Voltage-divider, limiting Resistor, Load. حسب موقعه في الدارة.

- Capacitors : Coupling for AC Signal

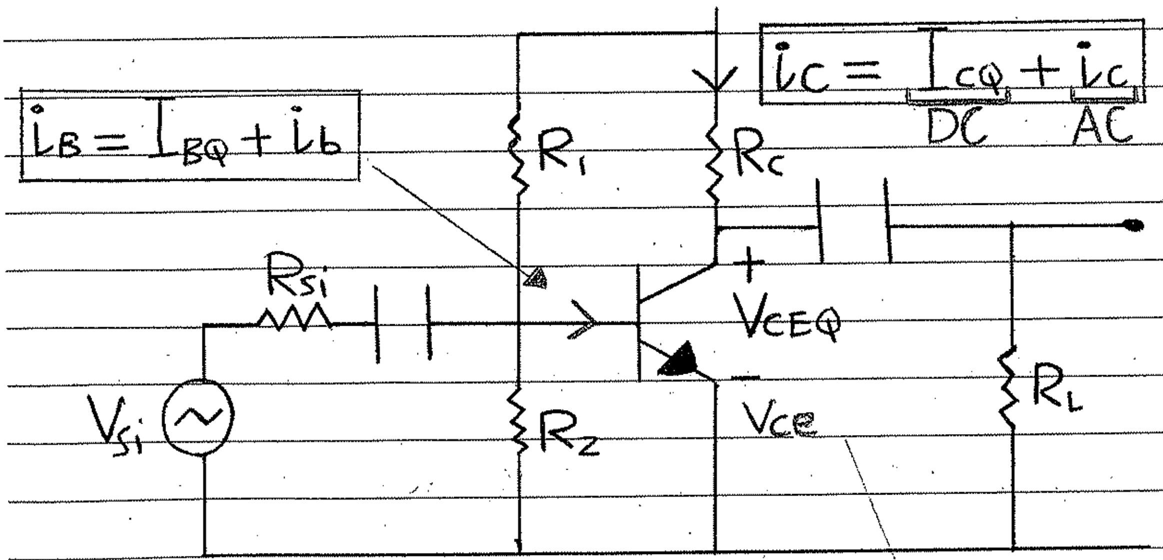
$$\left(X_c = \frac{1}{2\pi f C} \simeq 0\right).$$

($f \to \infty$)

Blocking for DC Signal

$$\left(X_c = \frac{1}{2\pi f C} = \infty\right).$$

($f \to 0$)



$$\boxed{v_{CE} = V_{CEQ} + V_{ce}}$$

Since the Amp. is linear CCt. So

Superposition Can be Applied :

i.e the total response is the D.C response

+ AC response.

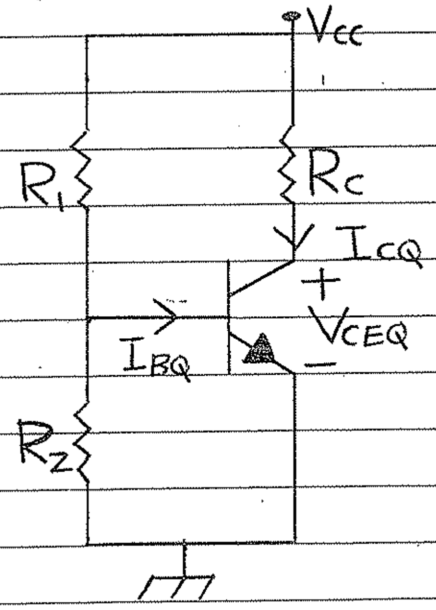
1) For D.C : [All Cap.s are open and

AC Source = 0]

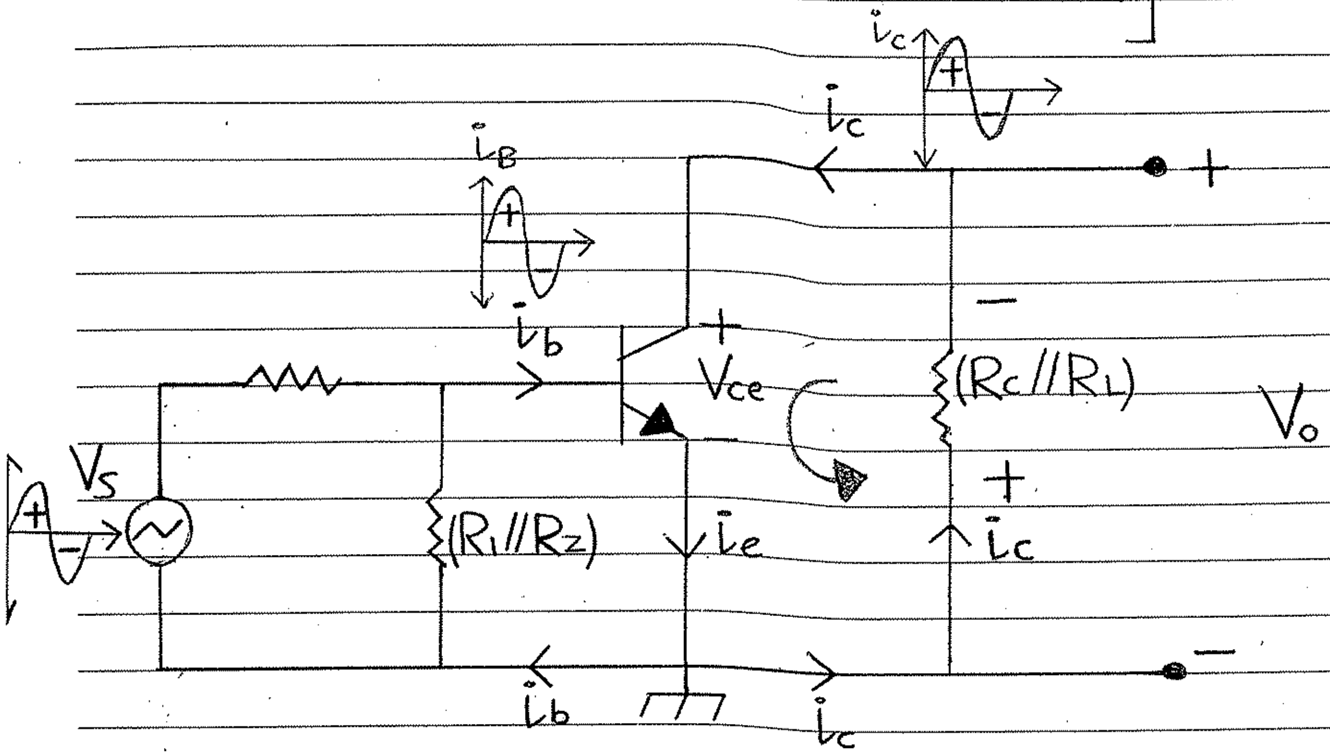
The DC Source will biase the BJT in

Forward Active mode at a Certain

Q-Pt. ; I_{BQ}, I_{CQ}, V_{CEQ}.

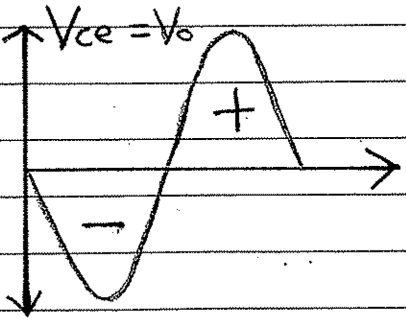


2) For AC : [All Cap.s are Short CCt. and DC Source → Short CCt.]



$$V_{ce} + i_c (R_c // R_L) = 0$$

$$V_{ce} = - i_c (R_c // R_L)$$



$$\boxed{V_o = - i_c (R_c // R_L)}$$

The AC i/P Signal will drive an (a.C base Current (i_b)) which will Cause an (a.C Collector Current ($i_c = \beta i_b$)).
i_c will flow through (R_c or $R_c // R_L$) Causing an a.C O/p Voltage:

$$\boxed{V_o = V_{ce} = - i_c (R_c // R_L)}$$

#

3) Since the Amp. Contains DC & AC Sources and it is Linear CCt., So according to Superposition the total Response is:

$$\boxed{i_B = I_{BQ} + i_b}$$

$$\boxed{i_C = I_{CQ} + i_c}$$

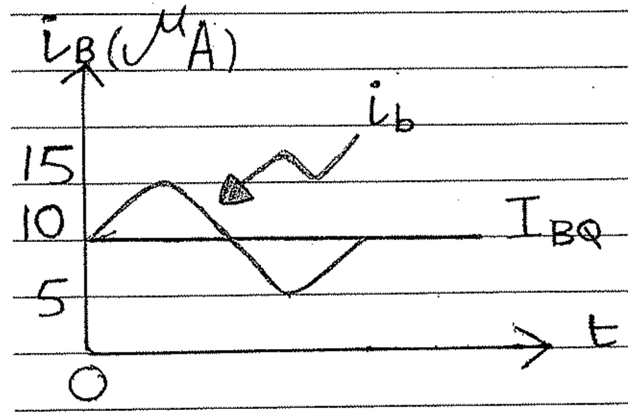
$$\boxed{V_{CE} = V_{CE} + V_{ce}}$$

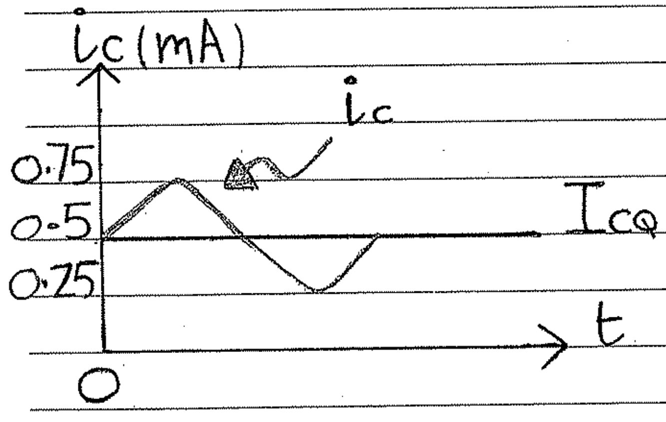
#

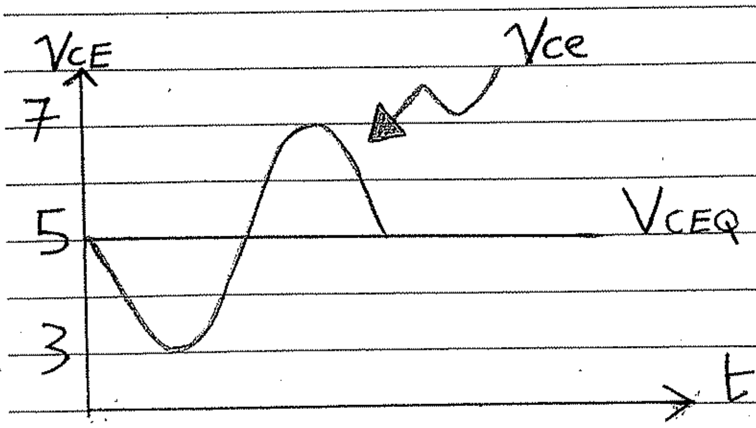
For $I_{BQ} = 10\mu A$, $I_{CQ} = 0.5\ mA$,

$V_{CEQ} = 5V$; $i_b = 5 \sin \omega t\ \mu A$,

$i_c = 0.75 \sin \omega t\ mA$, $V_{ce} = -2 \sin \omega t\ V$



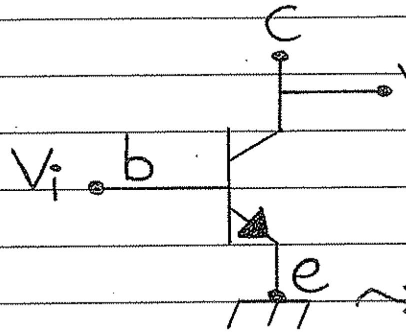




* For Amp., the BJT must be biased in Forward Active mode.

BJT Amp. :-

1] Common - Emitter Amp. :-



الى الأرض مباشرة

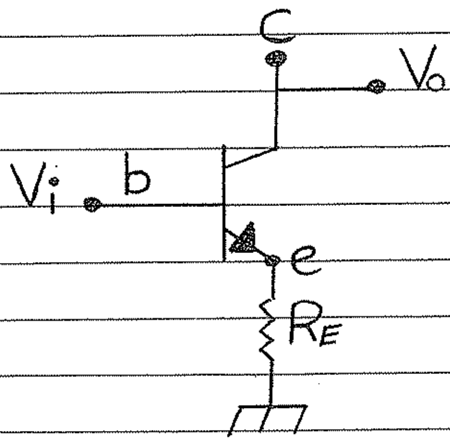
(i) Basic C-E Amp.

E $\longrightarrow$ Common-terminal.

Input to base.

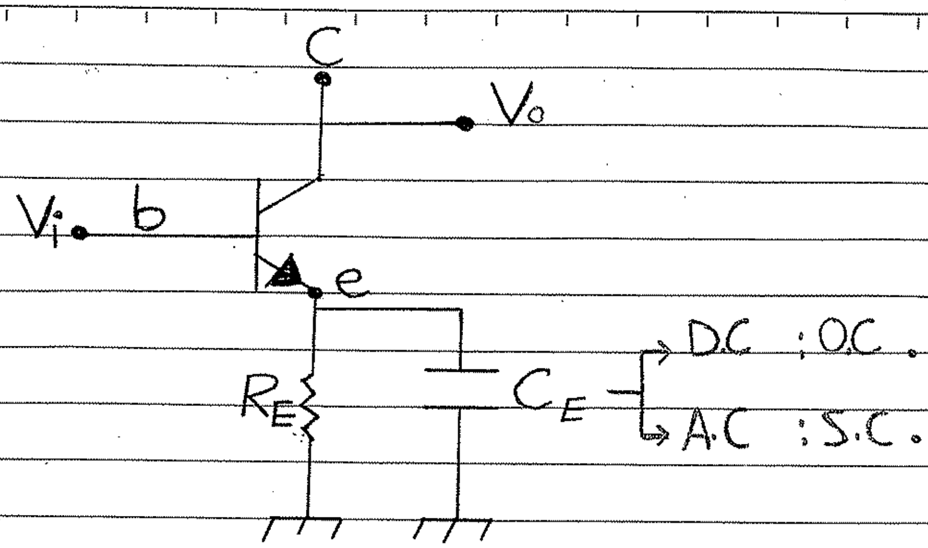
Output from Collector.

Or:



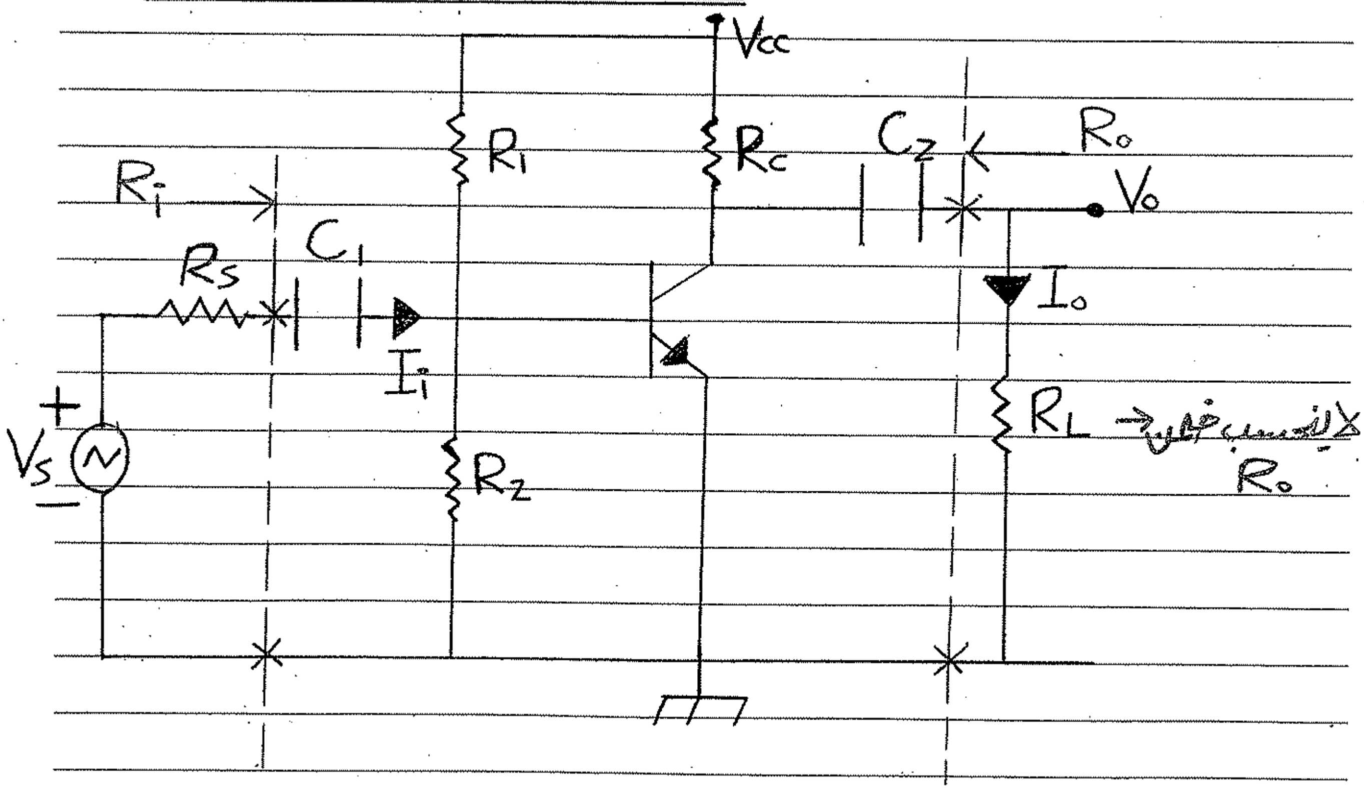
(ii) C-E with R_E.

Or :



(iii) C-E with bypass Cap. (C_E).

$\boxed{i}$ Basic C-E Amp. :-



Voltage-gain $= A_V = \frac{V_o}{V_s}$.

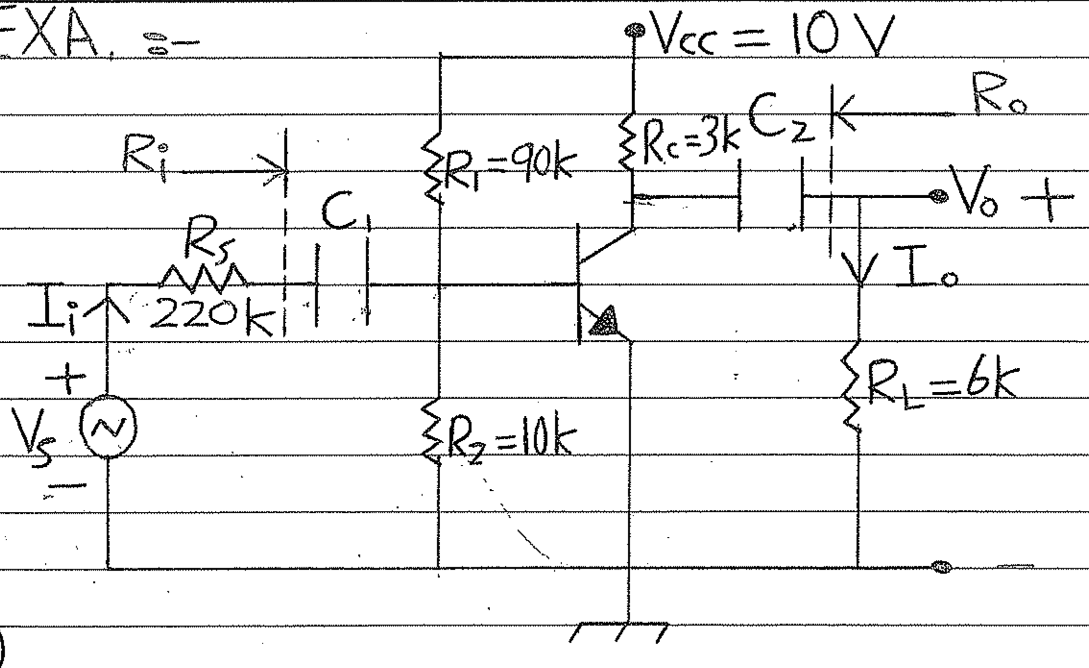
Current-gain $= A_I = \frac{I_o}{I_i}$.

Input Resistance : R_i.

Output Resistance : R_o.

R_i seen by Signal Voltage generator $= R_i + R_S$

EXA. :-



1)

Given $\beta = 50$, $V_{BE} = 0.7\,V$, $V_A = 160\,V$

Calculate I_{BQ}, I_{CQ}, V_{CEQ}.

2) Draw Small-Signal Equivalent CCt. of the Amp. and Find :

a) Voltage-gain. $A_V = \frac{V_o}{V_i}$.

b) Current-gain. $A_I = \frac{I_o}{I_i}$.

c) Input Resistance. R_i.

d) Output Resistance. R_o.

Sol.

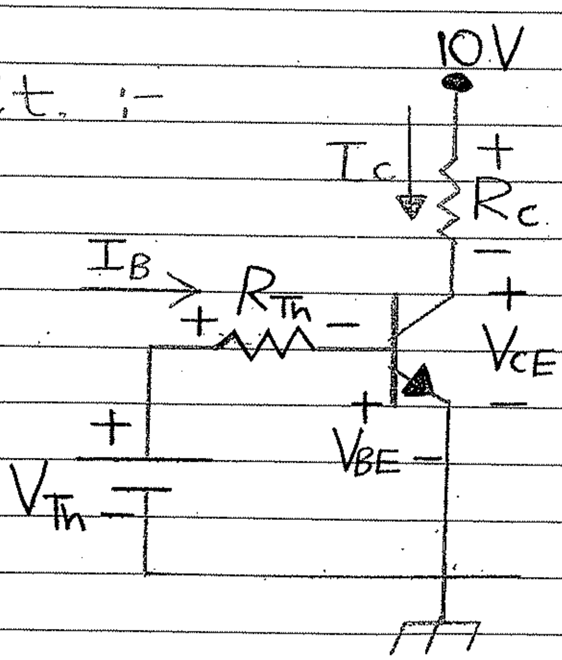
(1) For DC Analysis :-

All Caps are Open CCt. :-

$R_{Th} = R_1 // R_2$

$= 9 k\Omega$.

$V_{Th} = \frac{10 * 10}{100} = 1V$.



KVL for BE loop :

$$-V_{Th} + R_{Th} I_B + V_{BE} = 0$$

$$I_B = \frac{V_{Th} - V_{BE}}{R_{Th}} = \frac{1-0.7}{9} = \frac{0.3}{9} = 0.033\ mA = I_{BQ}$$

$$I_{CQ} = \beta I_{BQ} = 50 * 0.033 = 1.67\ mA$$

KVL for CE loop :

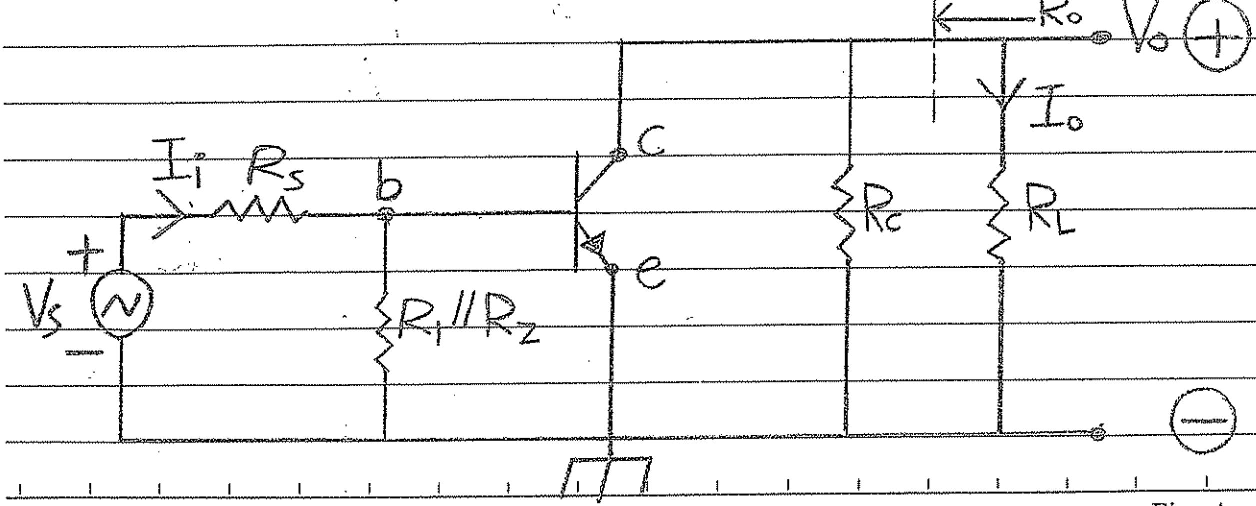
$$-V_{CC} + I_C R_C + V_{CE} = 0$$

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

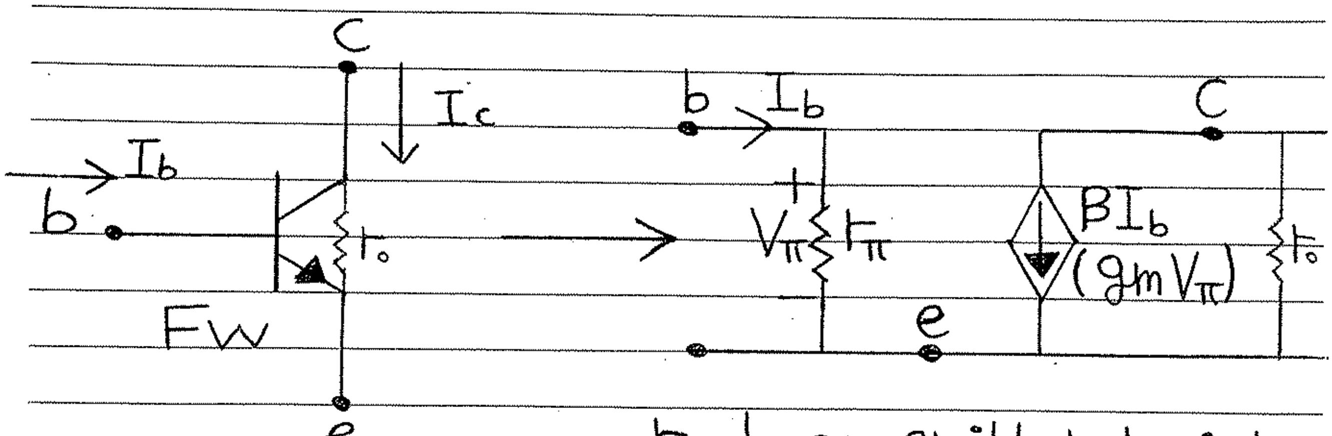
$$= 10 - 1.67 * 3 = 10 - 5 = 5V.$$

∴ The BJT in F.A.M.

(2) A.C Analysis : All Cap.s are short cct. and all DC Sources are short.



To perform A.C Analysis, the (BJT) must be replaced by its model.



r_π: base-emitter resistor.

$$\boxed{r_\pi = \frac{V_T}{I_{BQ}} = \frac{V_T}{\frac{I_{CQ}}{\beta}} = \frac{\beta V_T}{I_{CQ}}}$$

Where: V_T: Thermal Voltage

$V_T = 26\ mV$ at R.T.

g_m: Transconductance

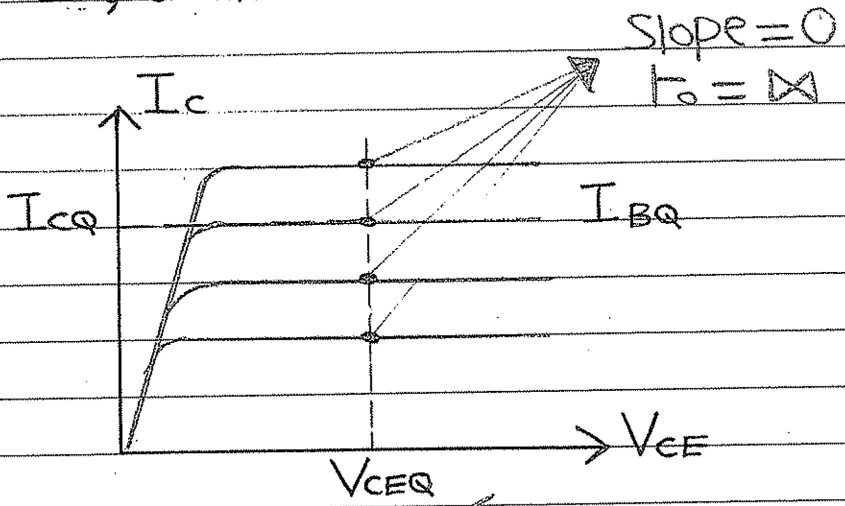
$$\boxed{g_m = \frac{I_{CQ}}{V_T}}$$

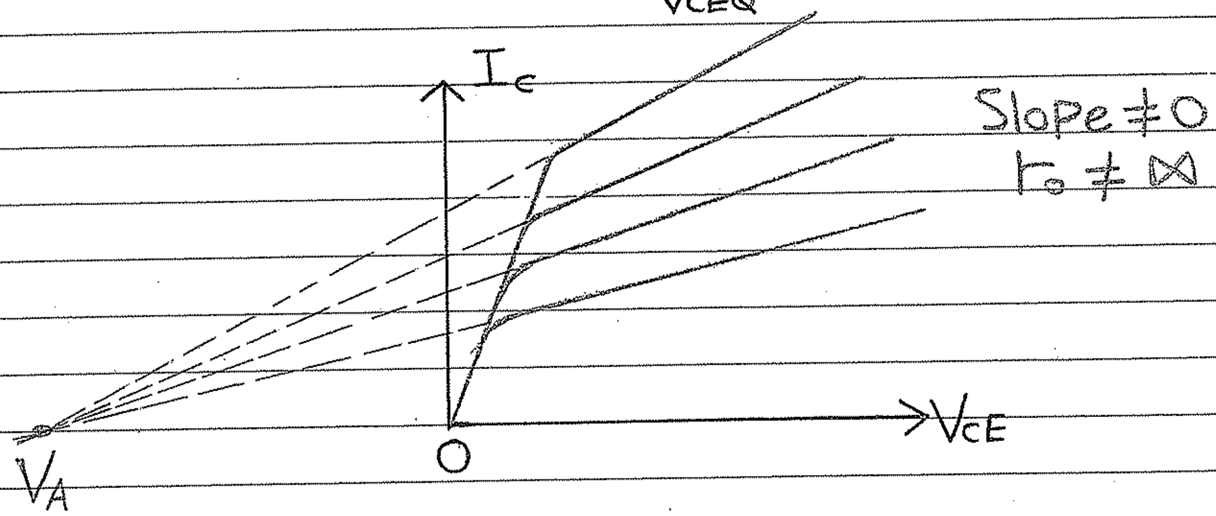
r_o: Transistor O/P Resistance.

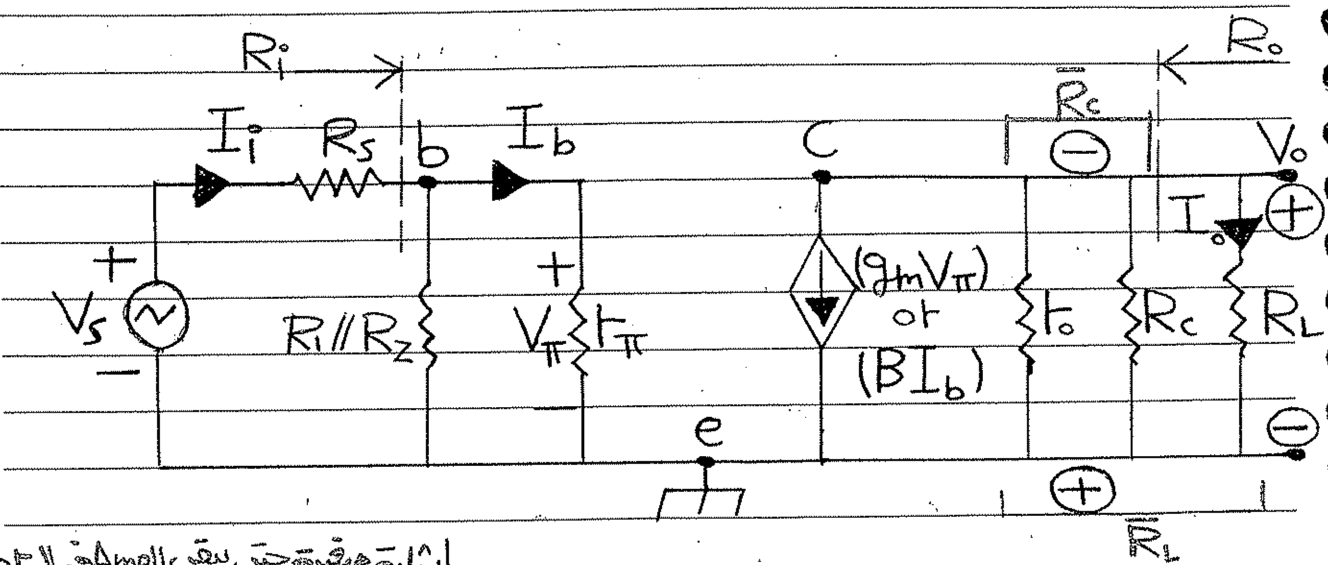
$$\boxed{r_o = \frac{V_A}{I_{CQ}}}$$

V_A : Early Voltage, (given). $\boxed{50V < V_A < 300V}$

$$r_o = \frac{1}{\text{Slope of } I_C, V_{CE} \text{ line}}$$







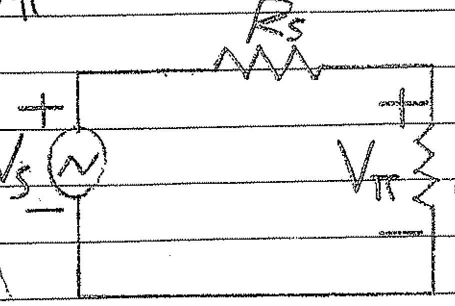
إشارة صغيرة حتى يبقى الـAmpl في الـlinear.

Small-Signal AC equivalent cct. for the Amplifier.

1) $$A_V = \frac{V_o}{V_s} = \frac{V_o}{V_\pi} * \frac{V_\pi}{V_s}$$

$$V_o = -g_m V_\pi R_L' \rightarrow \frac{V_o}{V_\pi} = -g_m R_L'$$

$$R_L' = r_o // R_c // R_L$$



$$V_\pi = V_s \frac{R_i}{R_s + R_i}$$

$$V_o = -g_m \frac{V_s \cdot R_i}{R_s + R_i} \bar{R}_L$$

$$\frac{V_o}{V_s} = A_V = \underbrace{-}_{\text{means } 180^\circ \text{ phase shift between } V_s \text{ and } V_o} g_m \bar{R}_L \frac{R_i}{R_i + R_s}$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{1.67 \text{ mA}}{26 \text{mV}} = 64 \text{ mA/V}.$$

$$\bar{R}_L = r_o // R_C // R_L$$

$$r_o = \frac{V_A}{I_{CQ}} = \frac{160 V}{1.67 \text{ mA}} \simeq 95 \text{ k}\Omega.$$

$$\bar{R}_L = 95 // 3 // 6 = 1.98 \text{ k}\Omega$$

$$R_i = r_\pi // R_{Th}$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{50 * 26}{1.67 \text{ mA}} = 780 \Omega.$$

$$A_V = -64 * 1.98 * \frac{0.78}{0.78 + 0.22}$$

$$= -126 * 0.78 = -98.3 = \frac{V_o}{V_s}.$$

$$V_o = -98.3\,V_s$$

بمعنى أن Vs تكبرت بمقدار 98.3 وانقلبت بـ 180° .

2) $$A_I = \frac{I_o}{I_i} = \frac{I_o}{I_b} * \frac{I_b}{I_i}$$

$$I_o = -\beta I_b \frac{\bar{R}_c}{\bar{R}_c + R_L} \rightarrow \frac{I_o}{I_b} = \frac{-\beta \bar{R}_c}{\bar{R}_c + R_L}$$

$$\bar{R}_c = r_o \,//\, R_c \rightarrow R_c = 2.9\,k\Omega$$

$$I_b = \frac{I_i * R_{Th}}{R_{Th} + r_\pi} \longrightarrow \frac{I_b}{I_i} = \frac{R_{Th}}{R_{Th} + r_\pi}$$

$$\therefore A_I = \frac{-\beta \bar{R}_c}{\bar{R}_c + R_L} \cdot \frac{R_{Th}}{R_{Th} + r_\pi}$$

$$= \frac{-50 * 2.9}{2.9 + 6} \cdot \frac{9}{9 + 780}$$

$$= \frac{-1305}{13728.6} = 0.09\,A$$

(A_I) and (A_V) relation :

$$A_I = \frac{I_o}{I_i} = \frac{\frac{V_o}{R_L}}{\frac{V_s}{R_s+R_i}} = \frac{V_o}{V_s} * \frac{R_s+R_i}{R_L}$$

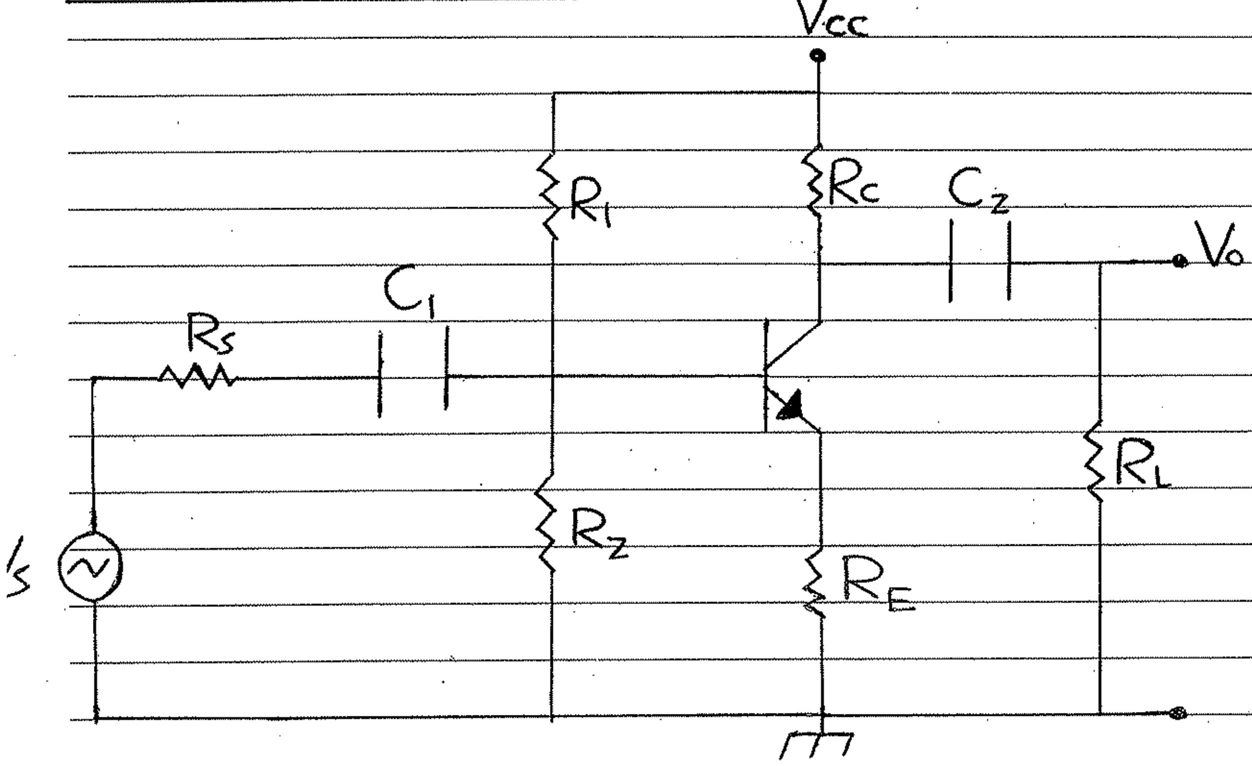
$$\boxed{A_I = A_V * \frac{R_s+R_i}{R_L}}$$

$$A_V = \frac{V_o}{V_i} = \frac{I_o \cdot R_L}{I_i(R_s+R_i)}$$

$$\boxed{A_V = A_I * \frac{R_L}{R_s+R_i}}$$

ii C-E with R_E :

$\boxed{R_{Th} = 0.1(\beta+1)R_E}$ Bias Stable Condition.

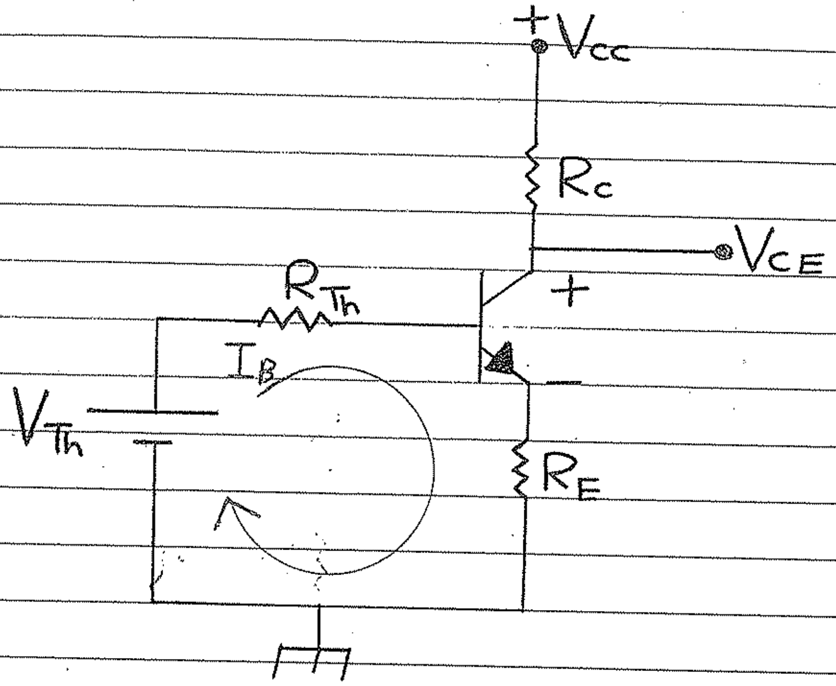


DC Analysis :

The advantages of R_E is Stabilize the Q-Point against β-Variation.

$\boxed{\beta \text{ لا تعتمد على } \text{Q-pt}}$

All Caps are Open Circuit :



$$R_{Th} = R_1 // R_2 \quad ; \quad V_{Th} = \frac{V_{cc} \cdot R_2}{R_1 + R_2}$$

$$-V_{Th} + I_B R_{Th} + V_{BE} + I_B(\beta+1) R_E = 0$$

$I_B = \dfrac{V_{Th} - V_{BE}}{R_{Th} + (\beta+1) R_E}$

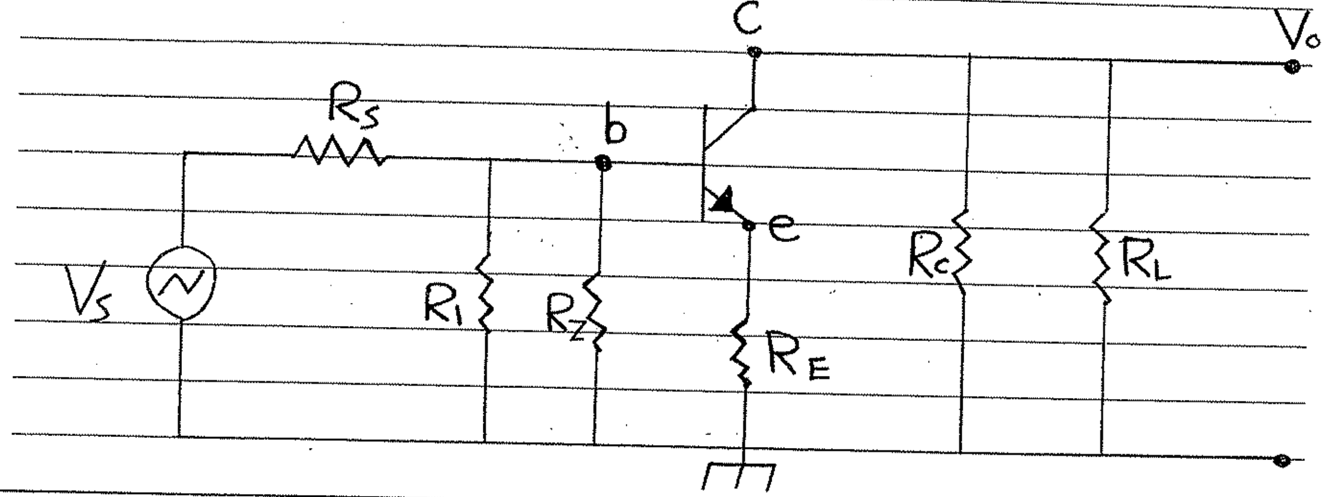
$I_C = \beta I_B$

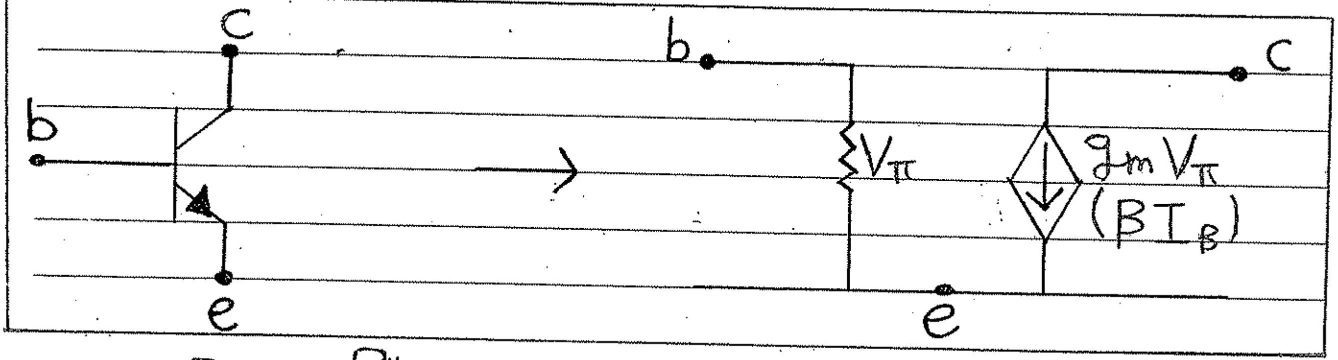
$V_{CE} = V_{cc} - I_C R_C - I_E R_E$

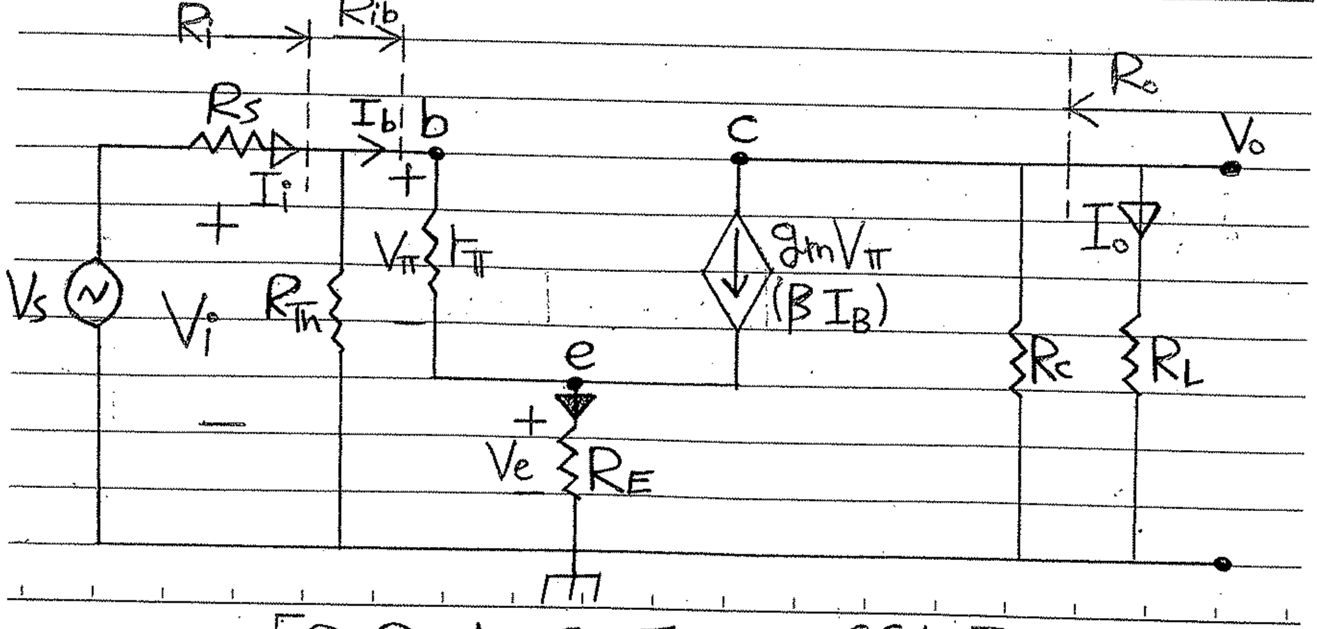
#.

AC Analysis:

All Caps. and DC Sources are Short CCt.







[S.S A.C Eqvt. CCt.]

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

$$V_i = V_\pi + V_e = I_b \cdot r_\pi + I \cdot R_E$$

$$I_e = (\beta+1) I_b$$

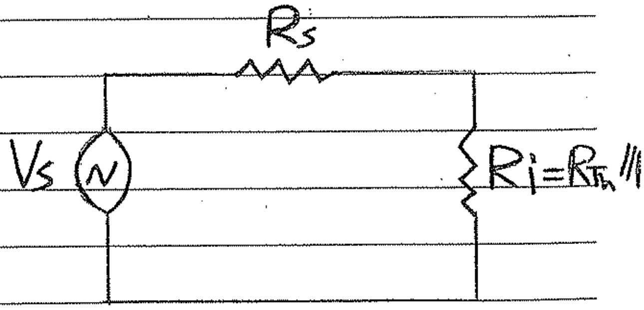
$$V_i = I_b (r_\pi + (\beta+1) R_E)$$

$$V_o = -\beta I_b (R_c // R_L)$$

$$\frac{V_o}{V_i} = \frac{-\beta \cancel{I_b} (R_c // R_L)}{\cancel{I_b}(r_\pi + (\beta+1) R_E)}$$

$$\frac{V_i}{V_s} = \frac{R_i}{R_i + R_s}$$

$$\frac{V_o}{V_s} = A_V = \frac{-\beta (R_c // R_L)}{r_\pi + (\beta+1) R_E} \cdot \frac{R_i}{R_i + R_s}$$



$\boxed{(R_E) \text{ reduces } (A_V)}$

$$R_i = R_{Th} // R_{ib}$$

$$\# \; R_{ib} = \frac{V_i}{I_b} = \frac{\cancel{I_b} r_\pi + (\beta+1) \cancel{I_b} \cdot R_E}{\cancel{I_b}}$$

$$\therefore \boxed{R_{ib} = r_\pi + (\beta+1) R_E}$$

$\boxed{(R_E) \text{ increases } (R_{ib})}$

$$A_I = \frac{I_o}{I_i} = \frac{\frac{V_o}{R_L}}{\frac{V_i}{R_i}} = \frac{\frac{V_o}{R_L}}{\frac{V_s}{R_i + R_s}}$$

$$= \frac{V_o}{V_s} * \frac{R_i + R_s}{R_L}$$

$$= A_V \frac{R_i + R_s}{R_L}$$

$\boxed{(R_E) \text{ reduces } (A_I)}$

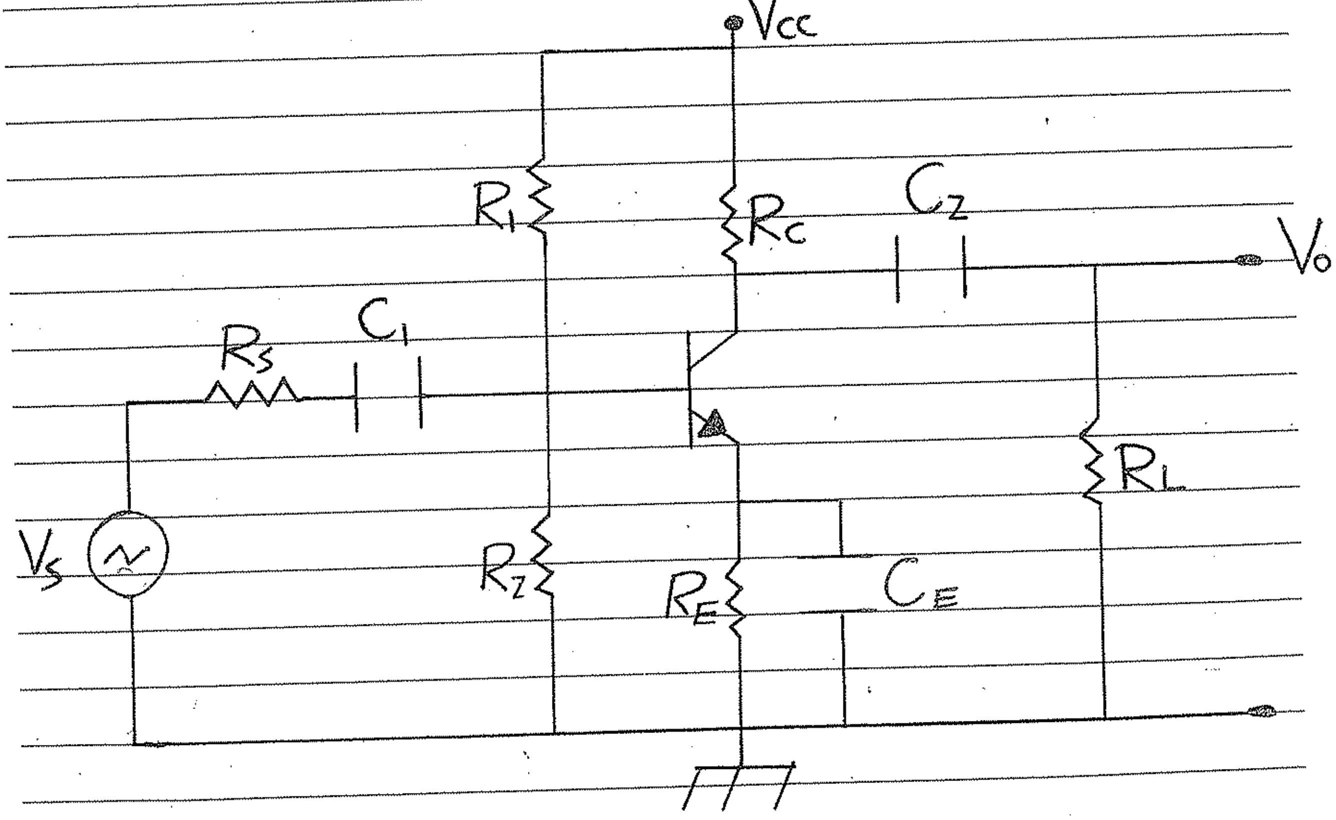
Consider A_v expression :-

If $\boxed{(\beta+1)R_E \gg r_\pi}$ and $\boxed{\beta \gg 1}$

$$\therefore \quad A_v \simeq \frac{-(R_C // R_L)}{R_E} \cdot \frac{R_i}{R_i + R_s}$$

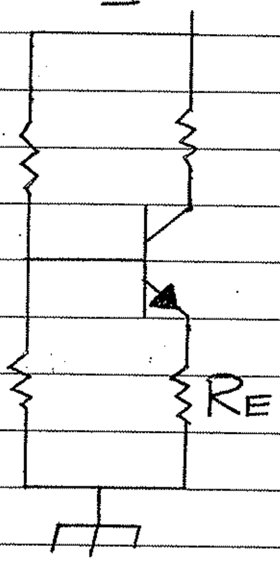
i.e (R_E) stabilize (A_v) against (β-Variation)

$\boxed{iii}$ C-E with bypass Cap. (C_E) :-



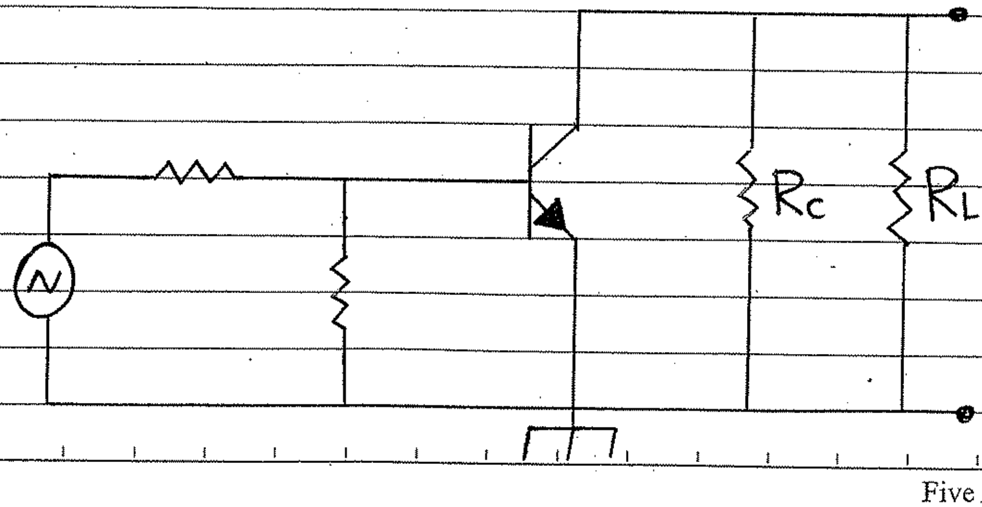
1) For DC Analysis :-

[C_E is Open CCt. , and the CCt. is analysis as CE with R_E].



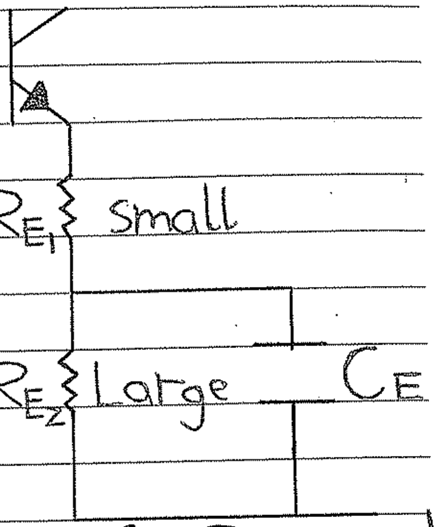
2) For AC Analysis :-

[C_E is Short CCt. , and the CCt. work as Basic CE Amp.].



$$A_V = -\frac{\beta(R_C\parallel R_L)}{V_\pi+(\beta+1)R_{E_1}}\cdot\frac{R_i}{R_i+R_s}$$

$$\simeq -\frac{(R_C\parallel R_L)}{R_{E_1}}\cdot\frac{R_i}{R_i+R_s}$$



To gain all advantages of R_E and minimize disadvantages; R_E is made of two parts, R_{E_1} (Small), R_{E_2} (Large), then bypass Large R_E with C_E. #

$$\boxed{\text{AC Slope} = \frac{-1}{(R_C\parallel R_L)+R_{E_1}}}$$

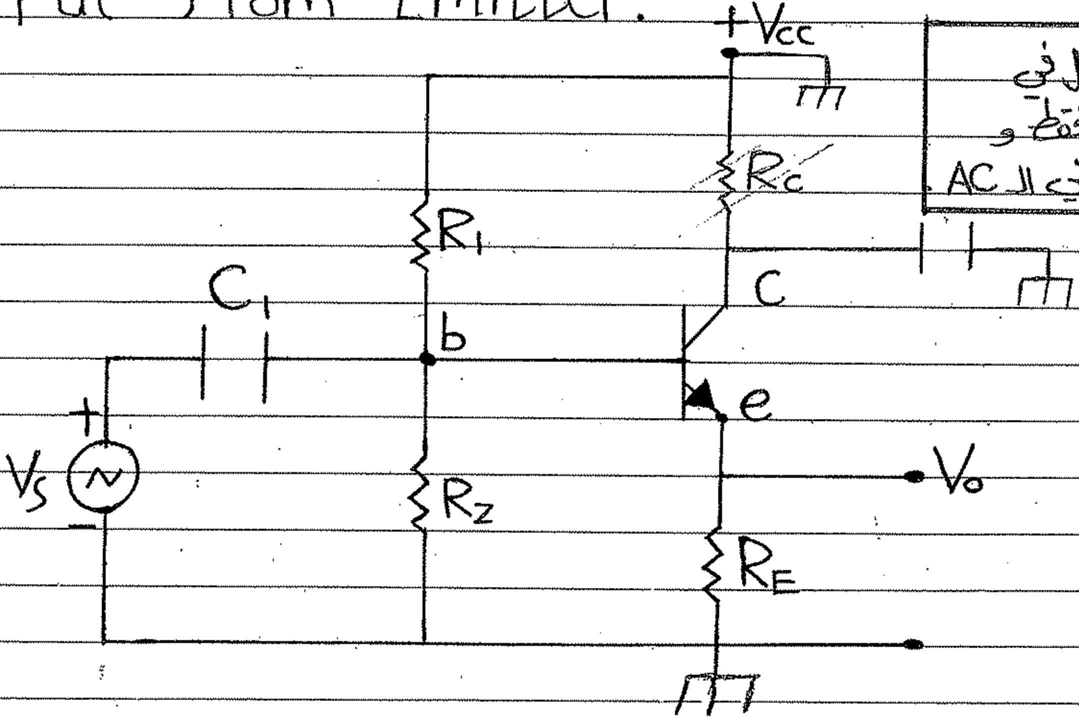
$$\boxed{\text{DC Slope} = \frac{-1}{R_C+R_{E_1}+R_{E_2}}}$$

2] Common – Collector Amp. [Emitter-Follower]

C ⟶ Common terminal.

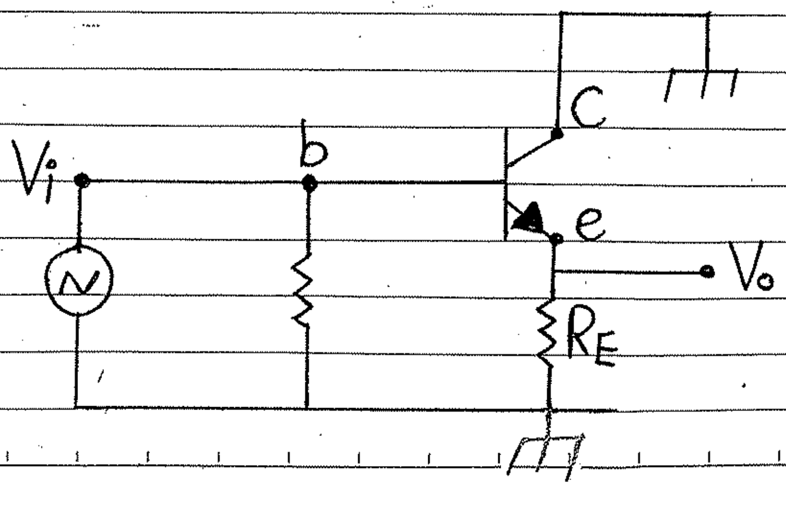
Input to base.

Output from Emitter.

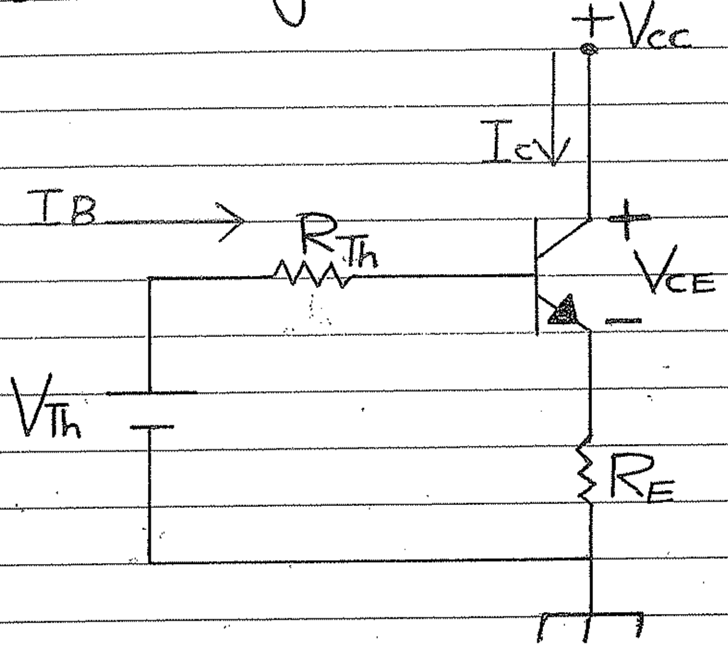


R_C: تدخل في الـ DC فقط و لاتدخل في الـ AC

*For AC : [C is at ground].



1) For D.C Analysis :-

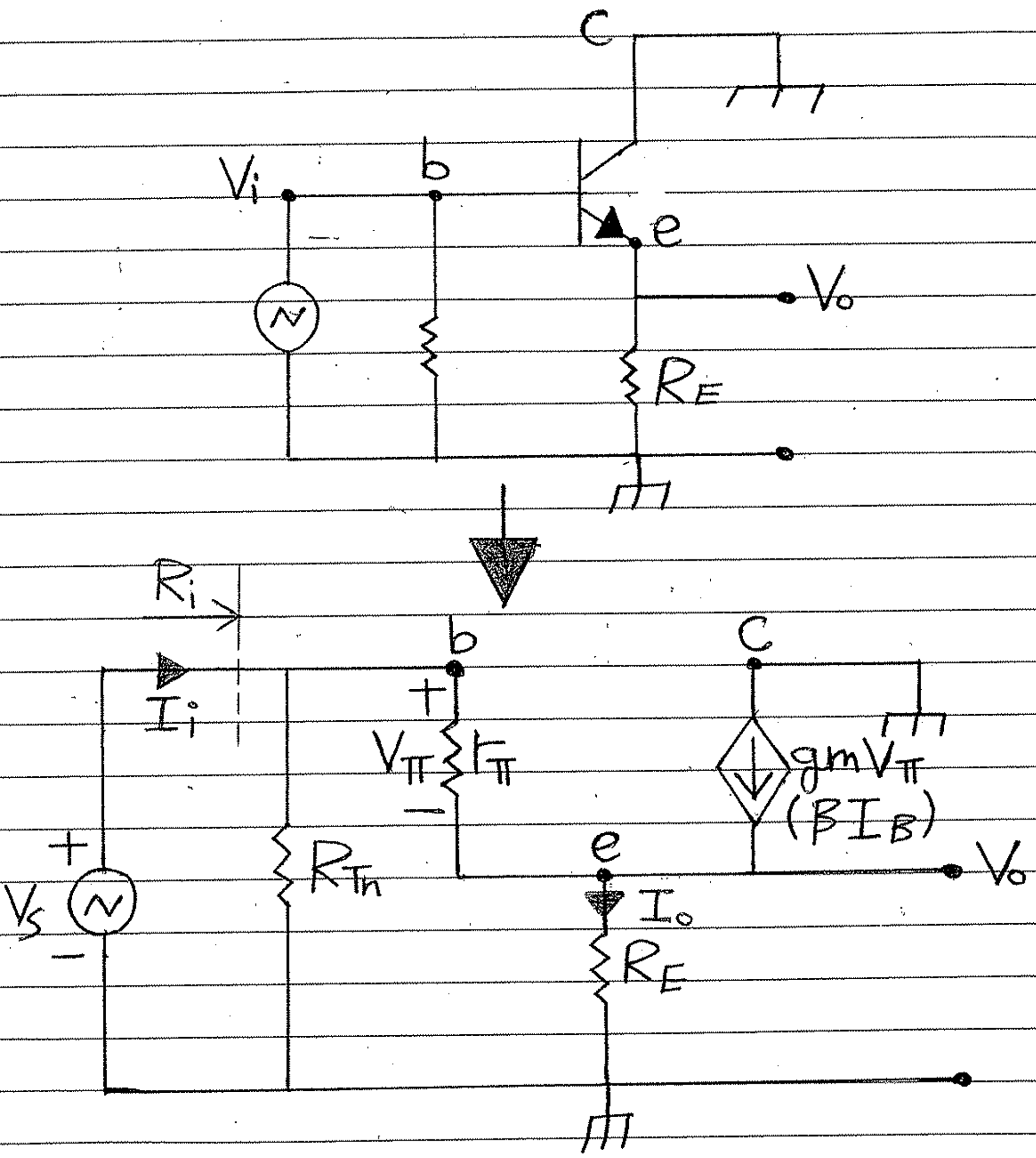


$$I_B = \frac{V_{Th} - V_{BE}}{R_{Th} + (\beta+1) R_E}$$

$$I_C = \beta \, I_B$$

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

2) For A.C Analysis :-



* $\boxed{\text{S.S A.C Eqnt. CCt.}}$

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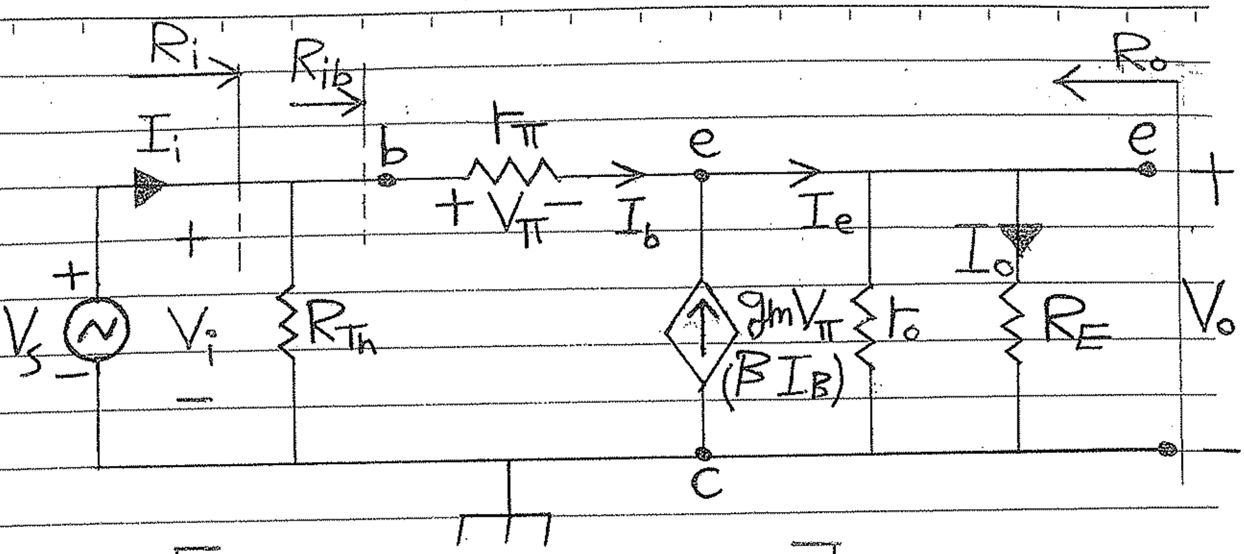


[S.S A.C Eqnt. CCt.]

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

$$V_o = I_e (r_o // R_E)$$

$$= (\beta + 1) I_b (r_o // R_E) \quad \#$$

$$-V_s + V_\pi + V_o = 0$$

$$V_s = I_b \cdot r_\pi + (\beta+1) I_b (r_o // R_E) \quad \#$$

$$A_v = \frac{(\beta+1) \cancel{I_b} (r_o // R_E)}{\cancel{I_b} r_\pi + (\beta+1) \cancel{I_b} (r_o // R_E)}$$

$$\boxed{A_v = \frac{(\beta+1)(r_o // R_E)}{r_\pi + (\beta+1)(r_o // R_E)}} \quad A_v < 1 , \; V_o < V_s , \; \phi = 0$$

If $\boxed{(\beta+1)(r_o // R_E) \gg r_\pi}$; then :

$$A_v = \frac{V_o}{V_s} \approx 1$$

$\boxed{V_o \simeq V_s}$

* It's Called Emitter-Followers because V_o follow $V_i (V_s)$ in magnetude and Sin.

$$R_i = R_{Th} // R_{ib}$$

$$\rightarrow R_{ib} = \frac{V_i}{I_b} = \frac{V_\pi + V_o}{I_b}$$

$$= \frac{\cancel{I_b} \cdot r_\pi + (\beta+1) \cancel{I_b} (r_o // R_E)}{\cancel{I_b}}$$

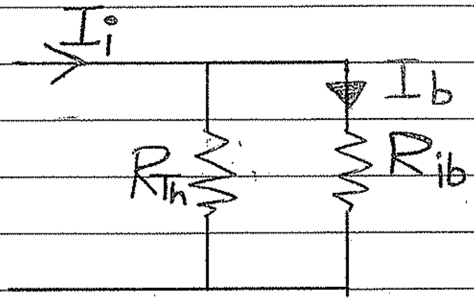
$$R_{ib} = r_\pi + (\beta+1)(r_o // R_E)$$

$\boxed{R_i \longrightarrow high}$

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

$$I_o = (\beta+1) I_b \frac{r_o}{r_o + R_E}$$

$$\boxed{\frac{I_o}{I_b} = \frac{(\beta+1) r_o}{r_o + R_E}}$$



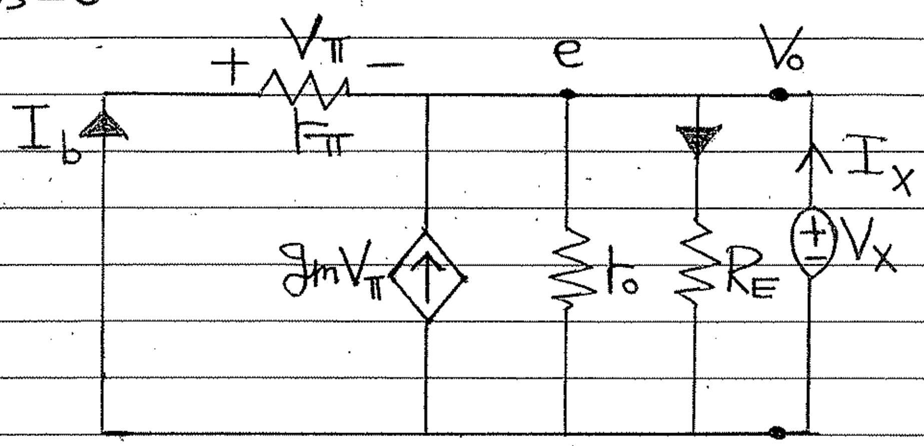
$$\boxed{\frac{I_b}{I_i} = \frac{R_{Th}}{R_{Th} + R_i}}$$

$$\boxed{A_I = \frac{(\beta+1) r_o}{r_o + R_E} \cdot \frac{R_{Th}}{R_{Th} + R_{ib}}}$$

$A_I > 1$

$$\boxed{(A_I)_{max} \simeq \beta + 1}$$

$$R_o = \left.\frac{V_x}{I_x}\right|_{V_s=0}$$



KCL at node e :

$$I_x + g_m V_\pi = \frac{V_x}{R_E} + \frac{V_x}{r_o} + \frac{V_x}{r_\pi}$$

But : $V_x = -V_\pi \rightarrow V_\pi = -V_x$

$$\therefore I_x = V_x \left(g_m + \frac{1}{r_\pi} + \frac{1}{r_o} + \frac{1}{R_E} \right)$$

$$\frac{I_x}{V_x} = \frac{1}{R_o} = \frac{g_m r_\pi + 1}{r_\pi} + \frac{1}{r_o} + \frac{1}{R_E}$$

$$* \; g_m r_\pi = \frac{I_{CQ}}{V_T} \cdot \frac{\beta V_T}{I_{CQ}} = \beta$$

$$\frac{1}{R_o} = \frac{\beta+1}{r_\pi} + \frac{1}{r_o} + \frac{1}{R_E}$$

$$\Rightarrow \boxed{R_o = \frac{r_\pi}{\beta+1} \parallel r_o \parallel R_E}$$

$$\boxed{R_o \longrightarrow \text{Low}}$$

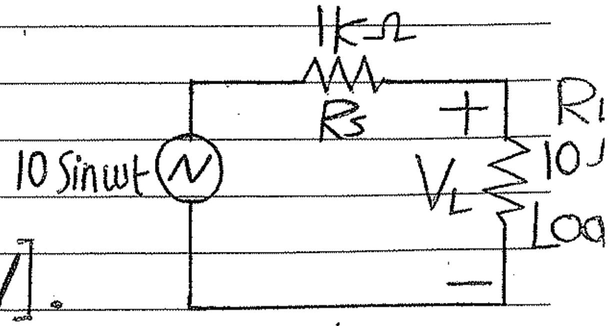
$$\left.\begin{array}{l} A_V < 1 \\ A_I > 1 \\ R_i : \text{high} \\ R_o : \text{Low} \\ \phi = 0^\circ \end{array}\right\} \text{for C.C Amp.}$$

C.C is used to Solve Loading Problem,

$$V_L = V_s \cdot \frac{R_L}{R_L + R_s}$$

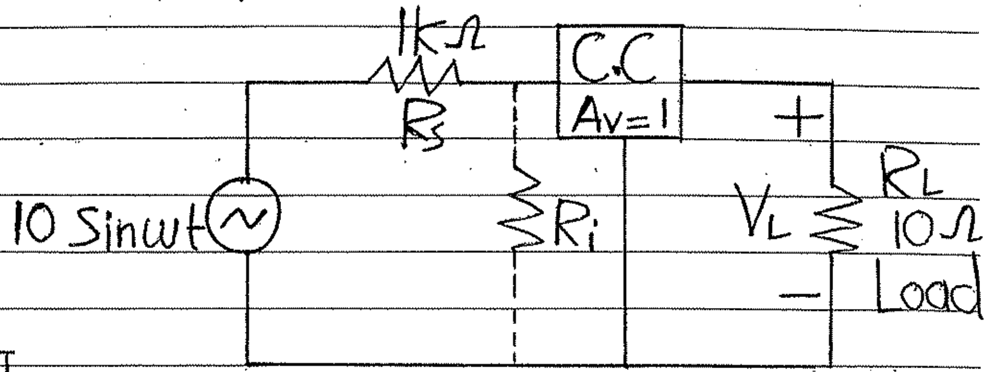
$$= V_s \cdot \frac{10}{10+1000} \approx 0.01 V_s$$

$$= 0.1 \sin\omega t \; [V].$$



[Sever Loading effect]

To Solve this problem :-



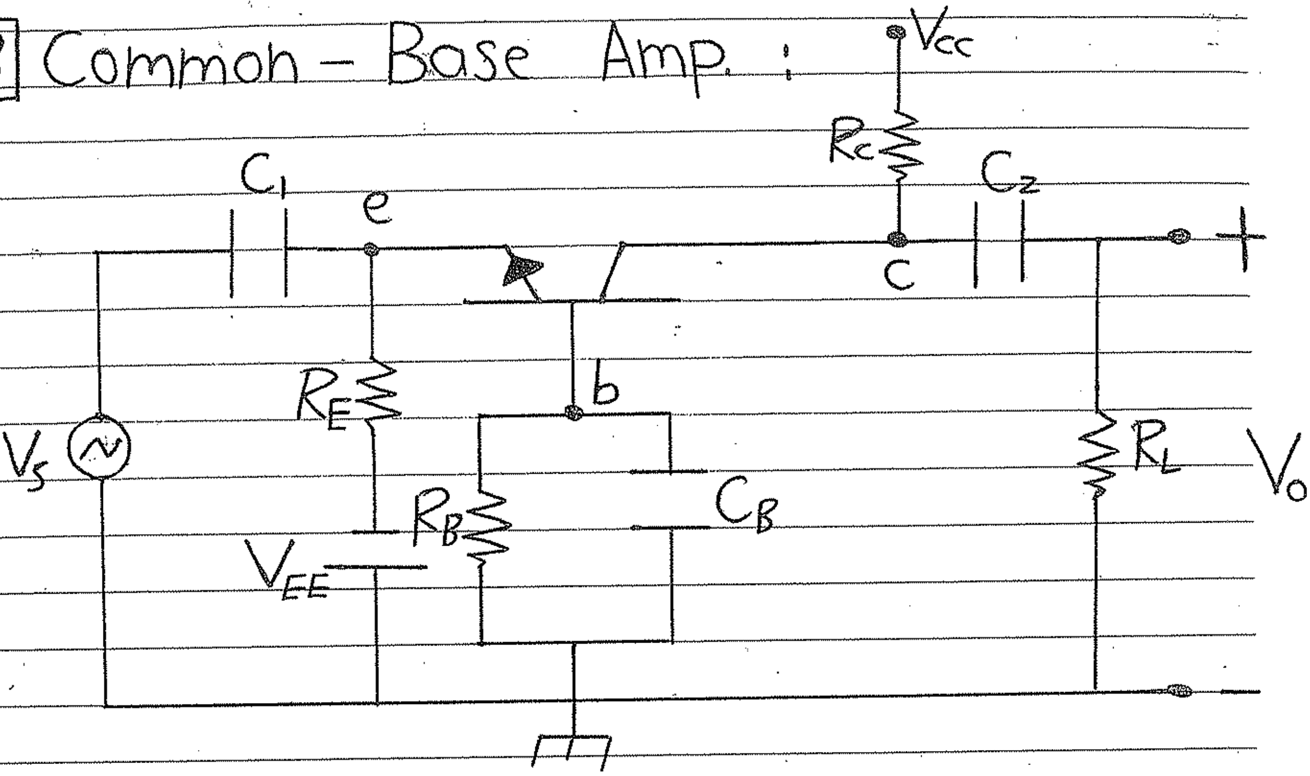
With C.C :-

$$V_x = V_s \frac{R_i}{R_i + R_s}$$

$\boxed{V_x \simeq V_s}$; $V_L = V_x$ $(A_V \approx 1)$

$\therefore$ $\boxed{V_L = V_s}$ [NO Loading Effect]

3] Common-Base Amp.:

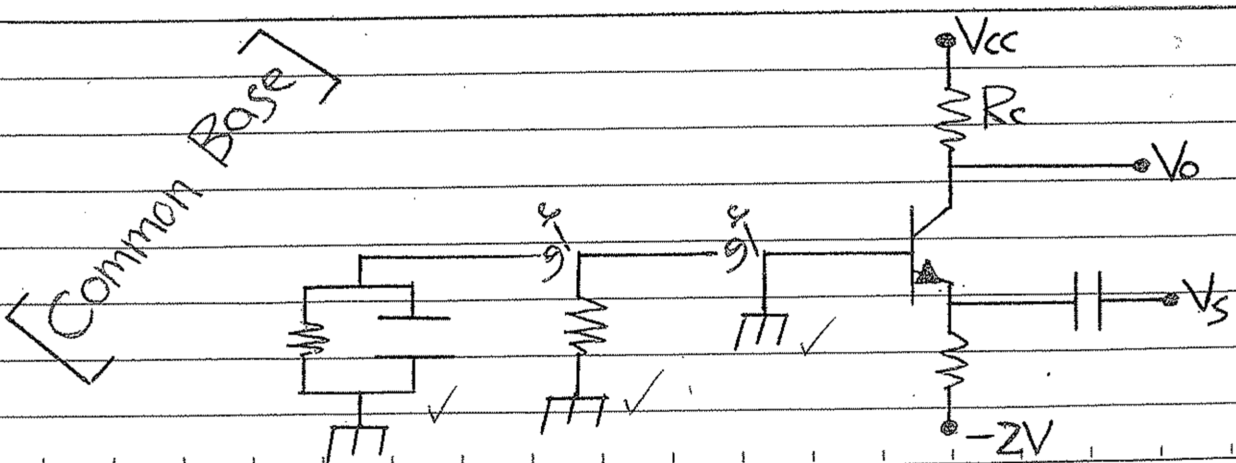


Base → common.

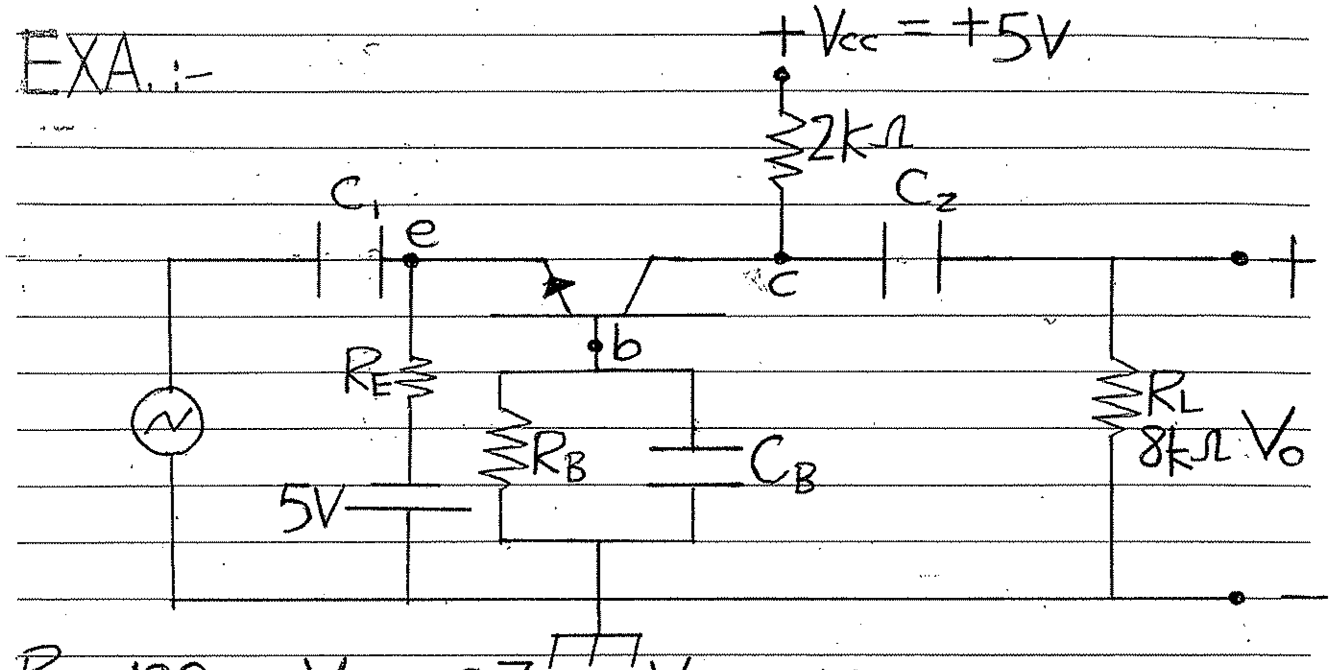
Input to Emitter.

Output from Collector.

For A.C : Base to ground.



EXA. :-



$\beta = 100$, $V_{BE} = 0.7$, $V_A = \infty$.

1) Calculate R_B, R_E, Such that ;

$I_{CQ} = 1mA$, $V_{CEQ} = 4V$.

2) Draw S.S AC Eqnt. CCt. & Find

A_v, A_I, R_i, R_o ?

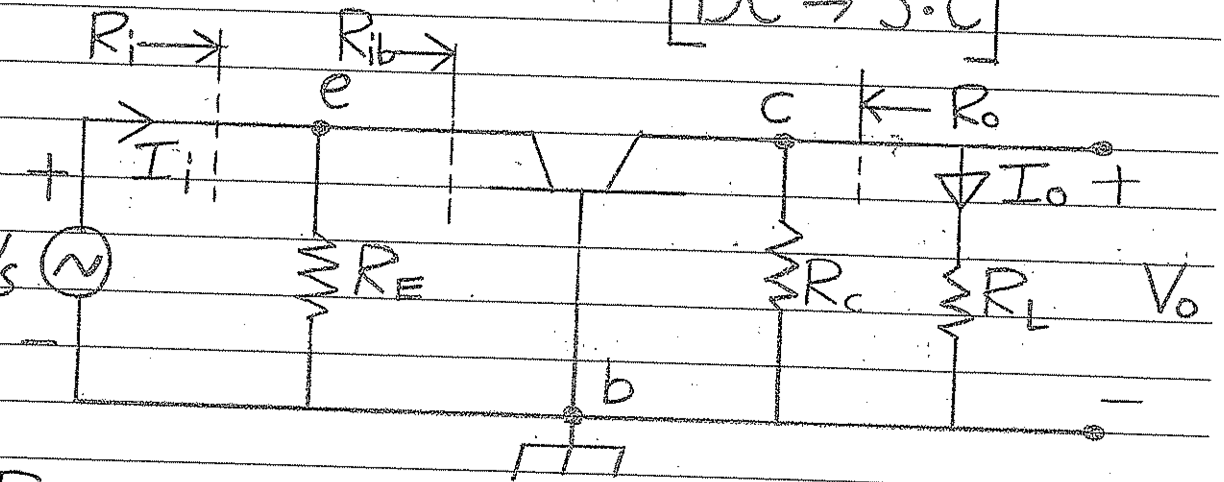
R_B :

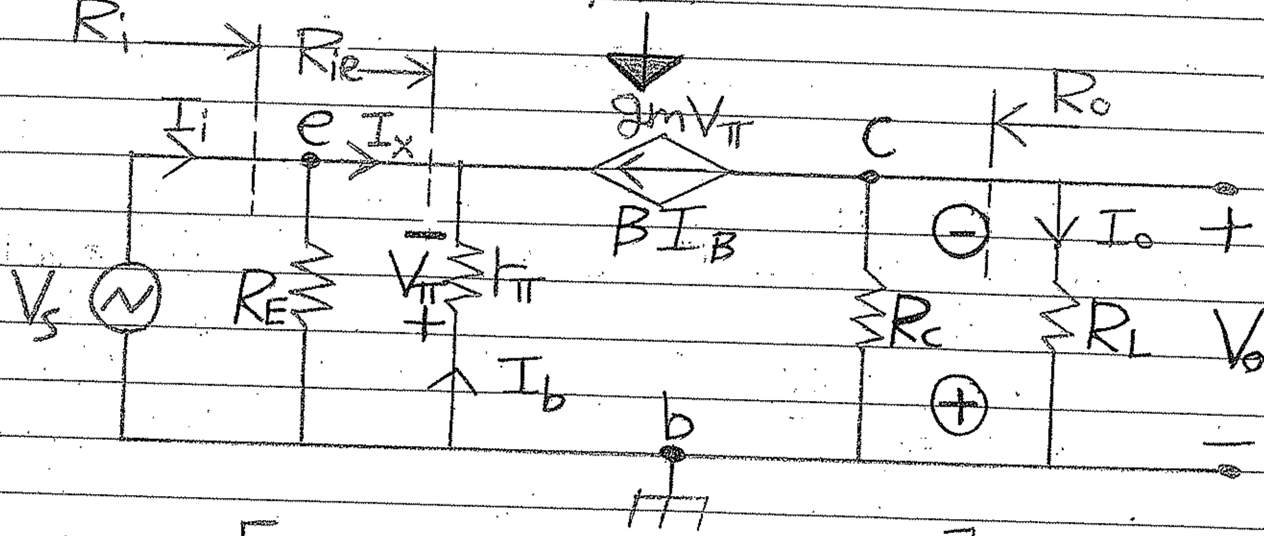
$$I_B R_B + V_{BE} + I_E R_E - 5 = 0$$

$$R_B = \frac{5 - 0.7 - 1.01 * 3.96}{\frac{1mA}{100}}$$

$$\boxed{R_B = 30\,k\Omega}$$

2) For AC Analysis :- [C → S.C, DC → S.C]





[S.S AC Eqnt. CCt.]

Five Apple

$$A_V = \frac{V_o}{V_S} = \frac{-g_m V_\pi (R_C // R_L)}{-V_\pi}$$

$$\boxed{A_V = g_m (R_C // R_L)} \quad A_V > 1 \ , \ \phi = 0^\circ$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{1\,mA}{26\,mV} = 38.5\ mA/V.$$

$$A_V = 38.5\,(2//8) \simeq 61$$

$$R_o = \left.\frac{V_x}{I_x}\right|_{V_S=0}$$

When $V_S = 0 \rightarrow V_\pi = 0$

$g_m V_\pi = 0 \rightarrow$ Current Source is Open.

$R_o = R_C = 2\,k\Omega$.

$$R_i = R_E // R_{ie}$$

$$R_{ie} = \frac{-V_\pi}{I_x} = \frac{-V_\pi}{-(\beta+1) I_b} = \frac{-I_b r_\pi}{-(\beta+1) I_b} = \frac{r_\pi}{\beta+1}$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{100 * 26\,mV}{1\,mA} = 2.6\,k\Omega.$$

$$R_i = 3.96 // \frac{2.6k}{101} \simeq 25\,\Omega.$$

$$A_I = \frac{I_o}{I_i} = \frac{\frac{V_o}{R_L}}{\frac{V_s}{R_i}} = \frac{V_o}{V_s} \cdot \frac{R_i}{R_L}$$

$$= A_V \cdot \frac{R_i}{R_L}$$

$$= 61 \cdot \frac{25\ \Omega}{8000}$$

$$= 0.19$$

$A_V > 1$

$A_I < 1$

$\phi = 0^\circ$

R_i : Law.

R_o : moderate to high.

} for C.B Amp.

Summary of S.S Amp :-

Amp.	A_V	A_I	R_i	R_o	phase
C.E (Basic)	>1	>1	moderate	moderate to high	180°
C.C	$\leqslant 1$	>1	high	Law (Ω)	0°
C.B	>1	$\leqslant 1$	Law (Ω)	moderate to high	0°

$A_V > 1$, Law R_o → V_i — $\boxed{C.E}$ — $\boxed{C.C}$ — V_o

Low R_i , Law R_o → V_i — $\boxed{C.B}$ — $\boxed{C.C}$ — V_o

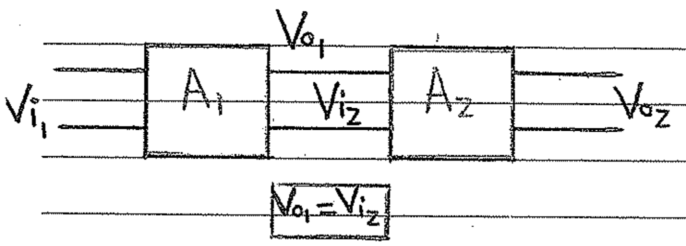
Multi Stage Amp.

MultiStage Amp.s :-

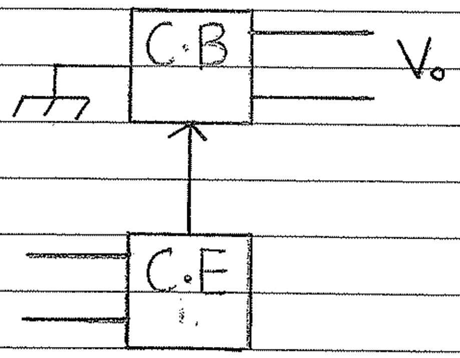
Amps Contain more than Single transistors (two at least), used to achieve certain Specifications ($A_v > 1$, Law R_o) which can not be achived used Single-Stage.

[M.S Amp.s]

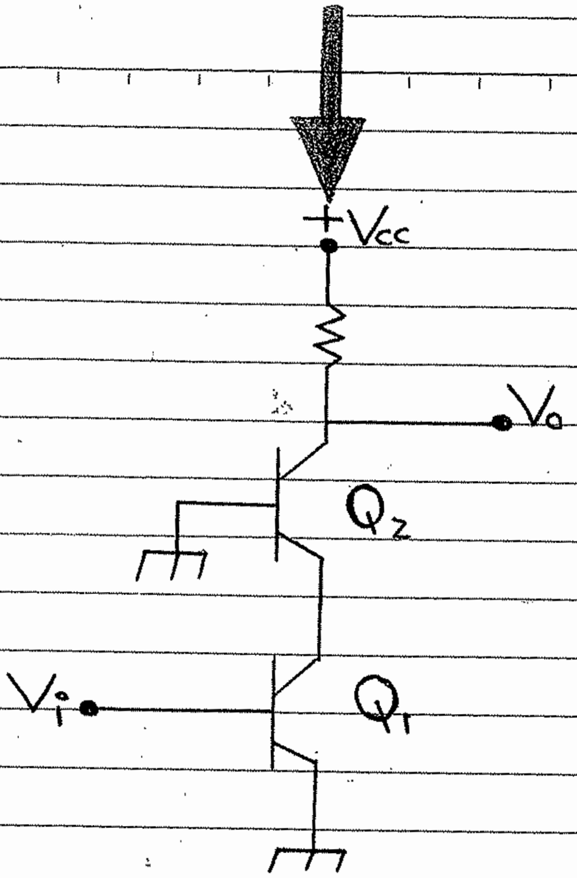
Cascade (Series Connection):-



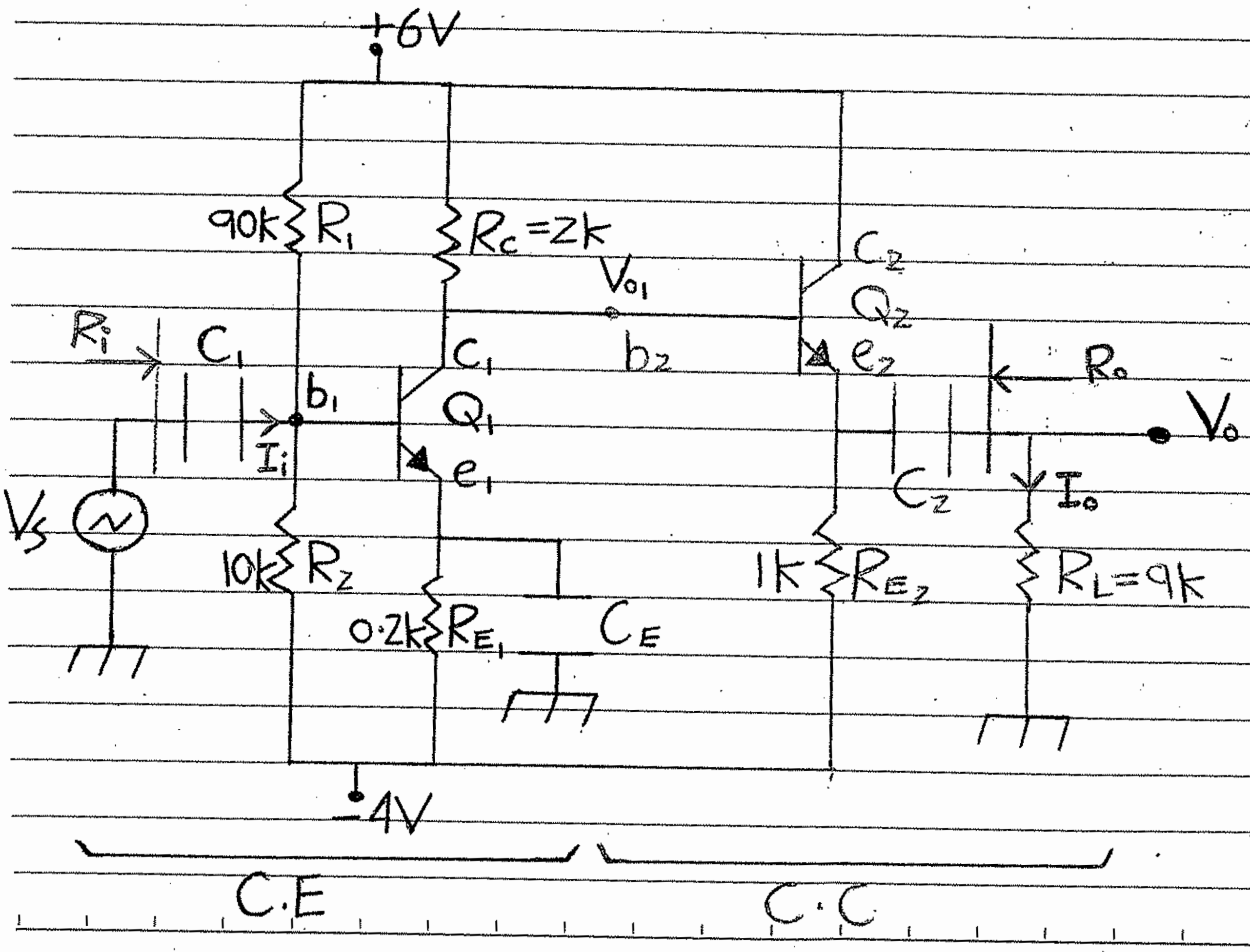
Cascode :-

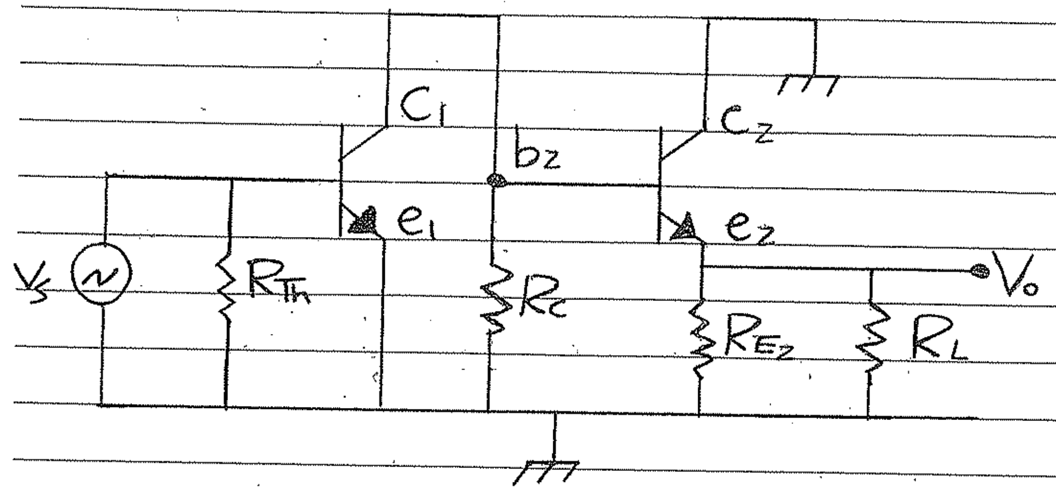


Standard



1| Cascade Amp.s :-





Q_1 and Q_2 are identical with $\beta_1 = \beta_2 = 150$

$V_{BE_1} = V_{BE_2} = 0.7V$, $V_{A_1} = V_{A_2} = \infty$

1) Calculate I_{CQ_1} , V_{CEQ_1} , I_{CQ_2} , V_{CEQ_2} .

2) Draw S.S. A.C Eqnt. cct. and find:

R_i , R_o , A_V , A_I .

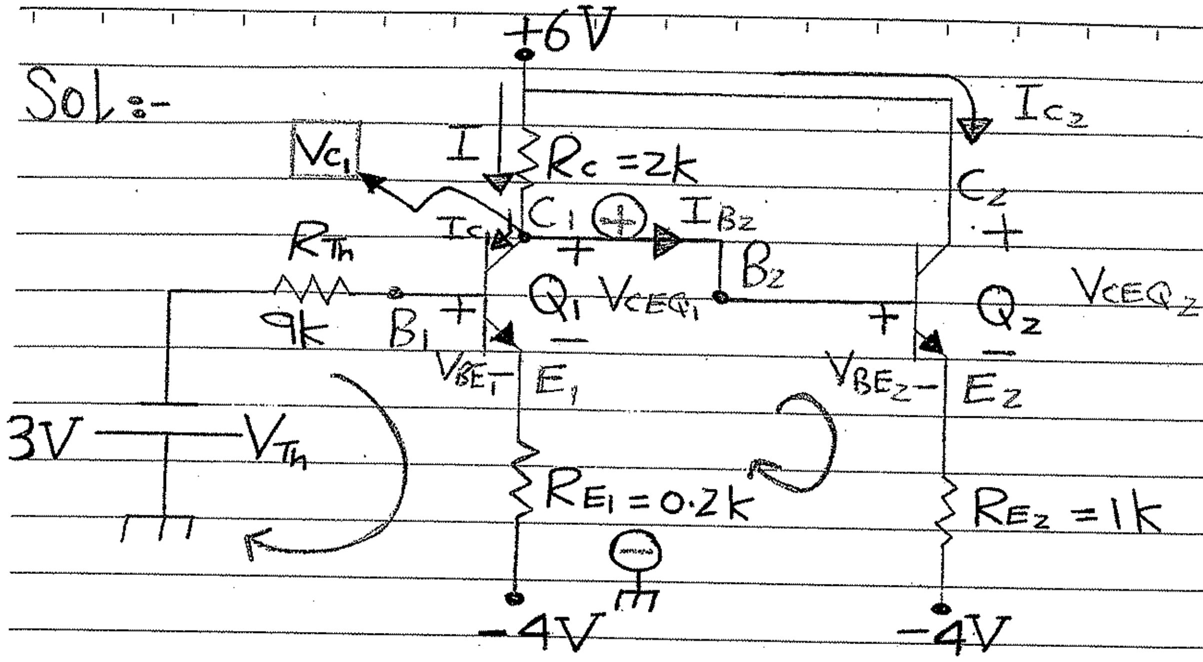
Ri for Stage 1

Ro for Stage 2

$A_{V_1} = \dfrac{V_{o1}}{V_s}$

$A_{V_2} = \dfrac{V_o}{V_{o1}}$

Sol :-



$$R_{Th} = 90 // 10 = 9k\Omega.$$

$$V_{Th} = \frac{6 * 10}{100} + \frac{(-4) * 90}{100} = -3V.$$

$$3 + R_{Th} I_{B_1} + V_{BE_1} + (B+1) I_{B_1} R_{E_1} - 4 = 0$$

$$I_{B_1} = \frac{(4-3-0.7)V}{R_{Th} + (B+1)R_{E_1}} \checkmark \rightarrow \boxed{I_{C_1} = B\, I_{B_1}} \checkmark$$

$$\rightarrow \boxed{I_{E_1} = (B+1)\, I_{B_1}} \checkmark$$

$$-6 + IR_C + V_{CE_1} + I_{E_1} R_{E_1} - 4 = 0$$

$$V_{CE_1} = 10 - I_{E_1} R_{E_1} - \underline{\underline{I}} \cdot R_C$$

To find I : KCL at node C_1 :-

$$I = I_{C_1} + I_{B_2}$$

$$I = \frac{6 - V_{C_1}}{R_C}$$

I_{B_2} :

$$-V_{C_1} + V_{BE_2} + (\beta+1) I_{B_2} R_{E_2} - 4 = 0$$

$$I_{B_2} = \frac{V_{C_1} + 4 - V_{BE_2}}{(\beta+1) R_{E_2}}$$

$$\Rightarrow \frac{6 - V_{C_1}}{2k} = I_{C_1}^{\checkmark} + \frac{V_{C_1} + 3.3}{151 * 1}$$

Solve for V_{C_1} ;

$\Rightarrow$ I ✓ , V_{CE_1} ✓ .

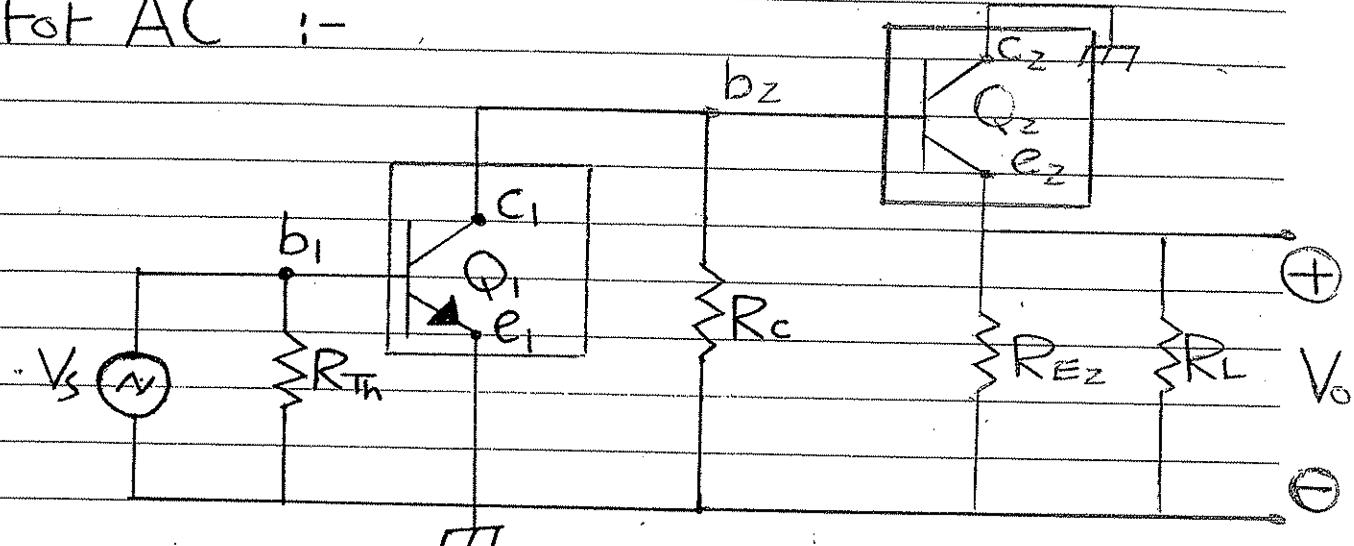
$\Rightarrow$ $I_{B_2} \rightarrow I_{C_2} \rightarrow I_{E_2} \rightarrow V_{CE_2}$ ✓ .

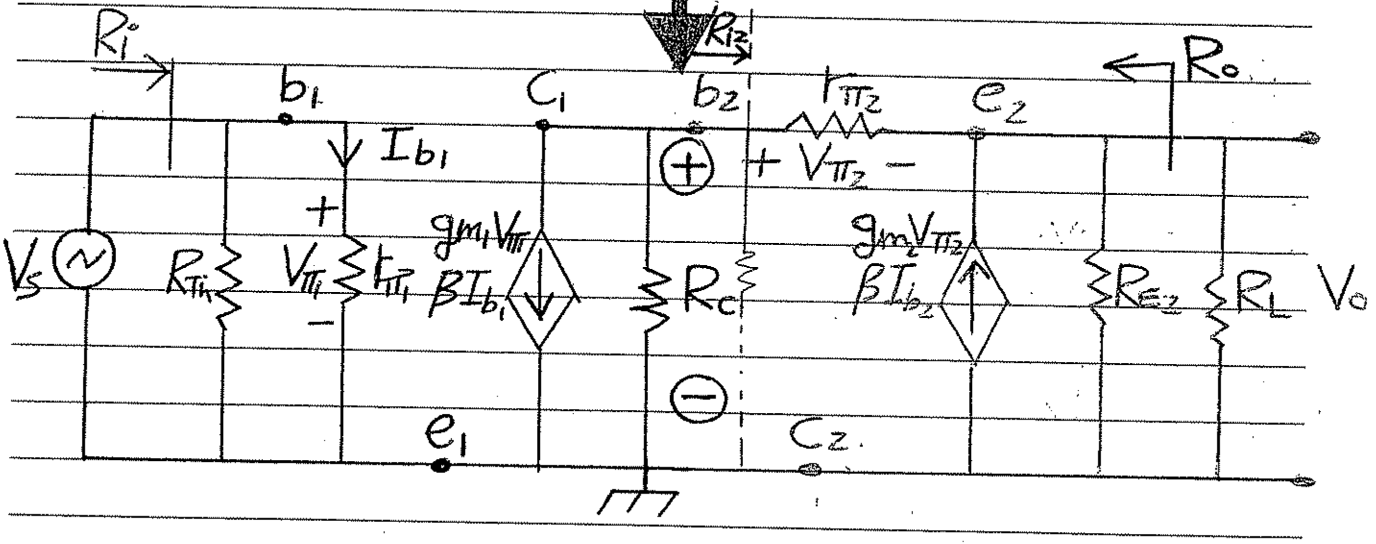
* Slope for Stage 2 :

DCLL $\Rightarrow$ $\dfrac{-1}{R_{E_2}}$.

ACLL $\Rightarrow$ $\dfrac{-1}{R_{E_2} // R_L}$.

For AC :-





S.S.A.C Eqnt. CCt.

$$R_i = R_{i_1} = R_{Th} \,||\, r_{\pi_1}$$

$$R_o = R_{o_2} = \left.\frac{V_x}{I_x}\right|_{V_s=0}$$

$V_s = 0 \longrightarrow V_{\pi_1} = 0 \longrightarrow g_{m_1} V_{\pi_1} = 0$; Open CCt.

$$R_o = \left(\frac{\overset{\text{*Stage 1}}{R_C} + r_{\pi 2}}{\beta+1}\right) // R_{E_2}$$

$$\boxed{R_{o_2} = \frac{r_\pi}{\beta+1} // R_{E_2}}$$

$$\text{*}\ A_V = \frac{V_o}{V_s} = \frac{V_o}{V_{o_1}} * \frac{V_{o1}}{V_s}$$

$$\frac{V_o}{V_{o_1}} = A_{V_2} = \frac{(\beta+1)(R_E // R_L)}{r_\pi + (\beta+1)(R_E // R_L)}$$

$$\frac{V_{o1}}{V_s} = A_{V_1} = \frac{V_{o1}}{V_{\pi_1}}$$

$$V_{o_1} = -g_{m_1} V_{\pi_1} (R_C // R_{i2})$$

$$\Rightarrow \frac{V_{o1}}{V_{\pi_1}} = -g_m (R_C // R_{i2})$$

$$R_{i2} = R_{ib} = r_{\pi_2} + (\beta+1)(R_E // R_L)$$

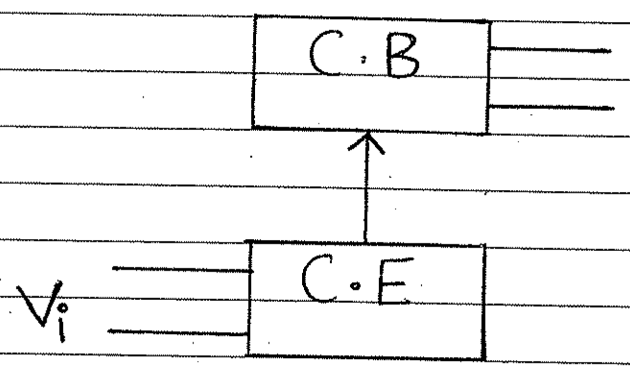
$$\rightarrow A_V = \underbrace{-g_{m_1}(R_C // R_{i_2})}_{A_{V_1}} \cdot \underbrace{\frac{(\beta+1)(R_{E_2} // R_L)}{r_{\pi_2} + (\beta+1)(R_{E_2} // R_L)}}_{A_{V_2}}$$

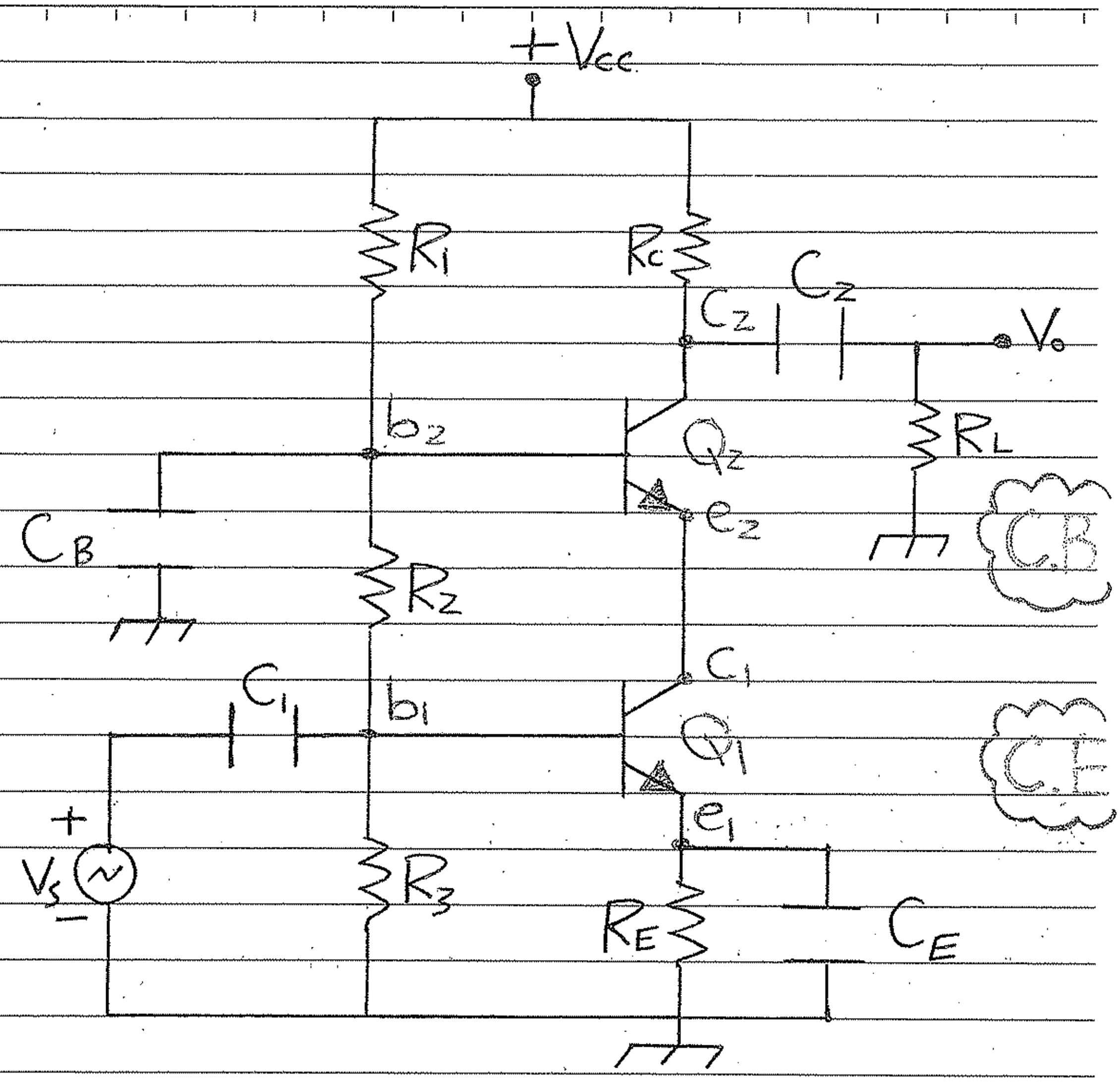
$$A_I = \frac{I_o}{I_i} = \frac{\frac{V_o}{R_L}}{\frac{V_s}{R_i}} = \frac{V_o}{V_s} * \frac{R_i}{R_L}$$

$$\boxed{A_I = A_V \cdot \frac{R_i}{R_L}}$$

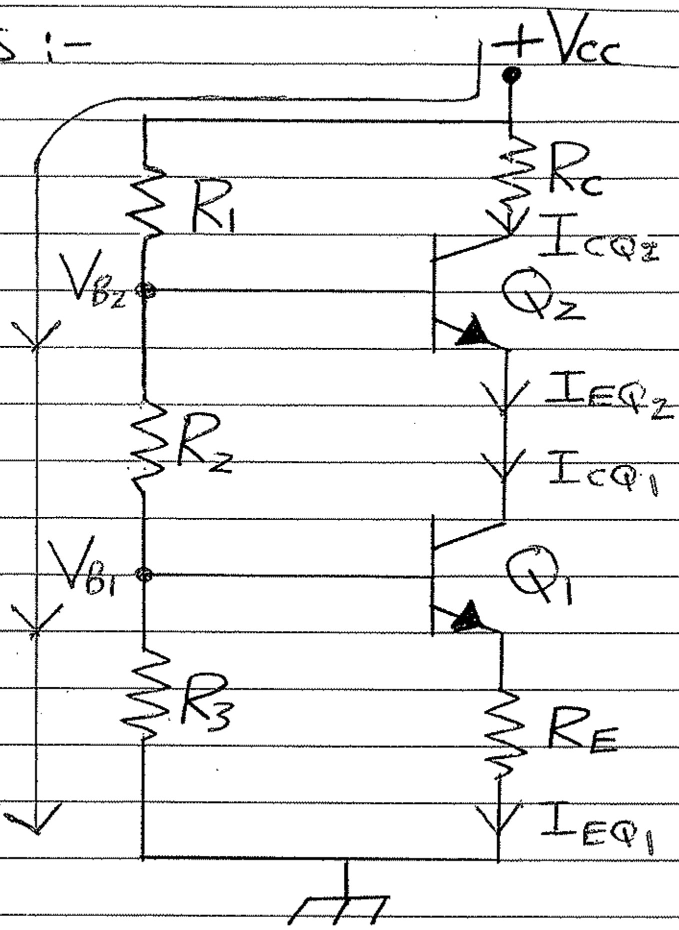
2] Cascode Amp.s :-

Used for high-freq. Application (as a wideband Amp.).




+Vcc
R1
Rc
Cz
Cz
Vo
b2
Qz
RL
CB
ez
C.B
Rz
C1
C1
b1
Q1
C.E
+
e1
Vs
R3
RE
CE
-

for DC Analysis :-



I_{CQ1} , I_{CQ2} ✓

V_{CEQ1} , V_{CEQ2} ✓

β ✓

V_{BE} ✓

Assume :

$\boxed{I_C = I_E}$

$\boxed{I_B = 0}$

$V_{B1} = I \cdot R_3$

$$\therefore V_{B1} = \frac{V_{CC}}{R_1 + R_2 + R_3} \cdot R_3$$

$$-V_{B1} + V_{BE1} + I_{E1} R_E = 0$$

$$I_{E1} = \frac{V_{B1} - V_{BE}}{R_E}$$

$$I_{E1} = I_{C1} = I_{E2} = I_{C2}$$

$$-V_{B_2} + V_{BE_2} + V_{CE_1} + I_{E_1}R_E = 0$$

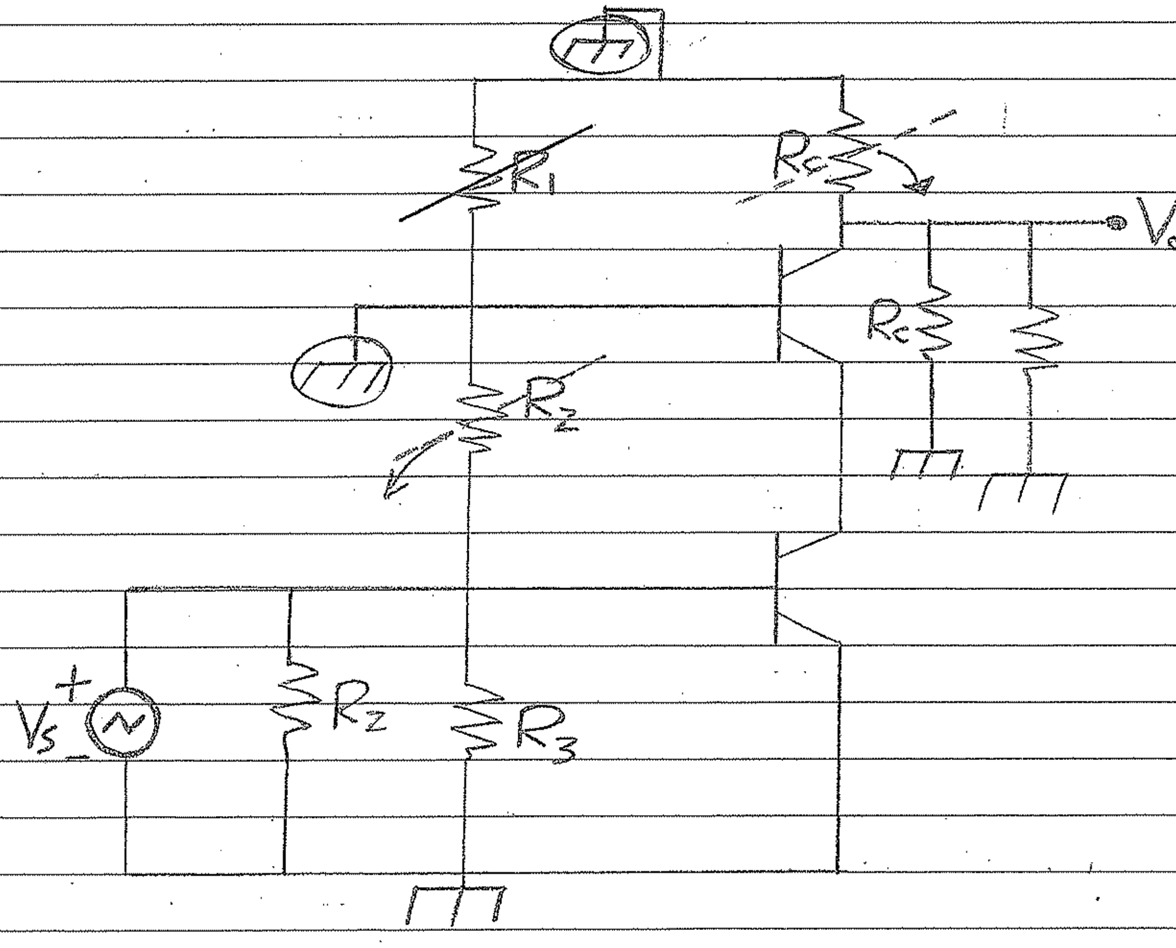
$$V_{CE_1} = V_{B_2} - V_{BE_2} - I_{E_1}R_E \quad \checkmark$$

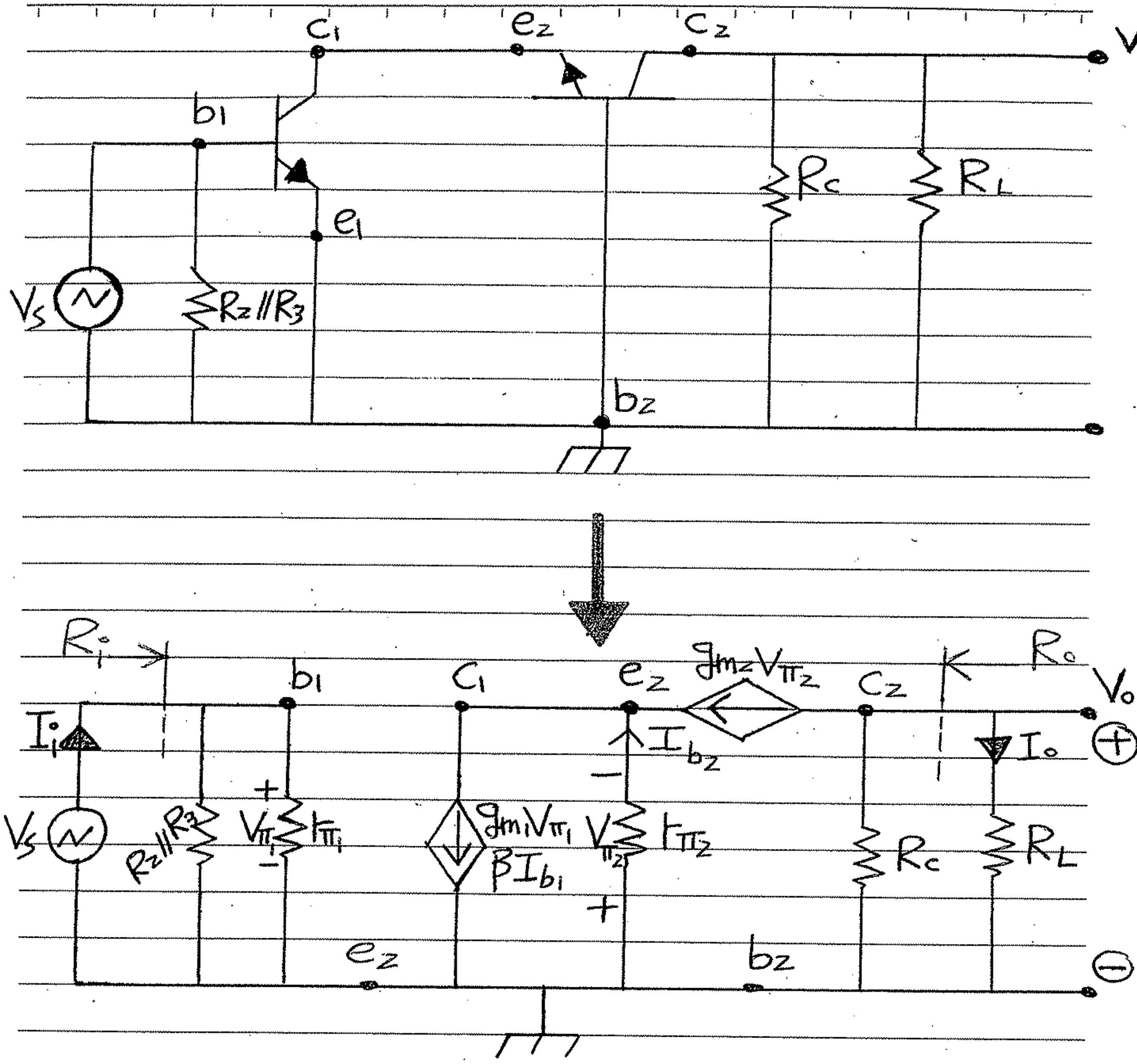
$$\boxed{V_{B_2} = I(R_2 + R_3)}$$

$$-V_{CC} + I_{C_2}R_C + V_{CE_2} + V_{CE_1} + I_E R_E = 0$$

$$V_{CE_2} = V_{CC} - V_{CE_1} - I_E R_E - I_C R_C \quad \checkmark$$

For AC Analysis :- [A_V, A_I, R_i, R_o]





S.S A.C Eqnt. CCt.

$$A_v = \frac{V_o}{V_s} ;$$

$$V_o = -g_{m2} V_{\pi 2} (R_c // R_L)$$

* KCL at node e_2 :-

$$g_{m2} V_{\pi 2} + I_{b2} = g_{m1} V_{\pi 1}$$

$$g_{m2} V_{\pi 2} + \frac{V_{\pi 2}}{r_{\pi 2}} = g_{m1} V_{\pi 1}$$

$$V_{\pi 2} \left(g_{m2} + \frac{1}{r_{\pi 2}} \right) = g_{m1} V_{\pi 1}$$

$$V_{\pi 2} \left(\frac{g_{m2} r_{\pi 2} + 1}{r_{\pi 2}} \right) = g_{m1} V_{\pi 1}$$

$$V_{\pi 2} \left(\frac{\beta_2 + 1}{r_{\pi 2}} \right) = g_{m1} V_{\pi 1}$$

$$\boxed{V_{\pi 2} = \frac{r_{\pi 2}}{(\beta + 1)} g_{m1} V_{\pi 1}}$$

- $V_o = -g_{m2} \frac{r_{\pi 2}}{(\beta + 1)} \cdot g_{m1} V_{\pi 1} (R_c // R_L)$

- $V_{\pi 1} = V_s$

$$\frac{V_o}{V_s} = -\frac{\beta_2}{\beta_2+1} g_{m_1} (R_C // R_L)$$

$$\boxed{A_V \simeq -g_m (R_C // R_L)}$$

for stage 1.

Stage 2 , common base : $i_{c_1} = i_{c_2}$ لأنّه نفس التيار.

$$A_I = \frac{I_o}{I_i} = \frac{\frac{V_o}{R_L}}{\frac{V_s}{R_i}}$$

$$\boxed{A_I = A_V \cdot \frac{R_i}{R_L}}$$

$$\boxed{R_i = R_2 // R_3 // r_{\pi_1}}$$

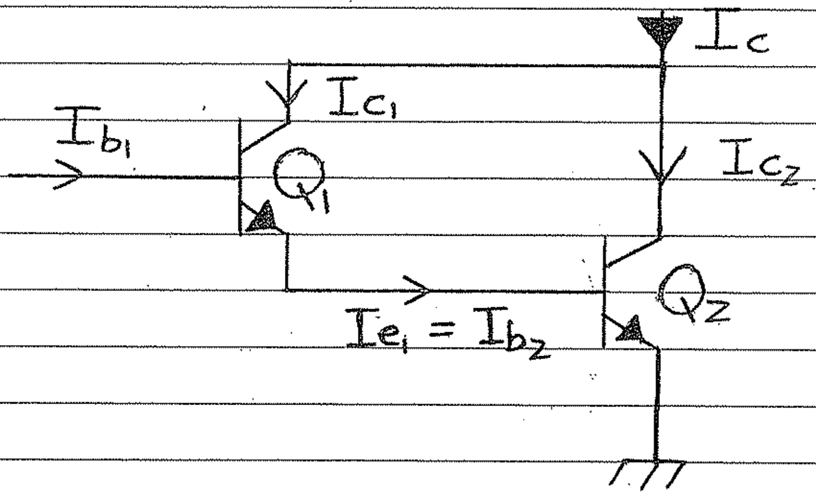
$$R_o = \left.\frac{V_x}{I_x}\right|_{V_s = 0}$$

$$\boxed{R_o = R_C}$$

Darlington pair CCt. :-

[Multi Stage]

Used for Very high Current gain.



Darlington pair

$$I_c = I_{c_1} + I_{c_2}$$
$$= \beta I_{b_1} + \beta I_{b_2}$$

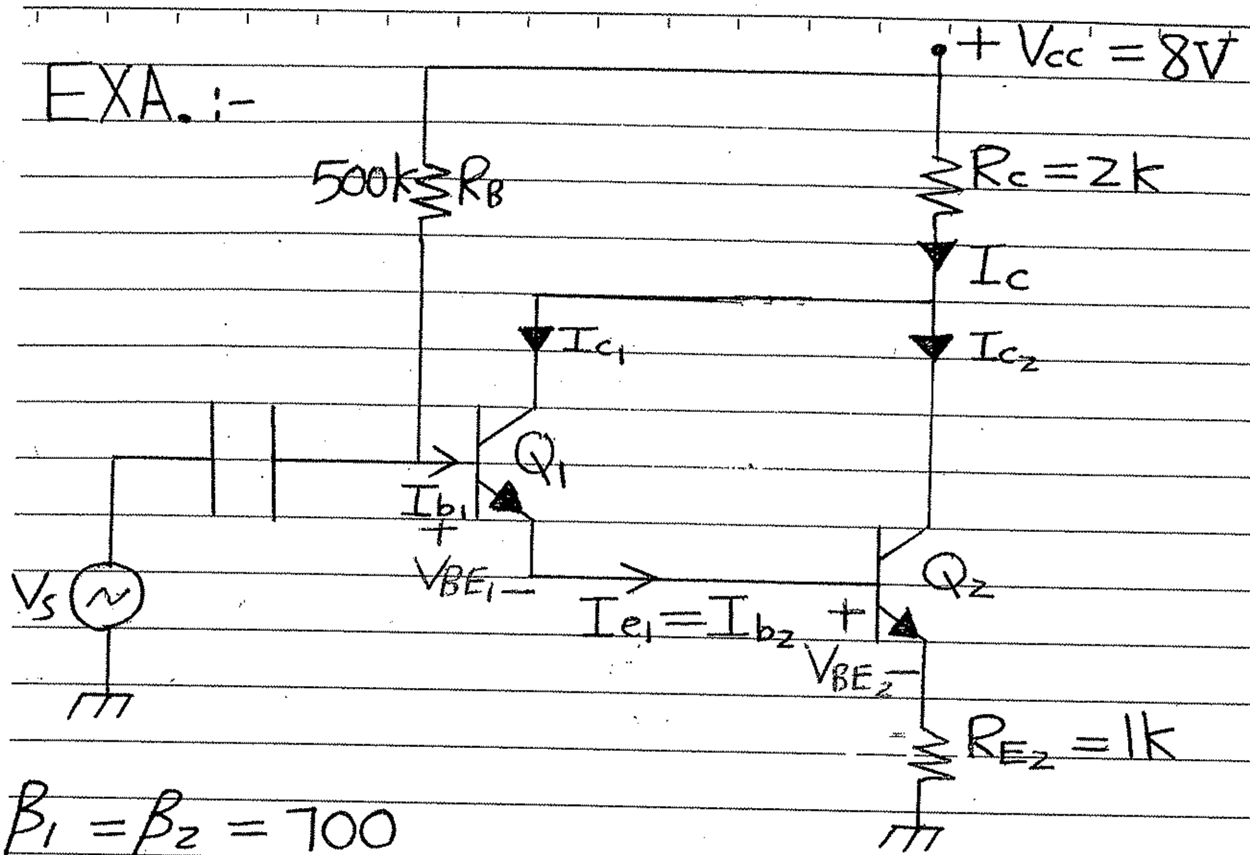
$$I_{b_2} = I_{e_1} = (\beta+1) I_{b_1}$$

$$I_c = \beta I_{b_1} + \beta(\beta+1) I_{b_1}$$
$$= \beta I_{b_1} + \beta I_{b_1} + \beta^2 I_{b_1}$$

$$I_c = I_{b_1} (\beta^2 + 2\beta)$$

$$\frac{I_c}{I_{b_1}} = \beta_{composit} \simeq \beta^2$$

EXA. :-



$\beta_1 = \beta_2 = 100$

$V_{BE_1} = V_{BE_2} = 0.6\,V$

Sol :- for DC analysis :-

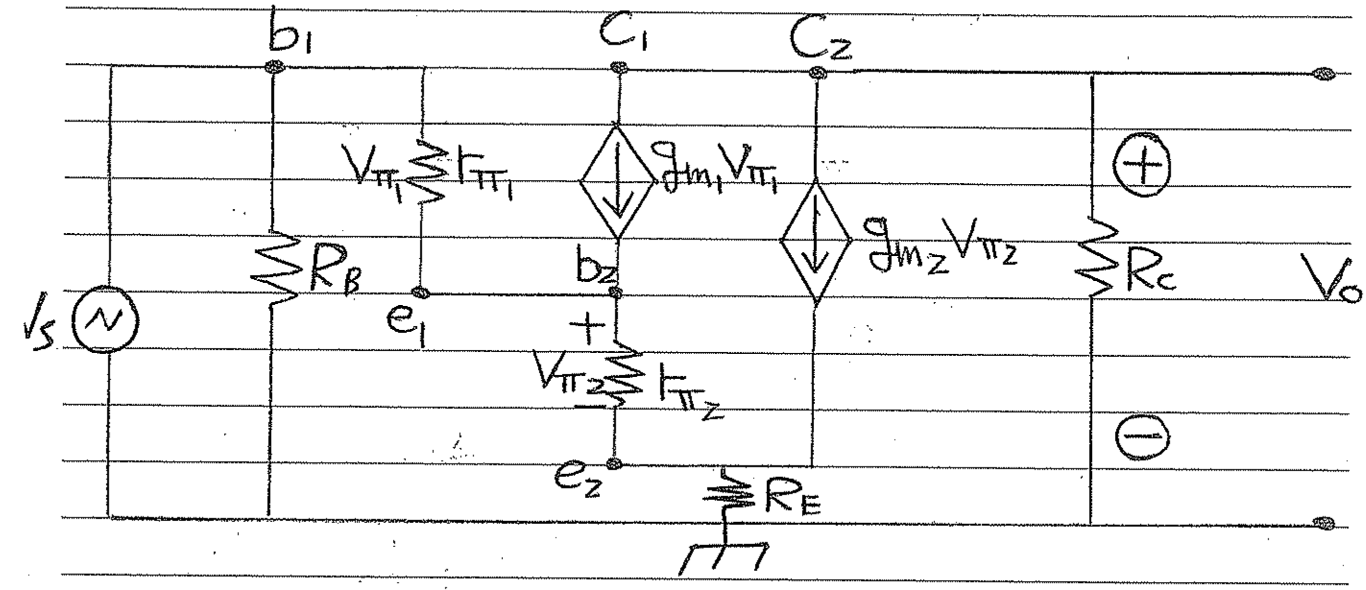
$-8 + I_{b_1} R_B + V_{BE_1} + V_{BE_2} + I_{E_2} R_{E_2} = 0$

$I_{E_2} = (\beta+1) I_{B_2} = (\beta+1)(\beta+1) I_{B_1} = (\beta+1)^2 I_{B_1}$

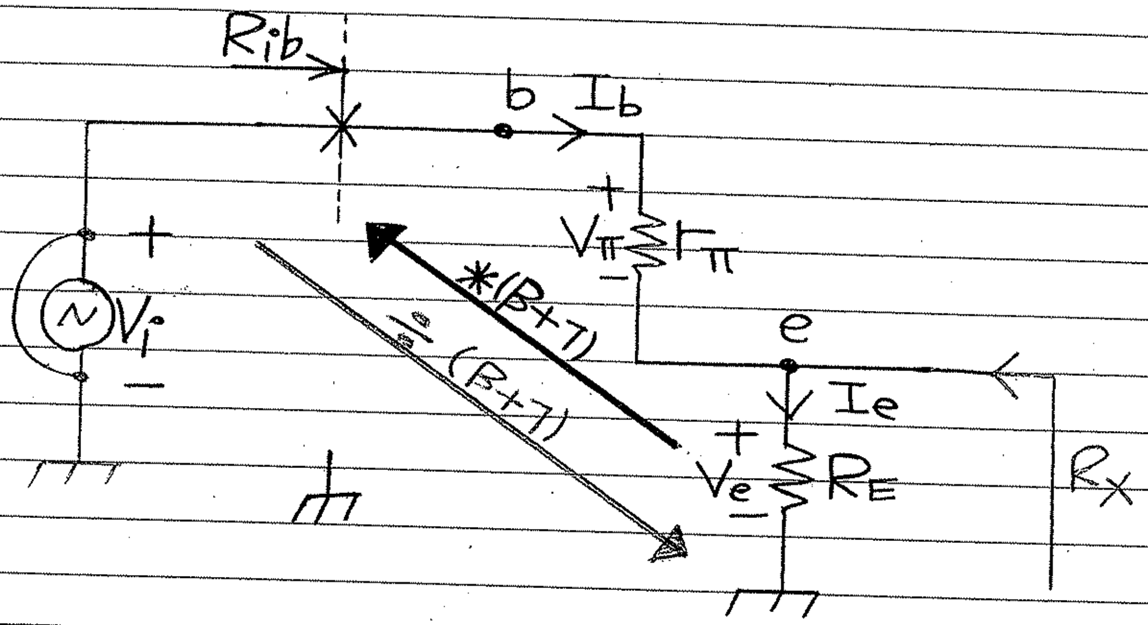
$\rightarrow I_{B_1} = \dfrac{8 - 0.6 - 0.6}{500k + (101)^2 * 1} = \ldots$

$V_{CE_1} = \ldots$; $V_{CE_2} = \ldots$

For AC analysis :



* Resistance-Reflection Rule [R.R.R] :-



$$\boxed{R_{ib} = r_\pi + (\beta+1) R_E}$$

* Inverse R.R.R :-

$$\boxed{R_x = \frac{r_\pi}{(\beta+1)} \parallel R_E}$$

Chapter (4): Basic (FET) Amplifiers :-

The MOSFET must be biased in Saturation Regn. to be used an Amplifier. This requires D.C Analysis of MOSFET CCt.

D.C Analysis of MOSFET CCt. :-

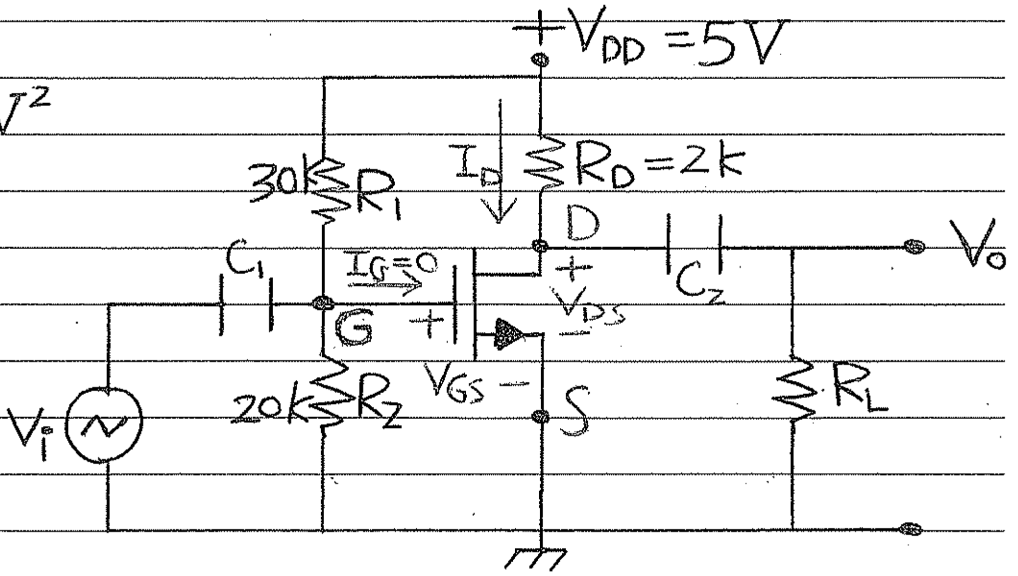
$K_n = 1 mA/V^2$

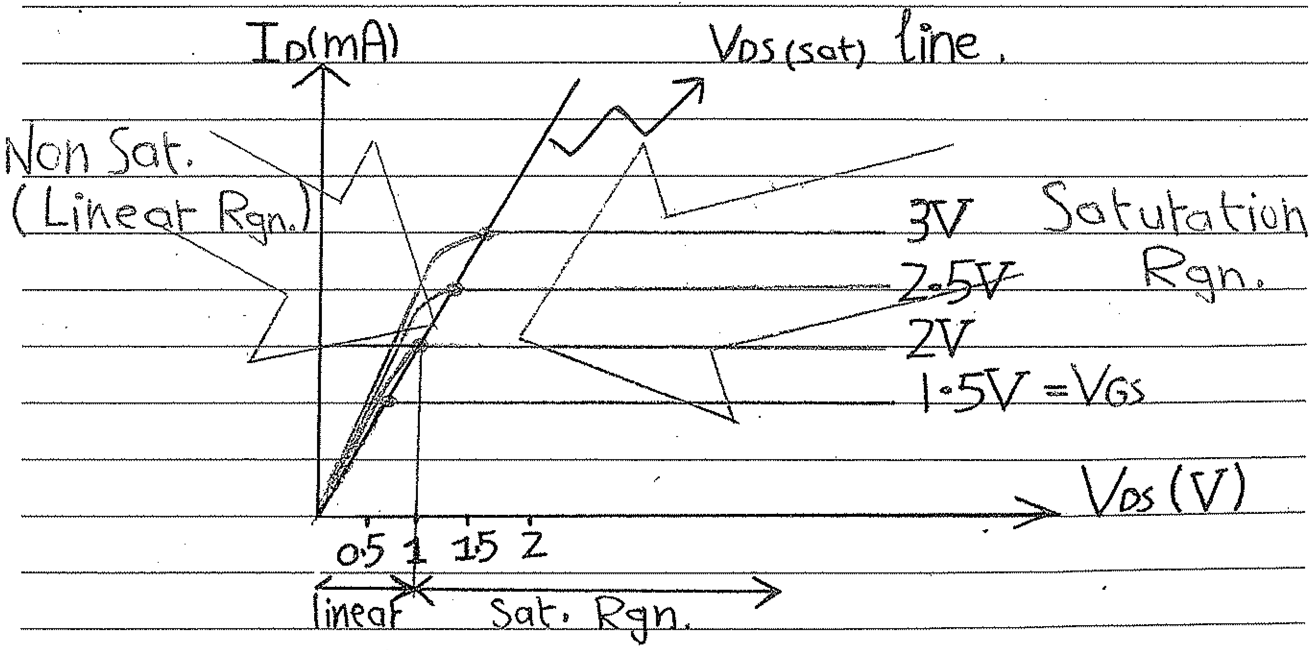
$V_{TN} = 1V$

$V_{GS} = ?$

$I_D = ?$

$V_{DS} = ?$





$$\boxed{V_{DS(sat.)} = V_{GS} - V_{TN}} \qquad V_{TN} = 1$$

* MOSFET Operations Regions :-

1] Saturation Regn. :-

In this Regn. : $V_{DS} > V_{DS(sat.)}$

Where $V_{DS(sat.)} = \underbrace{V_{GS}}_{\text{from cct.}} - \underbrace{V_{TN}}_{\text{given}}$.

their :-

$$\boxed{I_D = k_n (V_{GS} - V_{TN})^2}$$

& The MOSFET is used as an Amplifier.

2] NON Saturation Regn. :- [Linear Regn] :-

When $V_{DS} < V_{DS(sat)}$

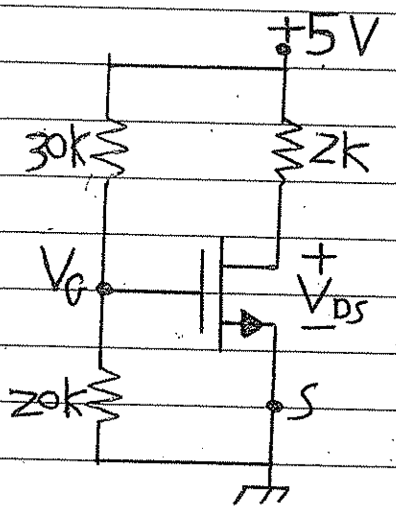
then : $\boxed{I_D = k_n \left[2(V_{GS} - V_{TN}) V_{DS} - V_{DS}^2 \right]}$

and the MOSFET is used as Voltage - Controlled Resistor.

For this EXAmple :-

→ For DC Analysis : Assume the MOSFET is in Sat. Regn. :-

$I_D = K_n (V_{GS} - V_{TN})^2$



$V_{GS} = V_G - V_S$

$= \frac{5 * 20}{50} - 0 = 2V$

$I_D = 1(2-1)^2 = 1\,mA$

$V_{DS} = V_{DD} - I_D R_D = 5 - 1*2 = 3V$

$V_{DS_{sat.}} = V_{GS} - V_{TN} = 2 - 1 = 1V$

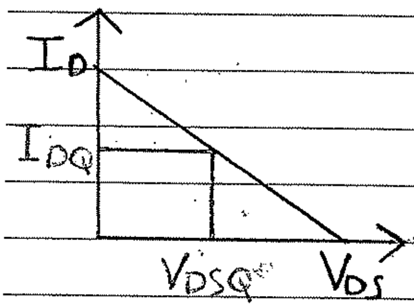
Since $V_{DS} > V_{DS_{sat.}}$ ∴ MOSFET is in Sat. and can be used as Amp.

$P_D = I_D \cdot V_{DS} = 1 * 3 = 3\,mW$

D.C.l.l :- KVL for D-S loop :-

$V_{DD} + I_D R_D + V_{DS} = 0$

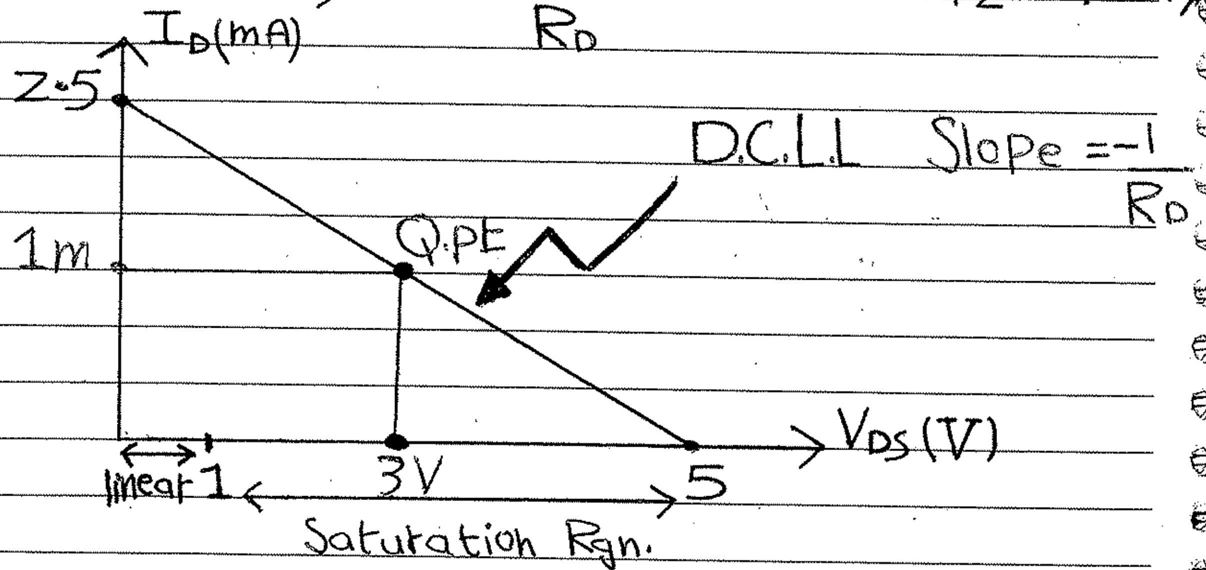
$\boxed{V_{DS} = V_{DD} - I_D R_D}$ D.C.l.l Eqn.



$$\boxed{\text{Slope} = \frac{-1}{R_D}}$$

1] For $I_D = 0$, $V_{DS} = V_{DD} = 5V. \rightarrow P_1(5V, 0)$

2] For $V_{DS} = 0$, $I_D = \frac{V_{DD}}{R_D} = 2.5mA \rightarrow P_2(0, 2.5m)$



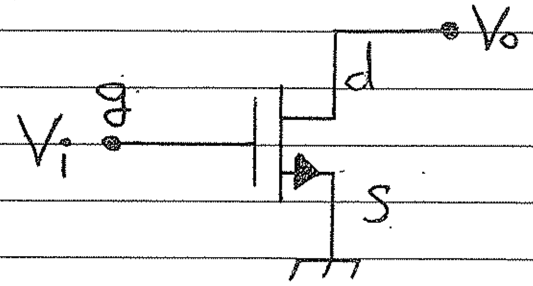
Q.Pt:

at the Center of Sat. Rgn. : $\frac{5+1}{2} = 3$,

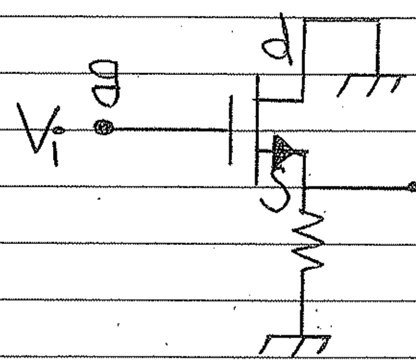
at the Center of D.C.l.l : $\frac{5}{2} = 2.5$,

MOSFET Amplifiers :-

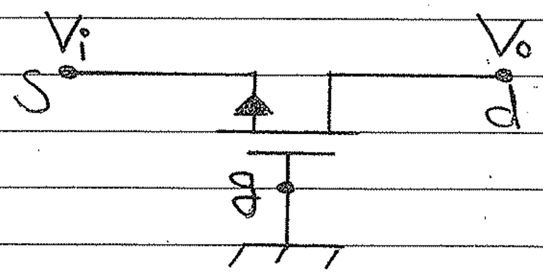
1) Common Source Amp. :-



2) Common Drain Amp. :-

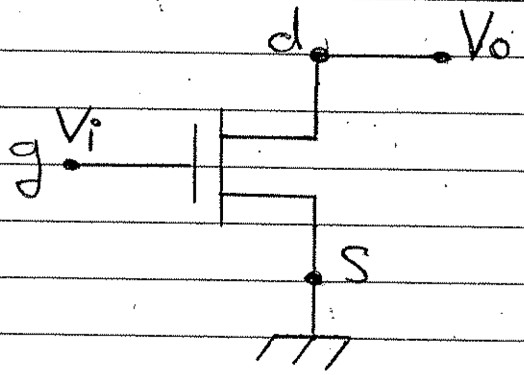


3) Common gate Amp. :-

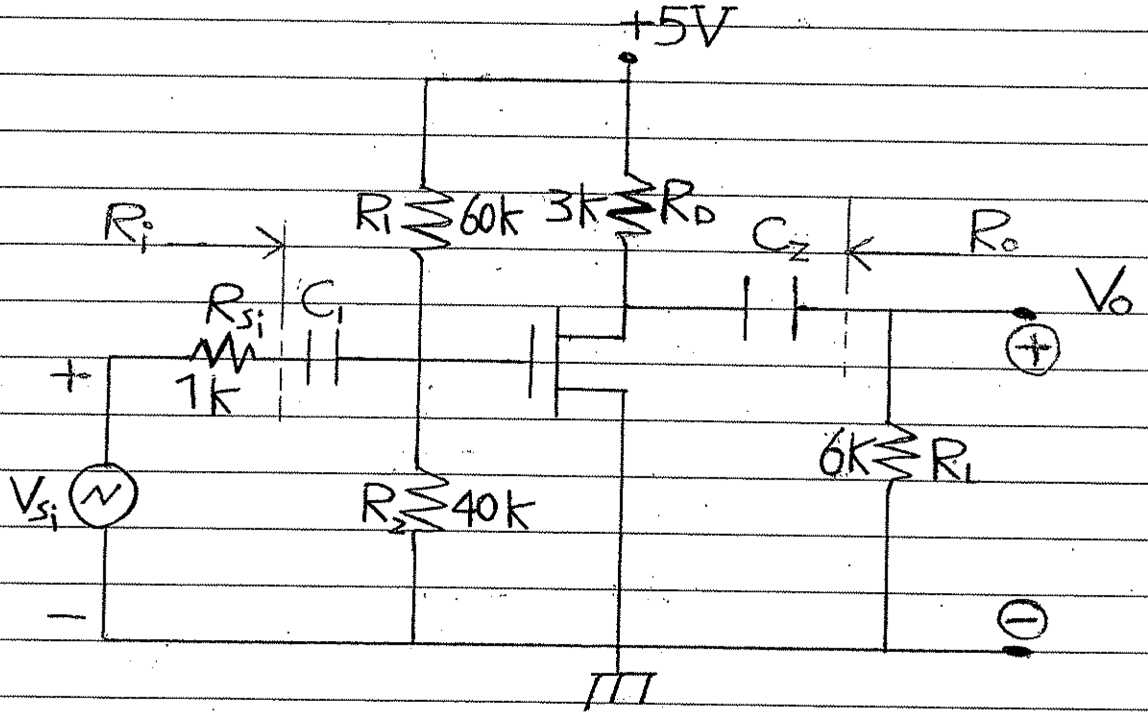


1] Common Source Amp. :

i) Basic Common Source Amp. :-



EXA. :-



$K_n = 1 \frac{mA}{V^2}$, $V_{TN} = 1V$, $\lambda = 0.01 V^{-1}$

1) Calculate V_{GSQ}, I_{DQ}, V_{DSQ}.

2) Draw S.S.A.C Eqnt. CCt. and find

$A_V = \frac{V_o}{V_{si}}$, R_i, R_o.

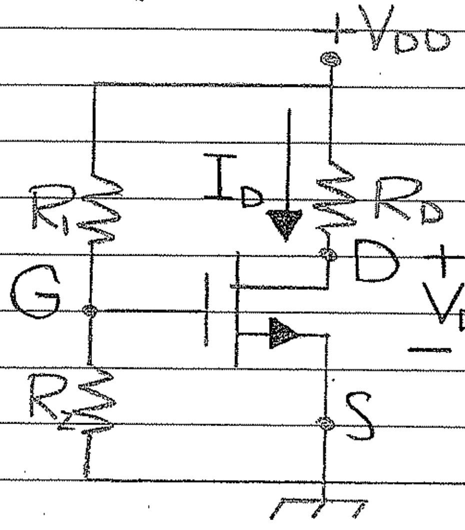
Solution :

1) DC analysis :- [C : O.C].

Assume the MOSFET

in Saturation Rgn. :-

$I_D = k_n(V_{GS} - V_{TN})^2$

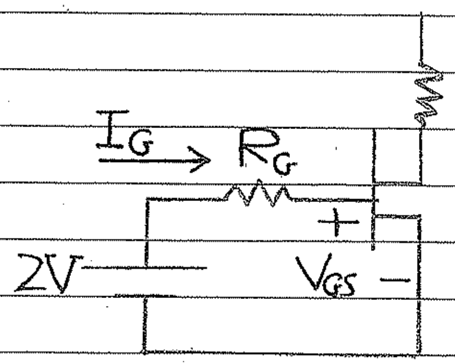


$V_{GS} = V_G - V_S$

$$= \frac{V_{DD} \cdot R_2}{R_1 + R_2} - 0 = \frac{5 * 40}{40 + 60} = 2V. \#$$

OR :-

$-2 + I_G R_G + V_{GS} = 0$



$V_{GS} = 2V. \#$

※ $I_D = 1(2-1)^2 = 1\,mA.$

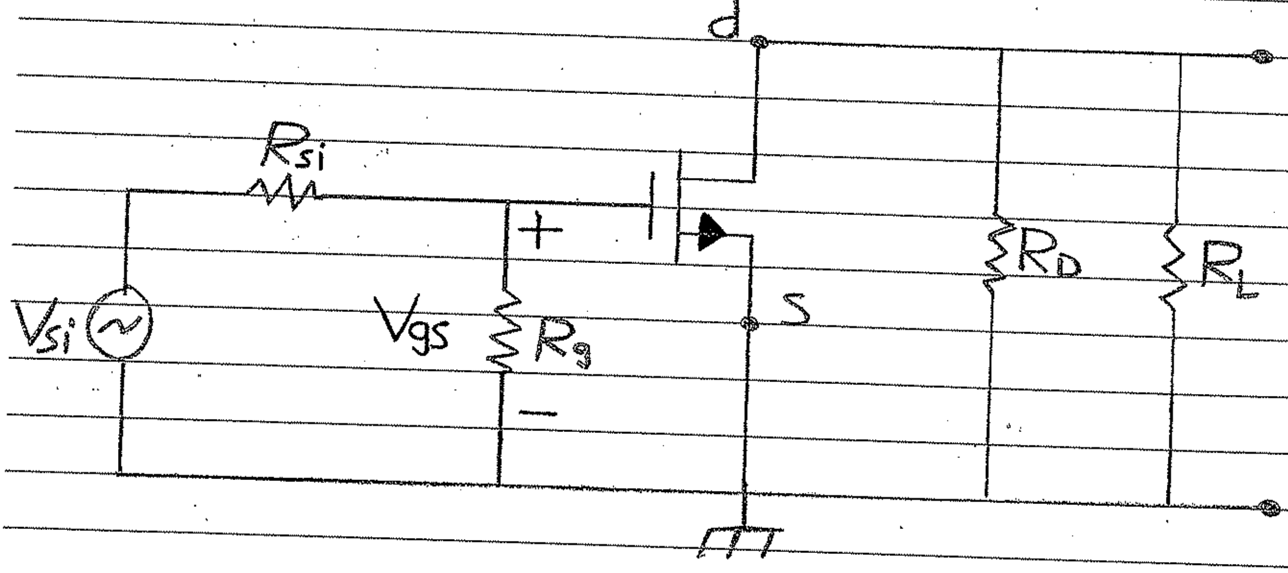
$-V_{DD} + I_D R_D + V_{DS} = 0$

※ $V_{DS} = 5 - 1 * 3 = 2V.$

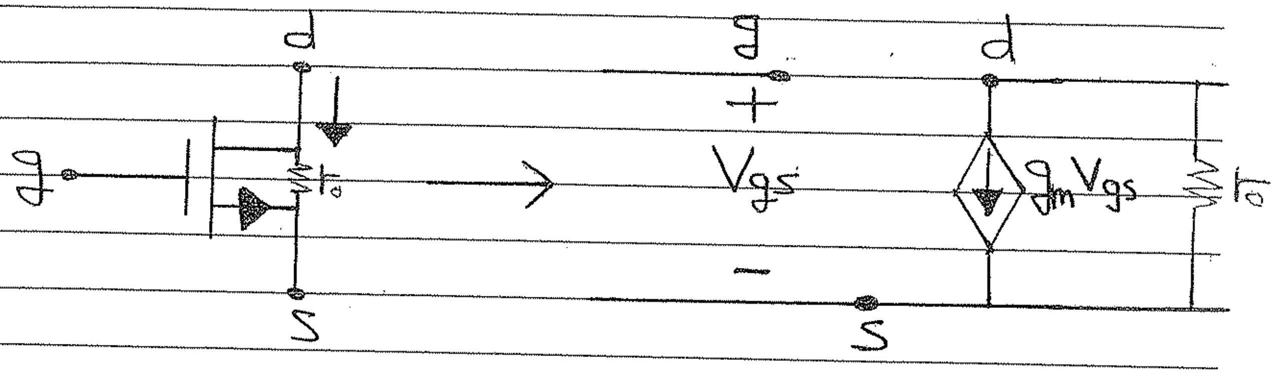
$V_{DS_{(sat.)}} = V_{GS} - V_{TN} = 2 - 1 = 1V.$

Since $V_{DS} > V_{DS_{(sat.)}}$ ∴ MOSFET in Sat. Rgn..

2) AC analysis :- [C : S.C ; DC : S.C] ※.



MOSFET Model:-



g_m: Transconductance $\left[\frac{mA}{V}\right]$

$$\boxed{g_m = \frac{\partial I_D}{\partial V_{GS}} = 2K_n(V_{GS} - V_{TN})}$$

or:

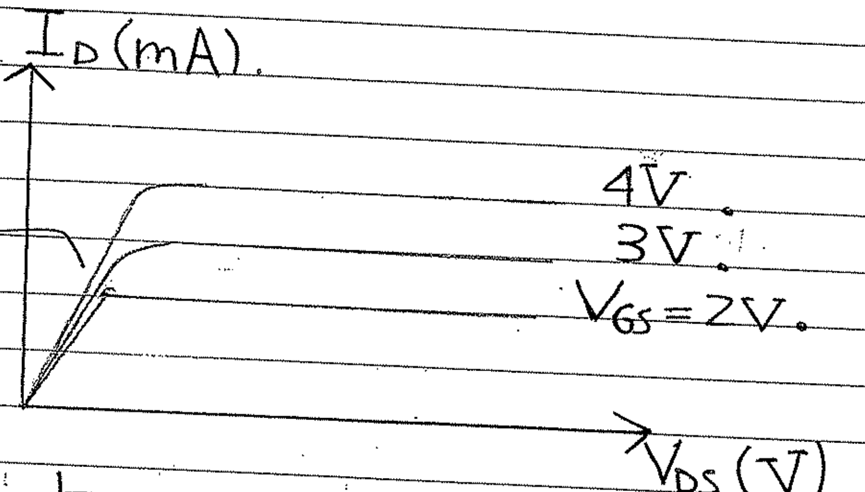
$$\boxed{g_m = 2\sqrt{K_n I_D}}$$

r_o : MOSFET O/P resistance.

$$\boxed{r_o = \frac{1}{\lambda I_{DQ}}}$$

λ : Channel length modulation parameter.

$[V^{-1}]$.

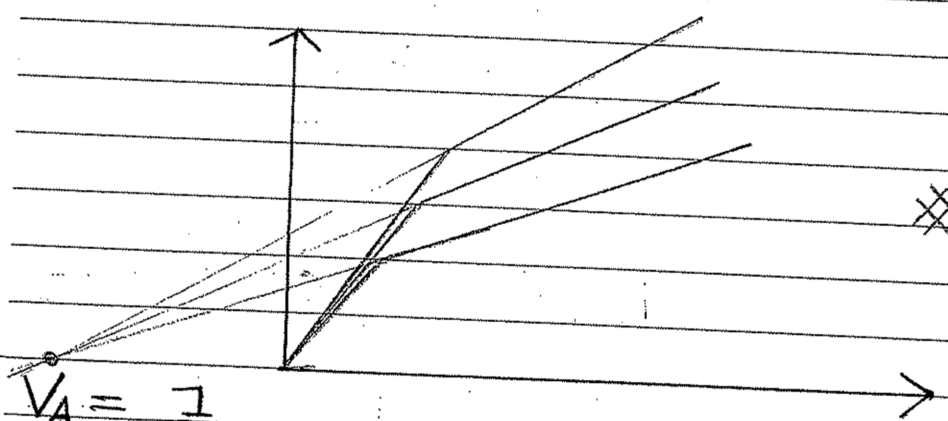


$\boxed{\text{Slope} = 0}$

※ $\Delta I_D = 0$

$$r_o = \frac{1}{\text{Slope of } (I_D, V_{DS}) \text{ line}}$$

$$r_o = \frac{1}{0} = \infty.$$

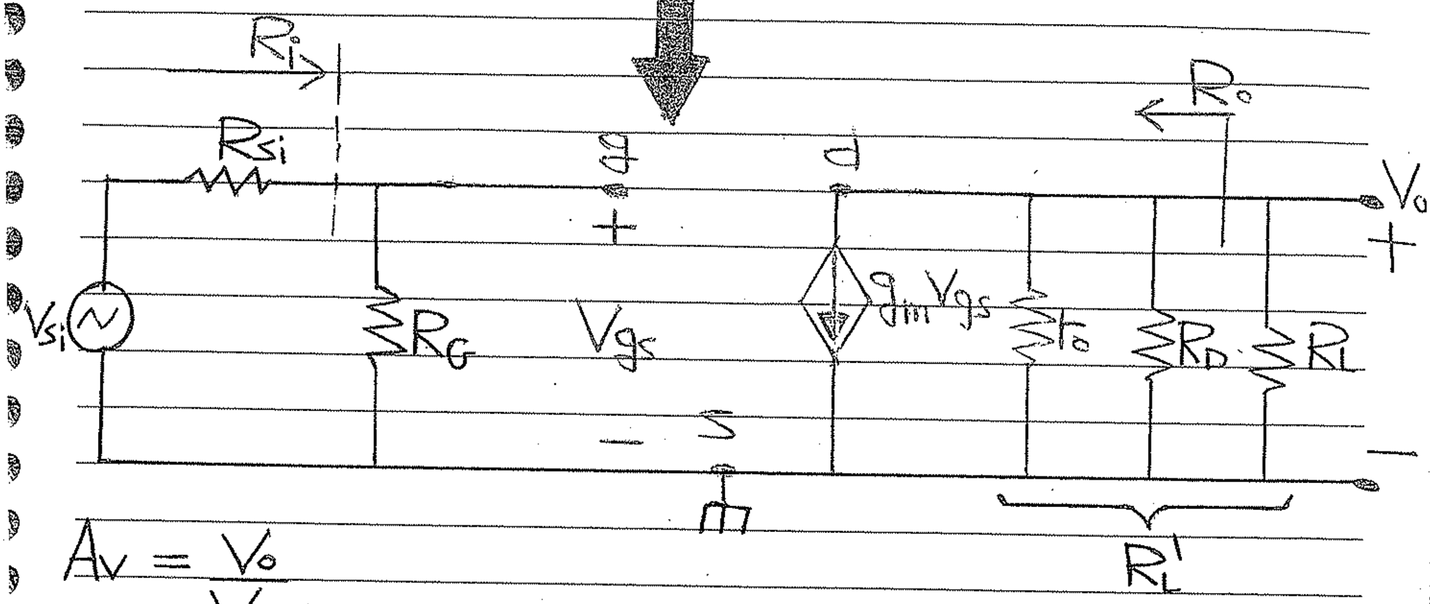


$\boxed{\text{Slope} \neq 0}$

※ $r_o \neq \infty$

$V_A = \frac{1}{\lambda}$

$$\boxed{r_o = \frac{1}{\lambda I_{DQ}}}$$



$$A_V = \frac{V_o}{V_{si}}$$

$$V_o = -g_m V_{gs} R_L' \quad ; \quad \boxed{R_L' = r_o \,//\, R_D \,//\, R_L}$$

$$\boxed{V_{gs} = \frac{V_{si} \cdot R_g}{R_g + R_{si}}}$$

$$\therefore V_o = -g_m R_L' \frac{V_{si} \cdot R_G}{R_G + R_{si}}$$

$$\frac{V_o}{V_{si}} = \boxed{A_V = -g_m R_L' \cdot \frac{R_G}{R_G + R_{si}}}$$

→ means 180° phase-Shift between (V_{si}) and (V_o) ‡.

$$g_m = 2\sqrt{k_n I_D} = 2\sqrt{1 * 1} = 2\,mA/V.$$

$R_L' = r_o // R_D // R_L$

$$r_o = \frac{1}{\lambda I_{DQ}} = \frac{1}{0.01 * 1 * 10^{-3}} = 100\,k\Omega.$$

$$\therefore R_L' = 100 // 3 // 6 = 1.95\,k\Omega.$$

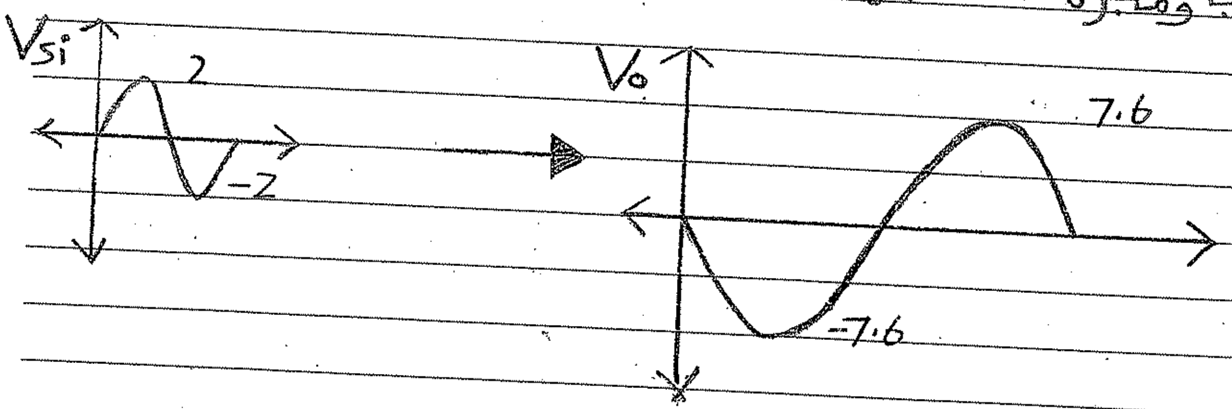
$$R_G = R_1 // R_2 = 40 // 60 = 24\,k\Omega.$$

$$A_V = -2 * 1.95 * \frac{24}{24+1}$$

$$= -3.9 * 0.96 = -3.8 \quad \#$$

For $V_{si} = 2 \sin wt\ (V)$, then:

$V_o = -3.8 * 2 = -7.6 \sin wt \rightarrow$ مقلوبة ومكبرة



$R_i = R_G = 24\,k\Omega$.

$R_o = \left.\dfrac{V_x}{I_x}\right|_{V_{si}=0}$, When $V_{si} = 0$:-

then $V_{gs} = 0 \longleftrightarrow g_m V_{gs} = 0$; dependent Current Source is Open Circuit.

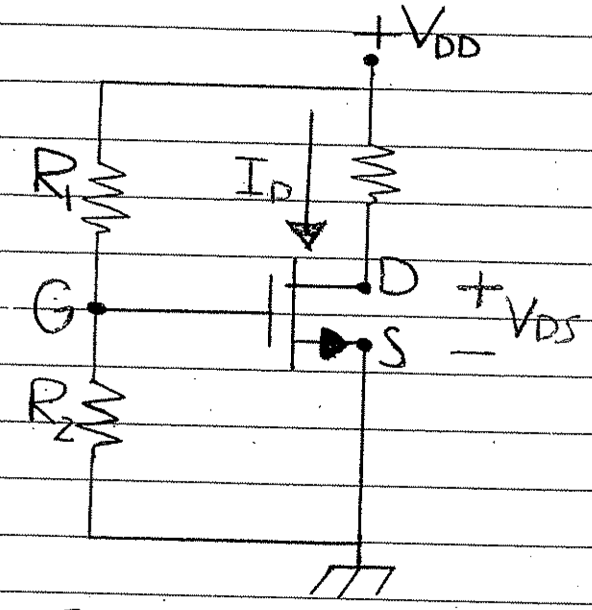
$R_o = R_D // r_o$

$= 3 // 100 = 2.9\,k\Omega$. #

※ $R_L \uparrow$, $R_L' \uparrow$, $A_v \uparrow$, R_o ثابت .

※ $V_2 \uparrow$, $V_g \uparrow$, $V_{gs} \uparrow$, $A_v \uparrow$.

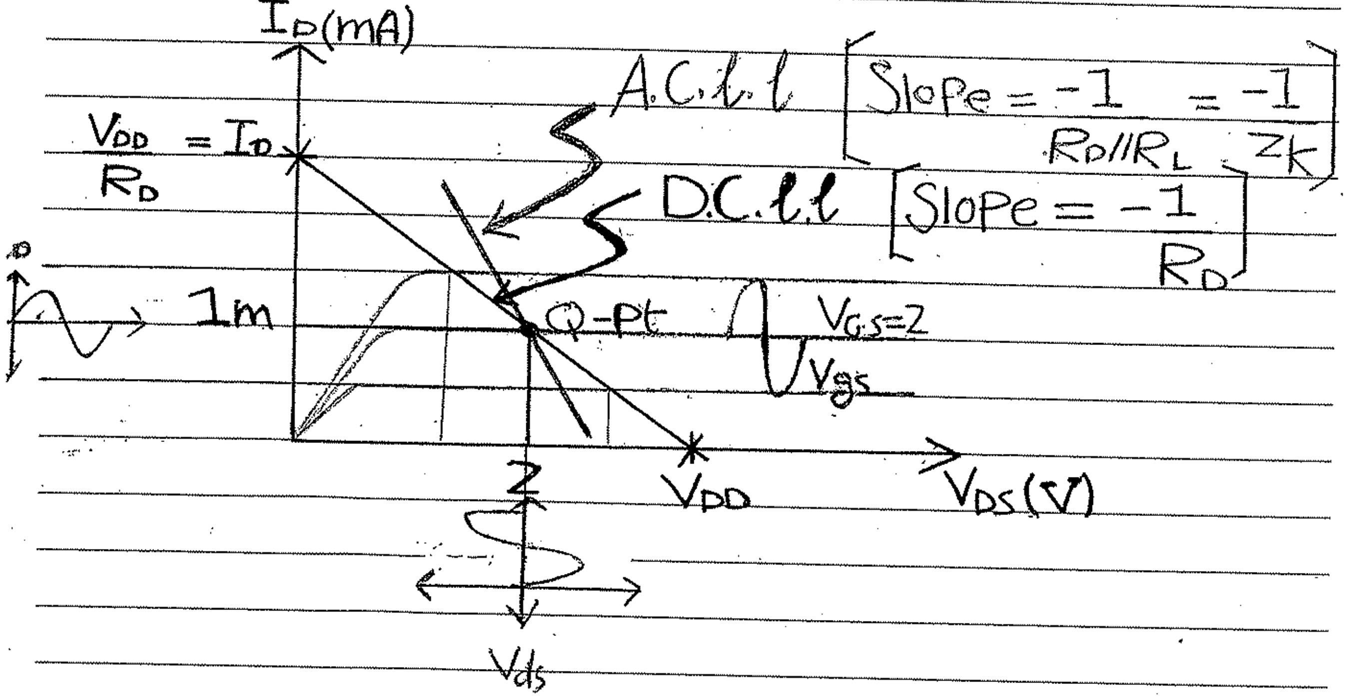
D.C.L.L :-



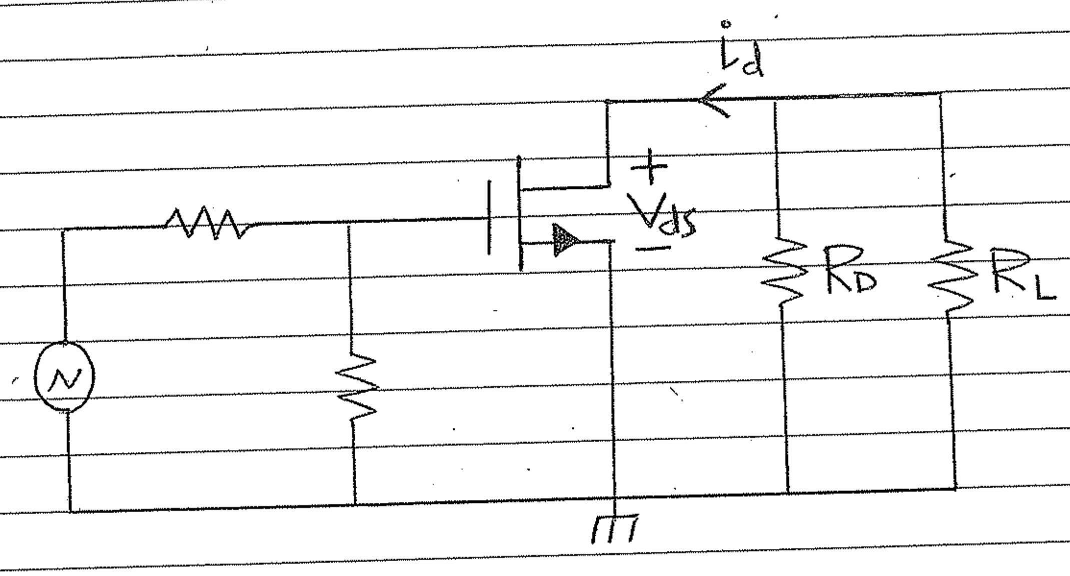
$$-V_{DD} + I_D R_D + V_{DS} = 0$$

$$I_D = \frac{V_{DD} - V_{DS}}{R_D} \rightarrow I_D = \frac{V_{DD}}{R_D} - \frac{V_{DS}}{R_D}$$

$$\boxed{Slope = \frac{-1}{R_D}}$$



A.C.l.l :-



$$V_{ds} + i_D(R_D // R_L) = 0$$

$$V_{ds} = -i_D(R_D // R_L) \quad \text{--- ACll Eqn.}$$

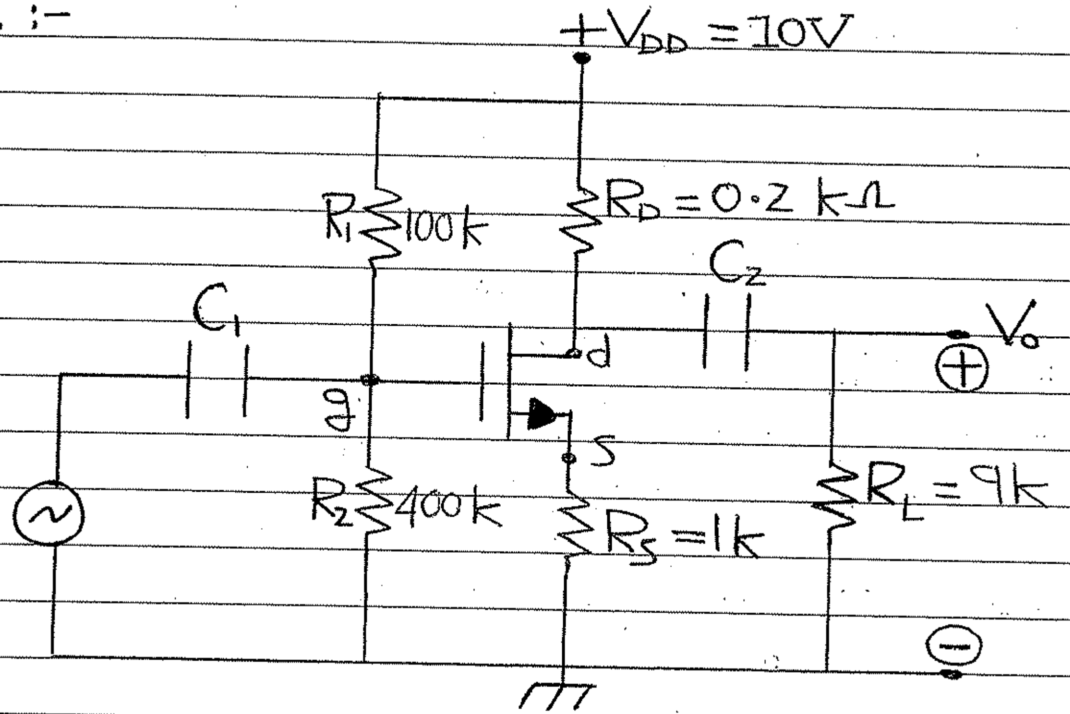
$$\boxed{\text{Slope} = \frac{-1}{(R_D // R_L)}}$$

لا تهمل (r_o)

ii) Common Source with R_S :-

R_S : Stabilize (Q-pt.) against (K_n) parameter Variation.

EXA. :-



$K_n = \frac{4mA}{V^2}$, $V_{TN} = 1V$, $\lambda = 0$:-

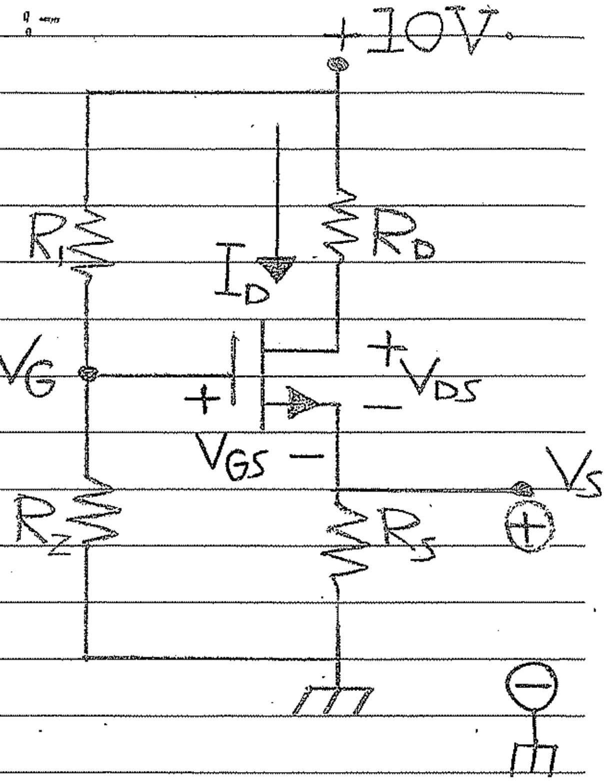
1) Calculate V_{GSQ} , I_{DQ} , V_{DSQ} .

2) Draw S.S.A.C Eqnt. CCt. and find A_v , R_i , R_o .

Five Apple

Sol :- For DC Analysis :-

Assume the MOSFET in Sat. Rgn. :-



$$I_D = K_n (V_{GS} - V_{TN})^2$$

※ $V_{GS} = V_G - V_S$

$$V_G = \frac{10 * R_2}{R_1 + R_2} = \frac{10 * 400}{500} = 8V$$

$$V_S = I_D R_S = 1 \cdot I_D = I_D$$

$\therefore V_{GS} = 8 - I_D \longrightarrow \boxed{I_D = 8 - V_{GS}}$

$\longrightarrow 8 - V_{GS} = 4(V_{GS} - 1)^2$

$$4(V_{GS}^2 - 2V_{GS} + 1) + V_{GS} - 8 = 0$$

$$4V_{GS}^2 - 7V_{GS} - 4 = 0 \qquad \{AX^2 + BX + C = 0\}$$

$$V_{GS} = \frac{7 \pm \sqrt{(49) + 4*4*4}}{8}$$

$$= \frac{7 \pm \sqrt{113}}{8} = \frac{7 \pm 10.6}{8} = 2.2V \text{ or } -0.45V$$

✓ موجبة واكبر من V_{TN} ✗

$\therefore V_{GSQ} = 2.2V$. #

$I_D = 8 - 2.2 = 5.8\ mA$. #

$-10 + I_D R_D + V_{DS} + I_D R_S = 0$

$V_{DS} = 10 - 5.8(1+0.2) \simeq 3V$.

$\therefore V_{DS(sat.)} = 2.2 - 1 = 1.2V$. #

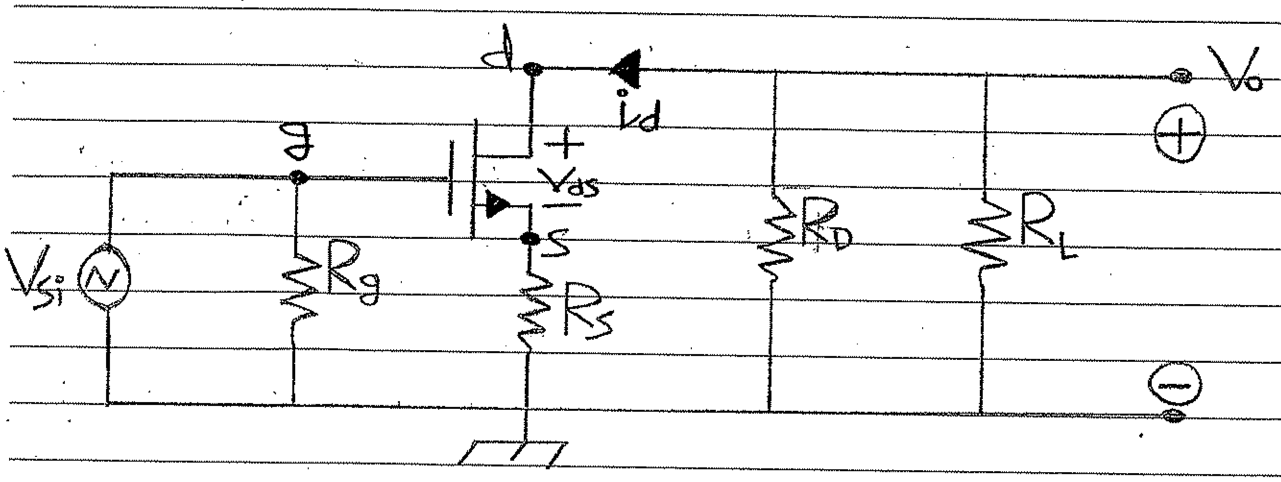
V_D :

$-10 + I_D R_D' + V_D = 0$

$V_D = 10 - (5.8 * 0.2) = 8.84V$. #

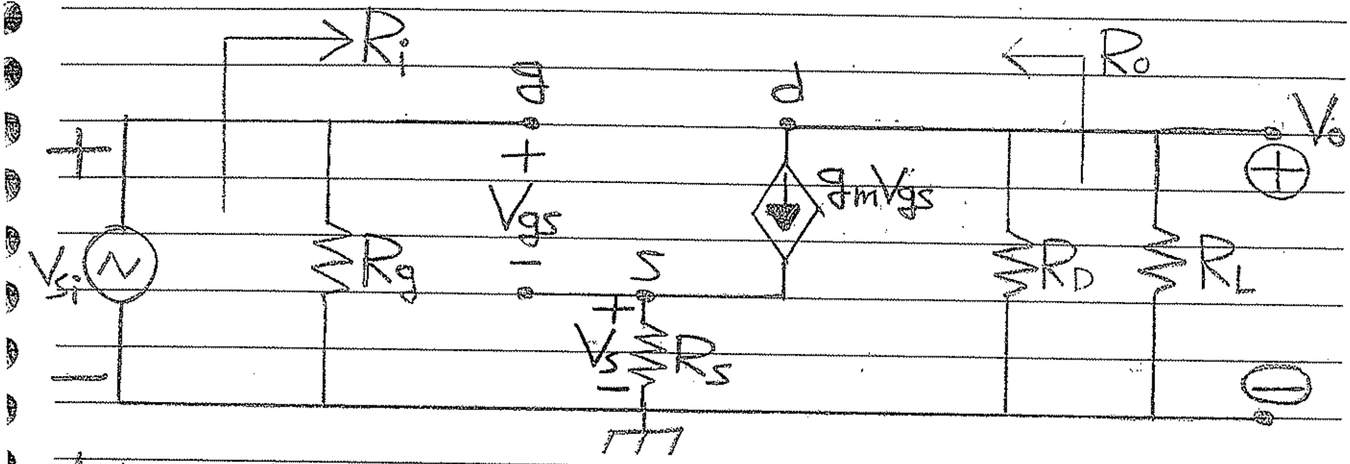
$Slope = \dfrac{-1}{R_D + R_S}$ #

* For AC Analysis :- [C : S.C ; DC : S.C].



$$V_{ds} + i_d R_s + i_d (R_L // R_D) = 0$$

$$V_{ds} = -i_d (R_s + R_L // R_D) \longrightarrow \text{A.C.l.l Eqn.}$$



$$A_V = \frac{V_o}{V_{si}} = \frac{-g_m V_{gs} (R_D // R_L)}{V_{si}}$$

$$-V_{si} + V_{gs} + V_s = 0$$

$$V_{gs} + g_m V_{gs} R_s = V_{si}$$

$$V_{gs} (1 + g_m R_s) = V_{si}$$

$$V_{gs} = \frac{V_{si}}{1 + g_m R_s}$$

$$A_V = \frac{-g_m \cancel{V_{gs}} (R_D // R_L)}{\cancel{V_{gs}} (1 + g_m R_s)} \rightarrow \boxed{A_V = \frac{-g_m (R_D // R_L)}{1 + g_m R_s}}$$

$\boxed{\text{※ } R_s \text{ reduces } A_V}$

$g_m = 2\sqrt{k_n I_D} = 2\sqrt{4*5.8} = 9.6\ mA/V$

$A_V = \dfrac{-9.6\,(0.2 // 9)}{1+(9.6*1)} = -0.17$ #

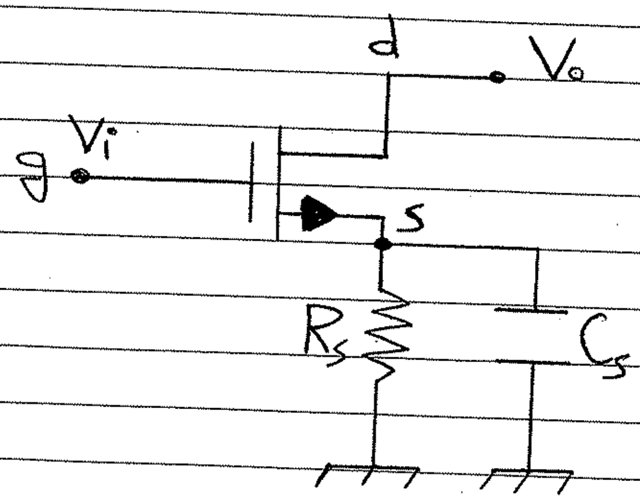
$R_i = R_g = 100 // 400$

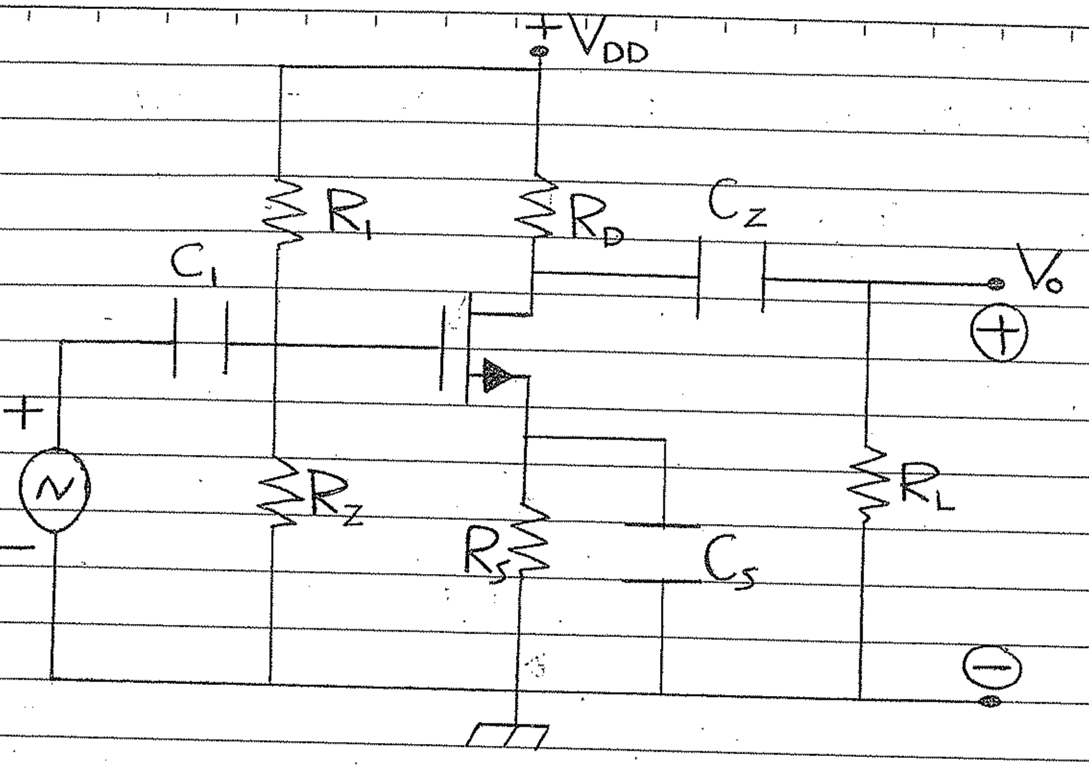
$= 80\ k\Omega$. #

$R_o = \left.\dfrac{V_x}{I_x}\right|_{V_s=0}$

$= R_D = 0.2\ k\Omega$. #

iii) Common Source with bypass Capacitor C_s:





For DC analysis, (C_S) is open CCt. and the CCt. behavies as [C.S with R_S].

For AC analysis, (C_S) is Short CCt. and the CCt. behavies as [Basic C.S Amp.].

EXA. :-

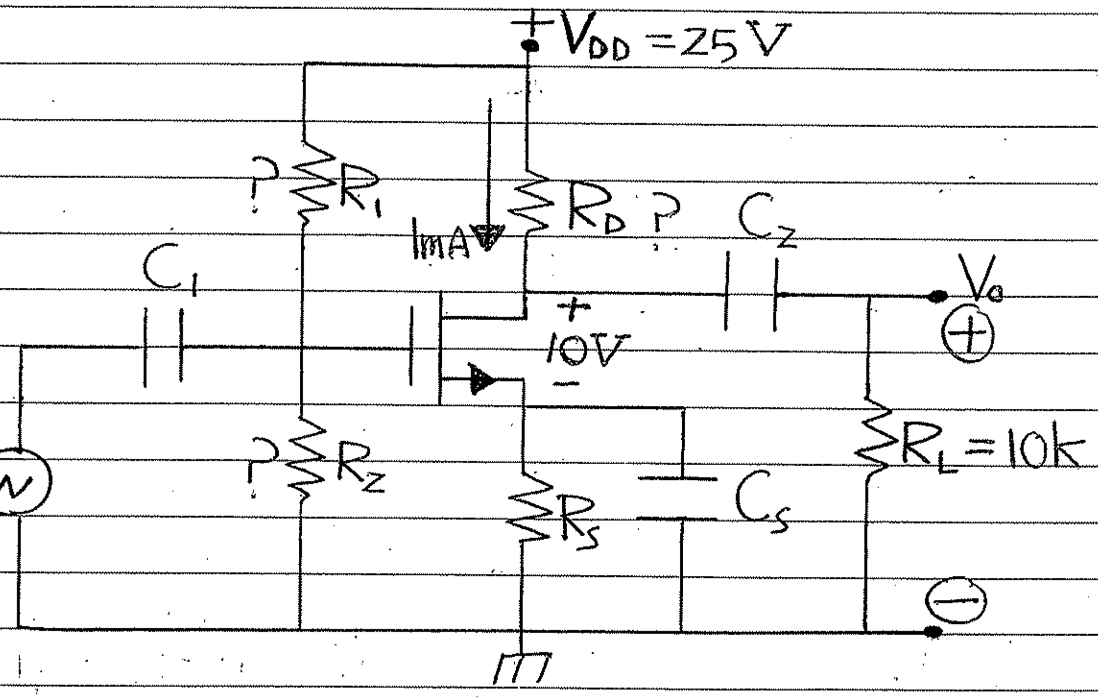
Design the Circuit Shown to have the following Specification :-

$I_{DQ} = 1\,mA$, $V_{DSQ} = 10V$, $A_v = -14$,

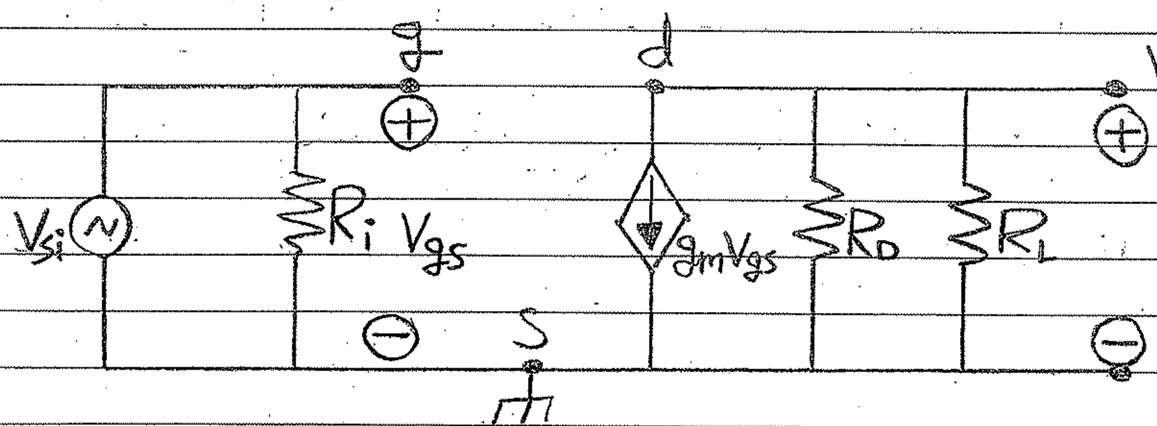
$R_i = 200\,k\Omega$;

Given :- $V_{TN} = 1V$, $k_n = 2\,\frac{mA}{V^2}$, $\lambda = 0$

$V_{DD} = 25V$, for $R_L = 10k\Omega$



Solution :-



$$A_V = -\frac{V_o}{V_{si}} = \frac{-g_m V_{gs} (R_D // R_L)}{V_{gs}}$$

$$\boxed{A_V = -g_m (R_D // R_L)}.$$

$$g_m = 2\sqrt{K_n I_D} = 2\sqrt{2*1} = 2.8 \text{ mA/V}.$$

$\therefore$

$$-14 = -2.8(R_D // R_L)$$

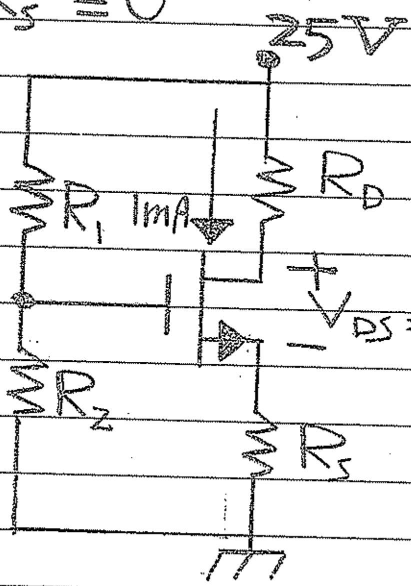
$$\rightarrow R_D // R_L = 5 \text{ k}\Omega.$$

$$5 = 10 // R_D \longrightarrow \underline{R_D = 10 \text{ k}\Omega}. \ \#$$

$$-V_{DD} + I_D R_D + V_{DS} + I_D R_S = 0$$

$$R_D + R_S = \frac{25-10}{1m} = 15 \text{ k}\Omega.$$

$$\therefore R_S = 15 - 10 = 5 \text{ k}\Omega.$$



From D.C analysis :-

$$V_G \cdot R_1 = \frac{V_{DD} R_2}{R_1 + R_2} \cdot R_1 \quad . \ R_1$$ بضرب طرفي المعادلة ب

$$R_1 = \frac{V_{DD}}{V_G} R_i \quad ; R_i = R_1 // R_2 = \frac{R_1 \cdot R_2}{R_1 + R_2}.$$

$$V_{GS} = V_G - V_S$$

$$\boxed{V_G = V_{GS} + V_S}$$

Five Apple

$V_S = I_D R_S = 1 * 5 = 5V.$

$I_D = k_n(V_{GS} - V_{TN})^2$

$$\mp\sqrt{\frac{I_D}{k_n}} = V_{GS} - V_{TN}$$

$$\rightarrow V_{GS} = V_{TN} \mp \sqrt{\frac{I_D}{k_n}}$$

$$= 2 \mp \sqrt{\frac{1}{2}} = 2 \mp 0.7$$

$$= \boxed{2.7} \text{ or } 1.3 \text{ V.}$$

✓ ✗

$V_G = 2.7 + 5 = 7.7\text{ V}.$

$\Rightarrow R_1 = \frac{25}{7.7} * 200k = 649\ k\Omega.$ #

$\Rightarrow R_2$:

$$R_i = \frac{R_1 \cdot R_2}{R_1 + R_2}$$

$$200 = \frac{649 \cdot R_2}{649 + R_2}$$

$$\therefore R_2 = \frac{649 * 200}{649 - 200} = 289\ k\Omega.$$ #

7 Common - Drain Amplifier :-

[Source Follower]

Note :-

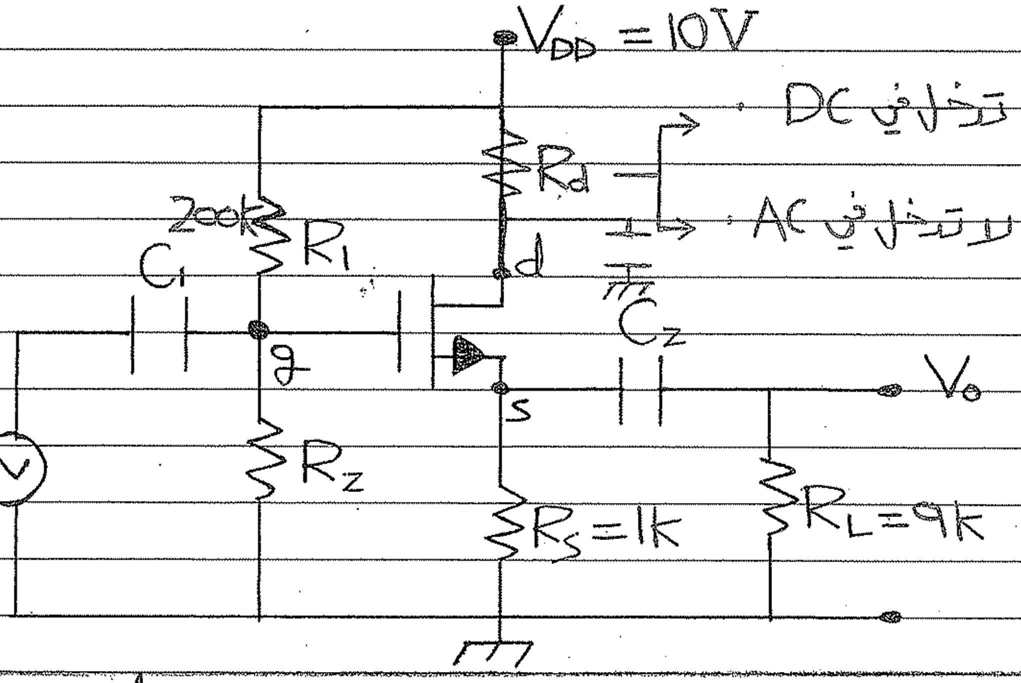
C-D & C-C :- Voltage - Followers.

($V_o \simeq V_i$).

C-B & C-G :- Current - Followers.

($I_o \simeq I_i$)

EXA. ;



D → ground.

i/P : to gate. , O/P : from Source.

$K_n = 4\frac{mA}{V^2}$, $V_{TN} = 1$, $\lambda = 0.01\ V^{-1}$

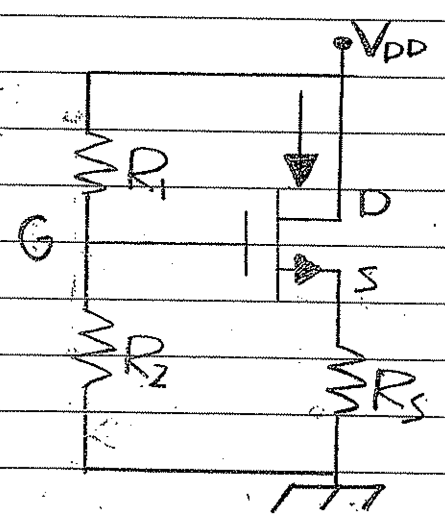
Given $V_S = 4V$:

1] Find V_{GSQ} , V_{DSQ} , R_2 ?

2] Draw A.C Eqnt. cct. & Find R_i, R_o, A_v.

Sol.

For DC analysis :- [C : Open cct.]



$V_S = I_D R_S \rightarrow I_D = \frac{V_S}{R_S} = \frac{4}{1k} = 4mA.$

$I_D = K_n(V_{GS} - V_{TN})^2$

$V_{GS} = V_{TN} \mp \sqrt{\frac{I_D}{K_n}} = 1 \mp \sqrt{\frac{4}{4}} = 2V$ or $0V$

✓ ✗

$V_{DS} = V_D - V_S = 10 - 4 = 6V.$; $\boxed{V_{DD} = V_D}$

$V_{GS} = V_G - V_S \longrightarrow V_G = V_{GS} + V_S$

$= 2 + 4 = 6V.$

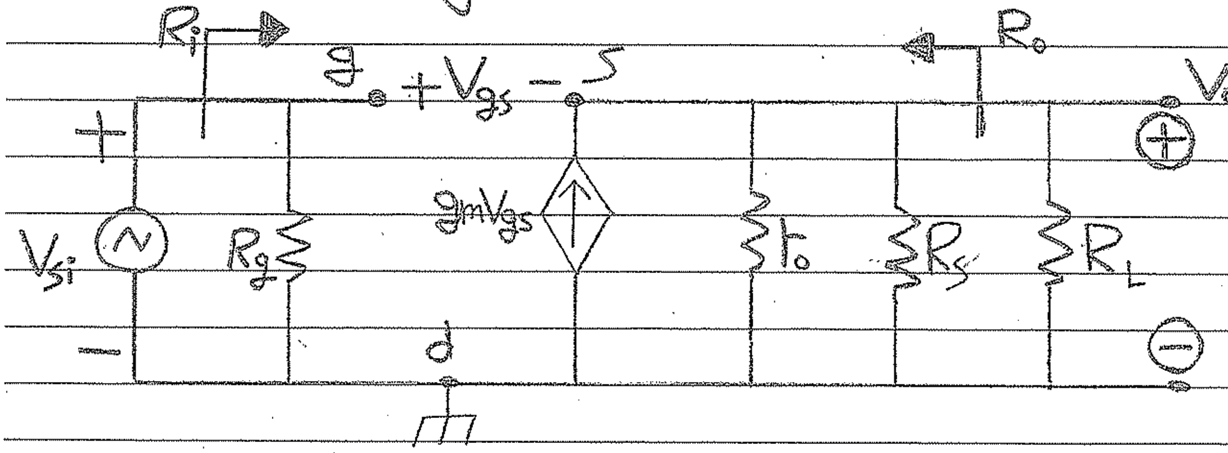
$V_G = \frac{V_{DD} \cdot R_2}{R_1 + R_2}$

$R_2 = \frac{10 \cdot R_2}{200 + R_2} \longrightarrow 10R_2 = 1200 + 6R_2$

$\therefore 4R_2 = 1200$

$R_2 = 300\,k\Omega.$

For A.C analysis :-



S.S.A.C Eqnt. CCt.

$$A_v = \frac{V_o}{V_{si}}$$

$$V_o = g_m V_{gs} \bar{R}_L \quad ; \quad \bar{R}_L = r_o // R_s // R_L$$

$$-V_{si} + V_{gs} + V_o = 0$$

$$V_{si} = V_{gs} + V_o$$

$$\rightarrow V_{si} = V_{gs} + g_m V_{gs} \bar{R}_L$$

$$\therefore A_v = \frac{V_o}{V_{si}} = \frac{g_m V_{gs} \bar{R}_L}{V_{gs}(1 + g_m \bar{R}_L)} = \frac{g_m \bar{R}_L}{1 + g_m \bar{R}_L}$$

$$\boxed{A_V = \frac{g_m \bar{R}_L}{1 + g_m \bar{R}_L}} \quad ; \quad A_V < 1 \, , \, \phi = 0 .$$

$$g_m = 2\sqrt{K_n I_D} = 2\sqrt{4 * 4} = 8 \text{ mA/V}.$$

$$\bar{R}_L = r_o // R_s // R_L .$$

$$r_o = \frac{1}{\lambda I_D} = \frac{1}{0.01 * 4 * 10^{-3}} = \frac{10^5}{4} = 25 \text{ k}\Omega .$$

$$\bar{R}_L = 25k // 1k // 9k$$

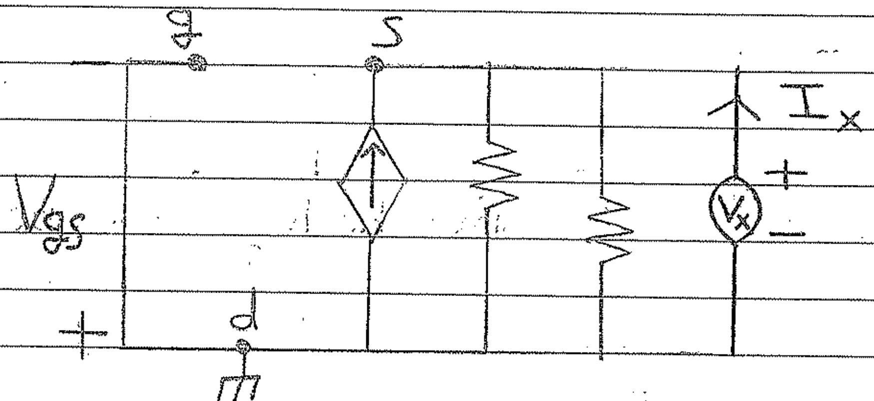
$$= 0.85 \text{ k}\Omega .$$

$$A_v = \frac{8 * 0.85}{1 + (8 * 0.85)} = \frac{7}{8} \simeq 0.88 \quad \#$$

$$R_i = R_g = R_1 // R_2$$

$$= 200 // 300 = 120 k\Omega \quad \#$$

$$R_o = \left.\frac{V_x}{I_x}\right|_{V_{si} = 0}$$



KCL at node (S) :-

$$I_x + g_m V_{gs} = \frac{V_x}{r_o} + \frac{V_x}{R_s}$$

but : When $V_{si} = 0 \longrightarrow V_{gs} = -V_x$

$$I_x = V_x \left(g_m + \frac{1}{r_o} + \frac{1}{R_s} \right)$$

$$\frac{I_x}{V_x} = \frac{1}{R_o} = g_m + \frac{1}{r_o} + \frac{1}{R_s}$$

$$\boxed{R_o = \frac{1}{g_m} // r_o // R_s}$$ Law in general. #

$R_o = \frac{1}{8 * 10^{-3}} // 25k // 1k$

$= 125\,\Omega // 25k // 1k = 120\,\Omega$.

$A_V < 1$.

$\phi = 0$

$R_o \rightarrow$ Law.

$R_i = R_{Th} \rightarrow$ R_2 و R_1 تحددها قيم
(maybe high maybe law.)

* $A_V = \frac{g_m R_L}{1 + g_m R_L}$

if $g_m R_L \gg 1$ then $A_V \approx 1$

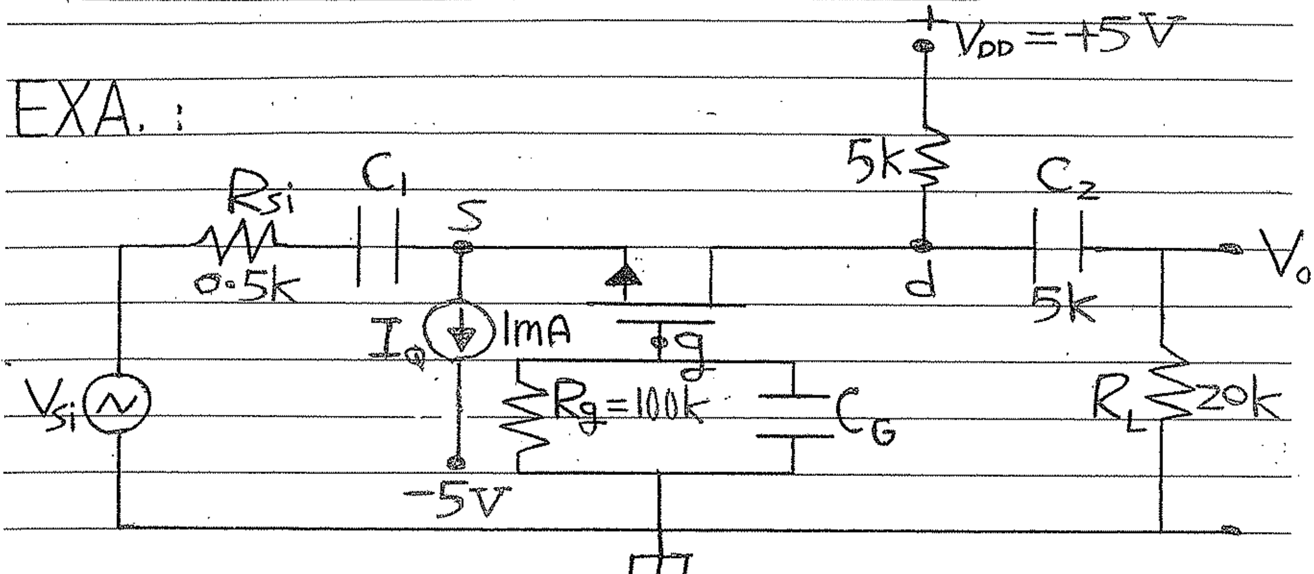
∴ $V_o = V_{si}$

So it's Source follower because V_i follow V_o in magnitued and ϕ.

* In General : MOSFET CCt.s have ($A_v \rightarrow$ Law) if we Compare it with BJT CCts

3] Common-Gate Amplifier :

EXA. :

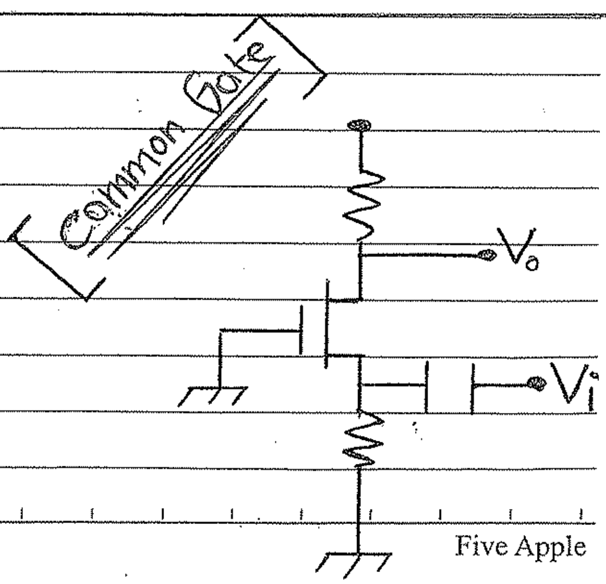


- R_g: To protect the gate from Static Charge.

$V_G = I_G R_g = 0$

- يجب أن تكون V_s (−) حتى تكون
V_{GS} (+) وتشتغل الدارة.

Bypass Cap. :- Because bypassing the AC Signal to ground.

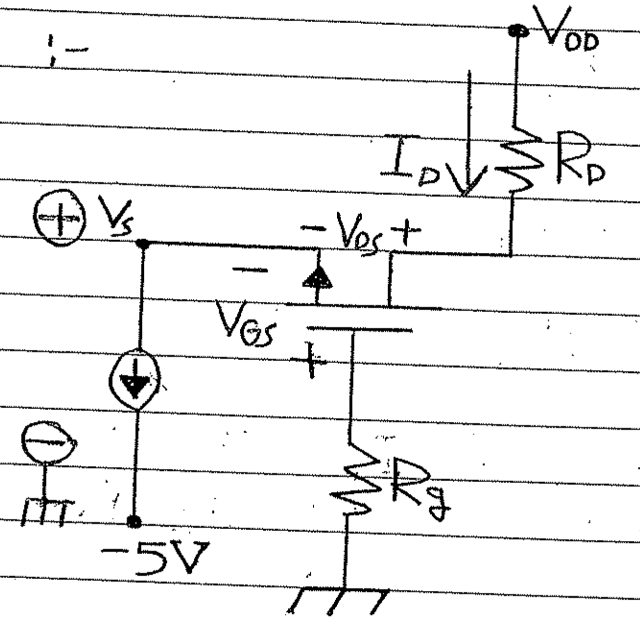


G → ground.

i/P to Source.

O/P from Drain.

※ D.C Analysis :-



Given :

$K_n = 25 \mu A/V^2$

$V_{TN} = 1V$

$\frac{W}{L} = 80$

$\lambda = 0$

1) Find: V_{DS} , V_s , P_D .

2) Draw AC Eqnt. cct. and find A_v , R_i , R_o , A_I .

Solution :-

For DC analysis :-

$-V_{DD} + I_D R_D + V_{DS} + V_s = 0$

$V_{DS} = 5 - I_D R_D - V_s = 5 - (1 * 5) - V_s$

$= -V_s$

→ $\boxed{V_{DS} = -V_s}$

$$V_{GS} = \cancel{V_G}^{\,0} - V_S$$

$$V_{GS} = -V_S \longrightarrow \boxed{V_S = -V_{GS}}.$$

$$V_{GS} = V_{TN} \mp \sqrt{\frac{I_D}{K_n}}$$

$$\boxed{K_n = \frac{\mu_n \cdot C_{ox} \cdot W}{2L} = k_n \cdot \frac{W}{2L}}, \quad \bar{k}_n = \mu_n \cdot C_{ox}$$

$$K_n = 25 * \frac{80}{2} = 1000\,\mu A/V^2.$$

$$= 1\,mA/V^2.$$

$$V_{GS} = 1 \mp \sqrt{\frac{1m}{1m}} = 2V \text{ or } 0V.$$

$$\checkmark \qquad \times$$

$$V_S = -V_{GS} = -2V. \;\#$$

$$V_{DS} = -(-2) = 2V. \;\#$$

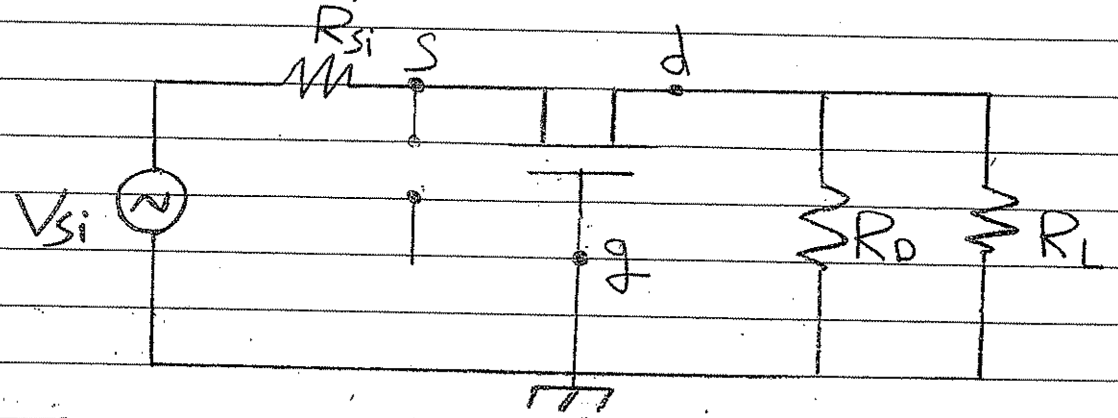
Or: $V_{DS} = V_D - V_S$

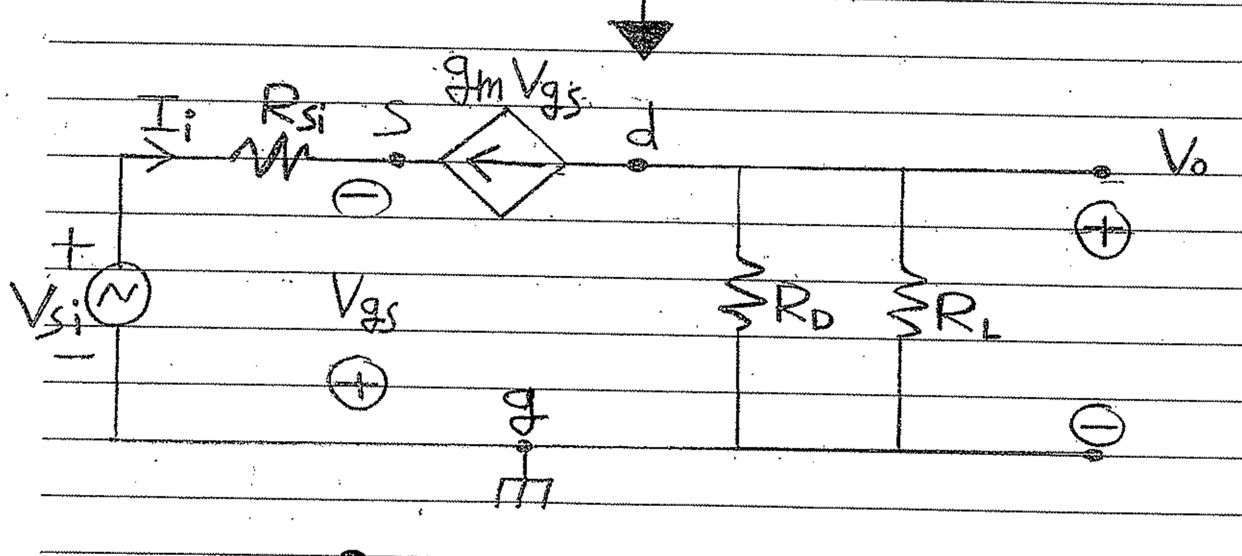
$$V_D = 5 - I_D R_D = 0$$

$$V_{DS} = -(-2) = 2V. \;\#$$

$$P_D = I_D * V_{DS} \;\#$$

A.C analysis :-





S.S.A.C Eqnt. CCt.

$$A_v = \frac{V_o}{V_{si}}$$

$$V_o = -g_m (R_D // R_L) V_{gs}$$

$$-V_{si} + I_i R_{si} - V_{gs} = 0$$

$$\boxed{I_i = -g_m V_{gs}}$$

$$-V_{si} - g_m V_{GS} R_{si} - V_{gs} = 0$$

$$V_{si} = -V_{GS}(1 + g_m R_{si})$$

$$\therefore A_v = \frac{V_o}{V_{si}} = \frac{-g_m (R_o // R_L) V_{gs}}{-V_{gs}(1 + g_m R_{si})}$$

$$\boxed{A_v = \frac{g_m (R_D // R_L)}{1 + g_m R_{si}}} \quad ; A_v > 1 \;,\; \phi = 0^\circ \quad \#$$

$$g_m = 2\sqrt{k_n I_D} = 2\sqrt{1 * 1} = 2\,mA/V$$

$$A_v = \frac{2 * (5 // 20)}{1 + 2(0.5)} = 4 \quad \#$$

$$R_o = \left.\frac{V_x}{I_x}\right|_{V_{si}=0}$$

$$R_o = R_D = 5k\Omega \quad \#$$

$$R_i = \frac{-V_{gs}}{I_i} = \frac{-V_{gs}}{-g_m V_{gs}} = \frac{1}{g_m} = \frac{1}{2m} = 0.5k$$

$$= 500\,\Omega \quad \#$$

* if their is (R_s) :

$$\therefore R_i = R_s // \frac{1}{g_m} \quad [Law]$$

* For NO R_L :

$$A_I = \frac{I_o}{I_i} \approx 1$$

$\therefore I_o \simeq I_i$, C-G is Current follower.

(I_o follow I_i)

In General :

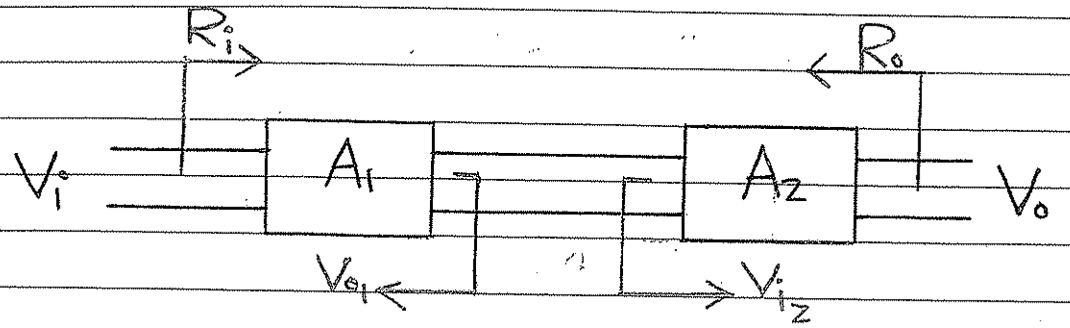
$$\boxed{A_I = \frac{g_m R_{si}}{1 + g_m R_{si}} \cdot \frac{R_D}{R_D + R_L}}$$

Summary of Single Stage MOSFET Amp. :-

Amp.	A_V	A_I	ϕ	R_i	R_o
C.S (Basic)	>1	—	180°	R_{Th}	moderate to high.
C.D	$\leqslant 1$	—	0°	R_{Th}	Law.
C.G	>1	1	0°	Law	moderate to high.

Multi-Stage :-

1] Cascade Amp. :- [Series Connection]



$A_{v_1} = \frac{V_{o1}}{V_i}$

$A_{v_2} = \frac{V_o}{V_{i2}}$

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

$R_i = R_{i1}$

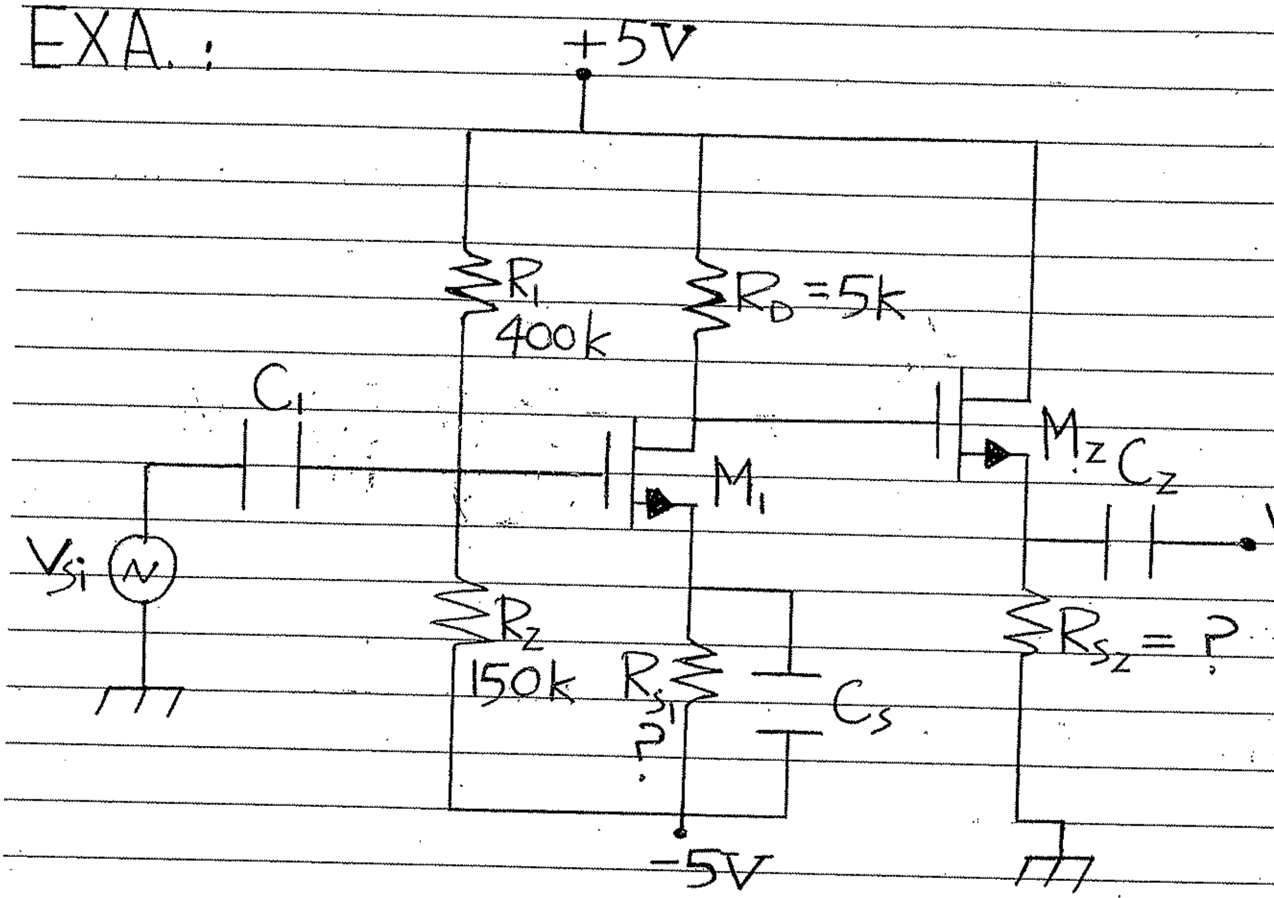
$R_o = R_{o2}$

تمعّن السماء وناظر النجوم في الفضاء ،

ففي كوكب بعيد ، ربما هناك من يتمعن في الفضاء

متسائلاً عن احتمالية وجودك .

EXA. :



$I_{D_1} = 0.2\ mA$, $K_{n_1} = 0.5\ mA/V^2$.

$I_{D_2} = 0.5\ mA$, $K_{n_2} = 0.7\ mA/V^2$.

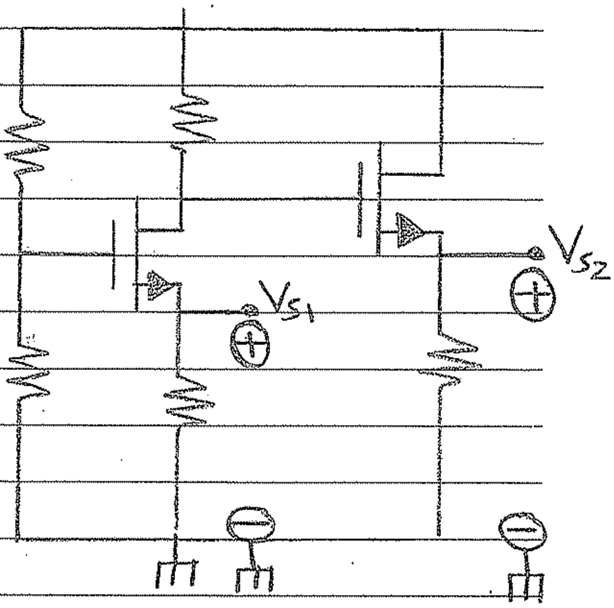
$V_{TN} = 1V$, $\lambda_1 = \lambda_2 = 0$.

1) Find R_{S_1} , R_{S_2} .

2) Draw S.S.A.C Eqnt. CCt. and find A_v , R_i , R_o .

Sol :-

1) $-V_{S_1} + I_{D_1} R_{S_1} - 5 = 0$



$R_{S_1} = \frac{5 + V_{S_1}}{I_{D_1}}$

$V_{GS_1} = V_{G_1} - V_{S_1}$

$V_{S_1} = V_{G_1} - V_{GS_1}$

$V_{G_1} = \frac{5 \cdot 150}{550} + \frac{-5 \cdot 400}{550}$

$V_{GS_1} = V_{TN} \mp \sqrt{\frac{I_{D_1}}{K_{n_1}}}$

$R_{S_2} = \frac{V_{S_2}}{I_{D_2}}$

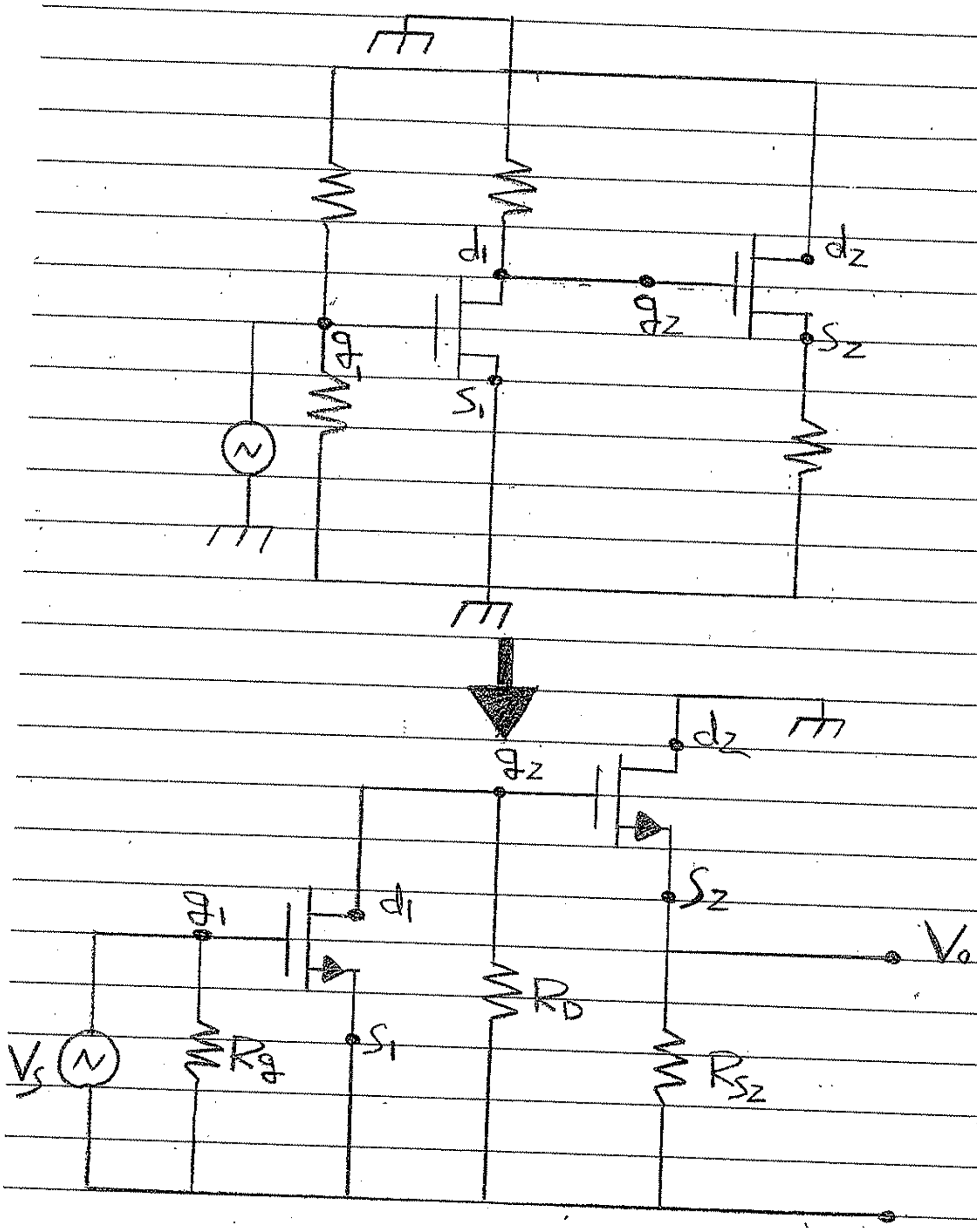
$V_{S_2} = V_{G_2} - V_{GS_2}$

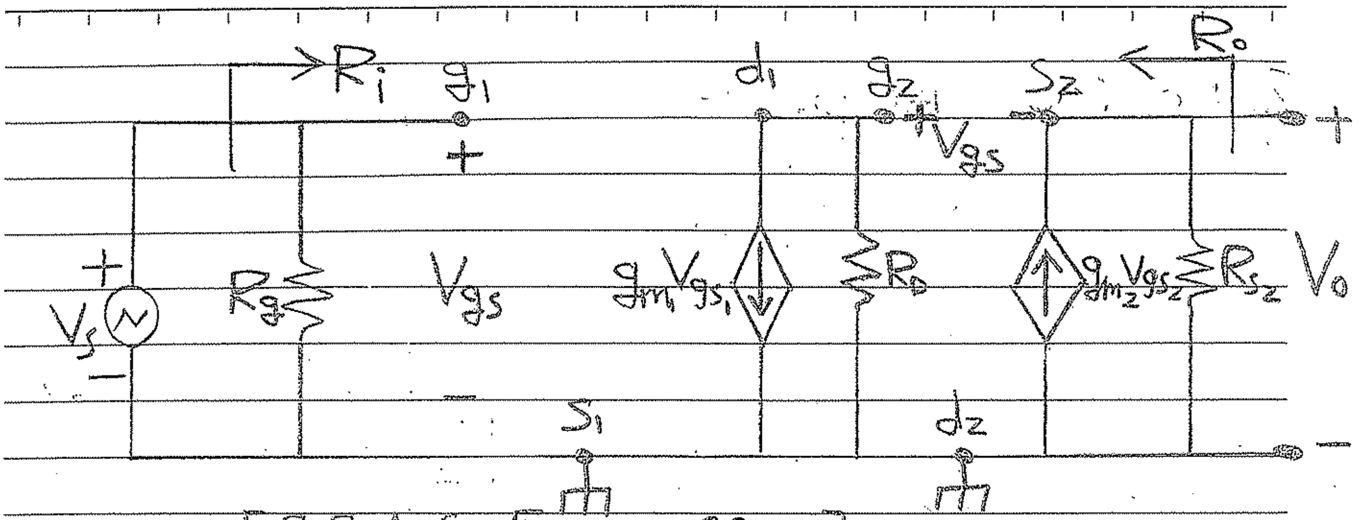
$V_{G_2} = V_{D_1} = 5 - (I_{D_1} * R_D)$

$V_{GS_2} = V_{TN} \pm \sqrt{\frac{I_{D_2}}{K_{n_2}}}$

#

2) For AC analysis :-





{S.S.A.C Eqnt. CCt.}

$R_i = R_{i_1} = R_g = R_1 // R_2$.

$R_o = R_{o_2} = \frac{1}{g_{m_2}} // R_{s_2}$.

$A_v = \frac{V_o}{V_{si}} = \underbrace{\frac{V_o}{V_{o_1}}}_{A_{v_2}} * \underbrace{\frac{V_{o1}}{V_{si}}}_{A_{v_1}}$

$\frac{V_o}{V_{o_1}} = \frac{g_{m_2} R_{s2}}{1 + (g_{m_2} R_{s_2})} = A_{v_2}$

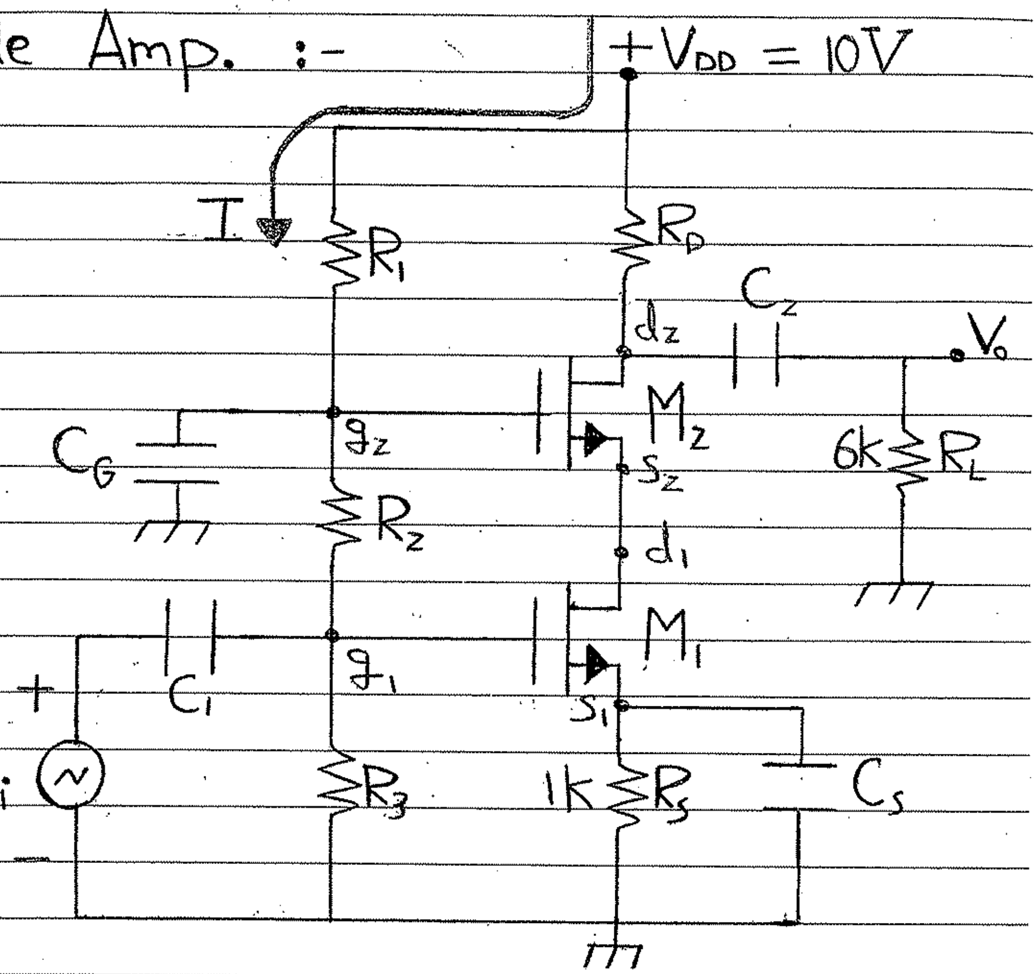
$\frac{V_{o1}}{V_{si}} = \frac{-g_{m1} V_{gs1} R_D}{V_{gs_1}} = -g_{m_1} R_D = A_{v_1}$

$\therefore A_v = \frac{-g_{m_1} R_D \cdot g_{m2} R_{s2}}{1 + g_{m_2} R_{s2}}$.

$R_{i_1} = R_g$. ; $R_{i2} = \infty$.

2] Cascode Amp. :-

EXA. :-



$K_{n_1} = K_{n_2} = 1 \frac{mA}{V^2}$

$V_{TN_1} = V_{TN_2} = 1V$

$\lambda_1 = \lambda_2 = 0$

1) Design the CCt. to have $I_D = 1mA$, $V_{DS_1} = V_{DS_2} = 3V$ and $I = 2\% \, I_D$.

2) Draw S.S.A.C Eqnt. CCt. and find: R_i, R_o, A_V.

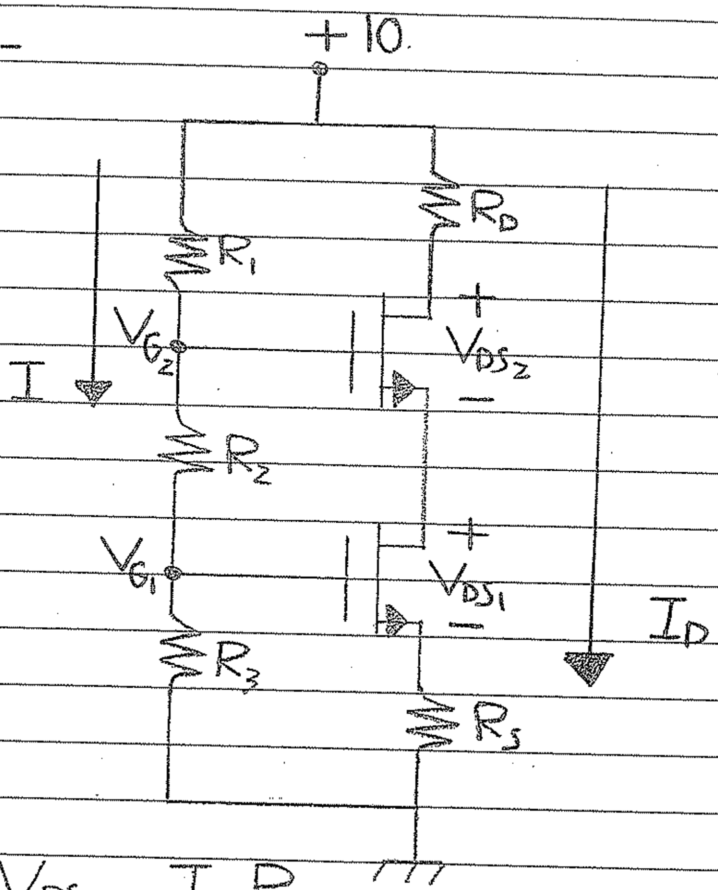
Sol.:

1) For D.C analysis :-

$I = 2\% \, I_D$

$= 2 * 1 / 100$

$= 0.02 \, mA.$



$$R_D = \frac{10 - V_{DS1} - V_{DS2} - I_D R_S}{I_D}$$

$$= \frac{10 - 7}{1m}$$

$$= 3k\Omega.$$

$$R_3 = \frac{V_{G1}}{I} , \quad R_2 = \frac{V_{G2} - V_{G1}}{I} , \quad R_1 = \frac{10 - V_{G2}}{I}$$

※ $V_{G1} = V_{GS1} + I_D R_S$

$= V_{GS1} + 1.$

$$V_{GS_1} = V_{TN} \pm \sqrt{\frac{I_D}{k_n}} = 1 \pm \sqrt{\frac{1}{1}} = 2V \checkmark \text{ or } 0V \times$$

$$\rightarrow V_{GS_1} = V_{GS_2} = 2V. \quad \therefore V_{G_1} = 2 + 1 = 3V.$$

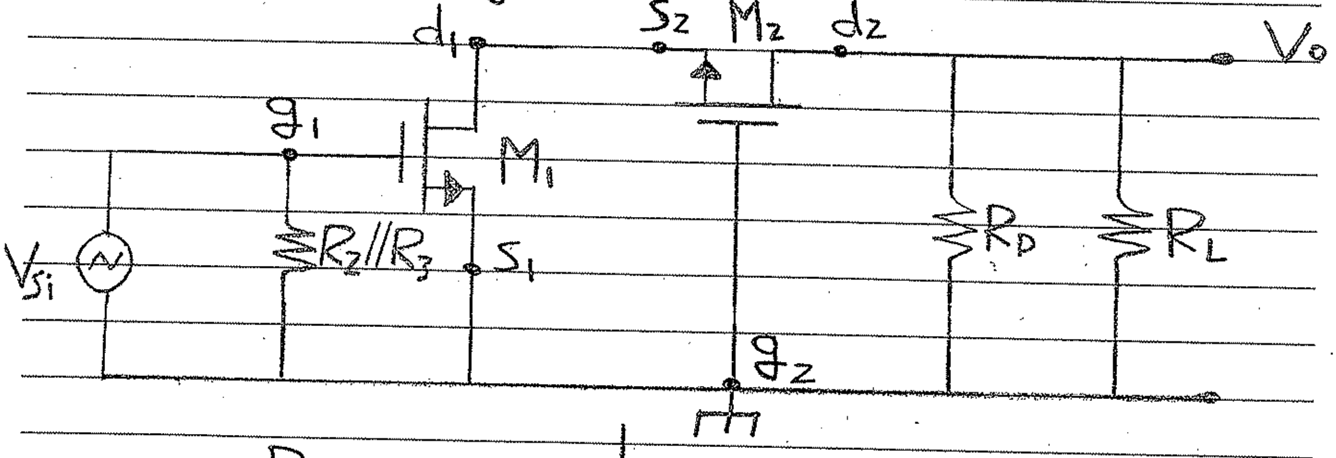
$$R_3 = \frac{3}{0.02} = 150\,k\Omega.$$

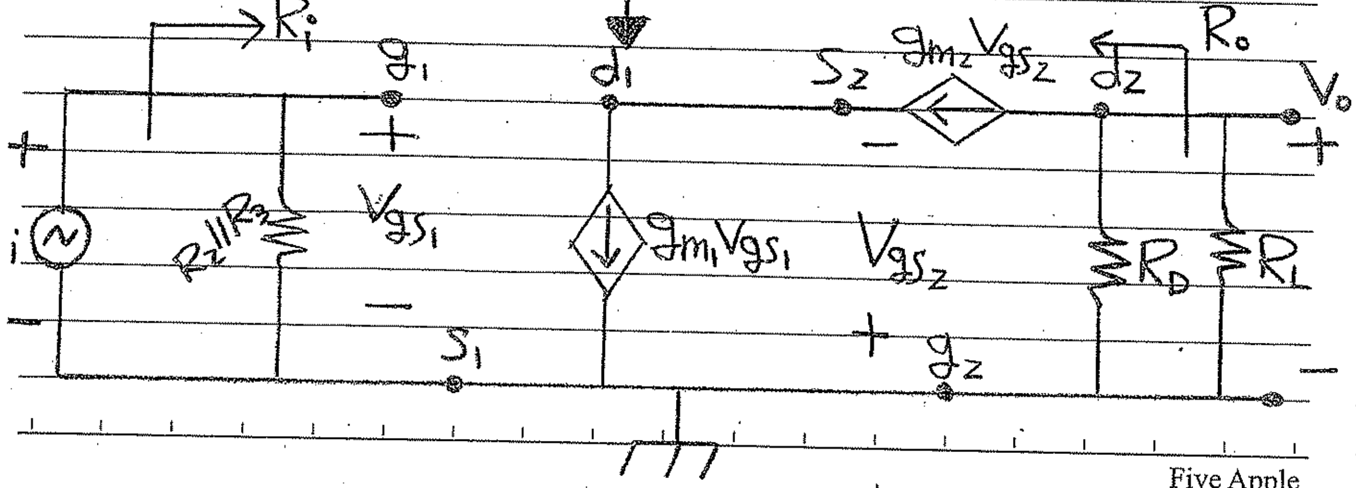
$$V_{G_2} = V_{GS_2} + V_{DS_1} + I_D R_S$$

$$= 2 + 3 + 1 = 6V.$$

$$R_2 = \frac{6-3}{0.02} = 15k\Omega. \; ; \; R_1 = \frac{10-6}{0.02} = 200k\Omega.$$

2) For AC analysis:-





$R_i = R_2 // R_3 = 75\ k\Omega.$

$R_o = R_D = 3k\Omega.$

$$A_v = \frac{V_o}{V_{si}} = \frac{V_o}{V_{gs_1}}$$

$$A_v = \frac{-g_m V_{gs1}(R_D // R_L)}{V_{gs_1}}$$

$$\boxed{A_v = -g_{m_1}(R_D // R_L)}$$

$\rightarrow A_v = -2\,(3//6)$

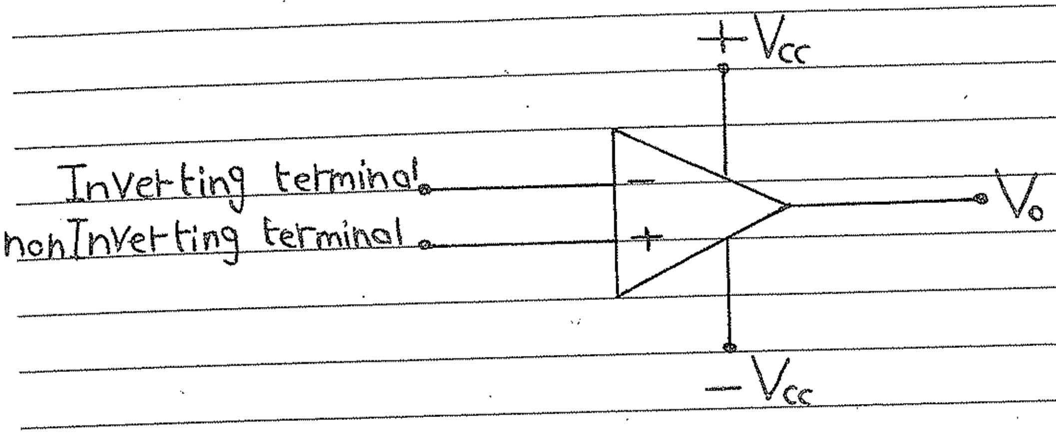
$= -4.$

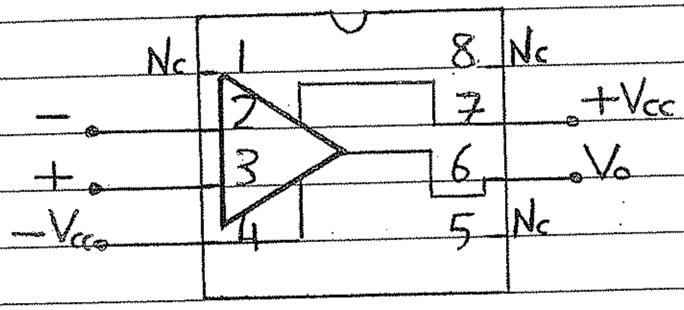
$g_{m_1} = 2\sqrt{1*1} = 2\ mA/V.$

$R_{o_1} = \infty.$

$$R_{i_2} = \frac{1}{g_{m2}}.$$

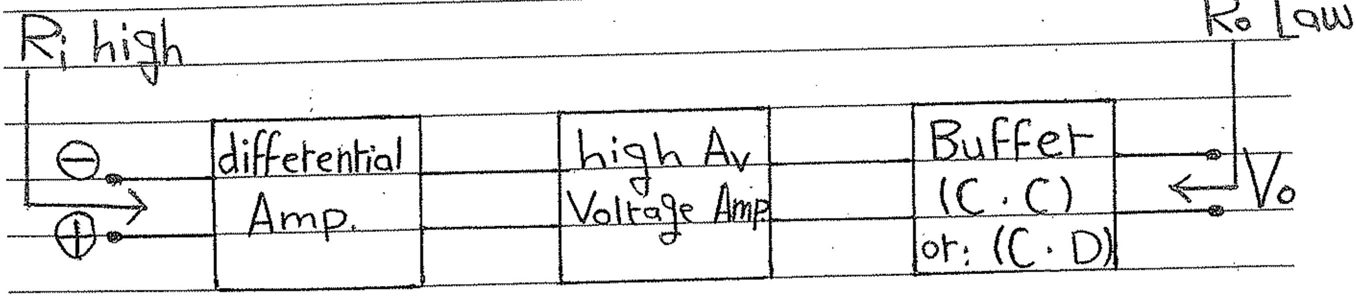
Chapter(13) :- Operational Amplifier :-
(OP- Amp.)





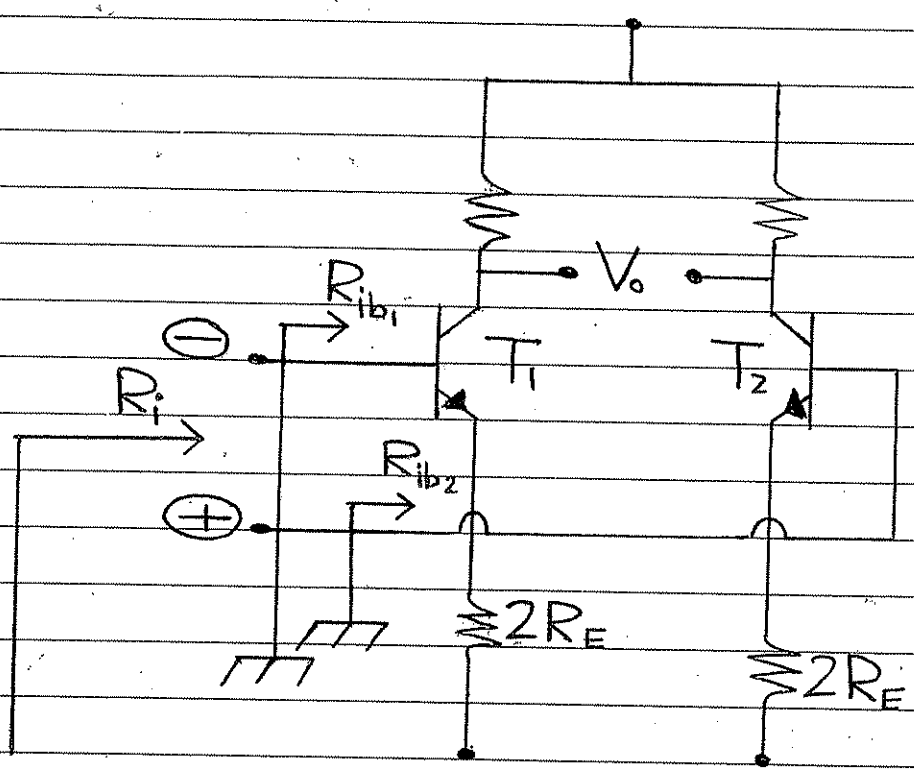
Nc : Not Connected

741



Block diagram for Simple OP - Amp.

1) [R_i high] : Why ?



$$R_{ib_1} = R_{ib_2} = (\beta+1)\,2R_E + r_\pi$$

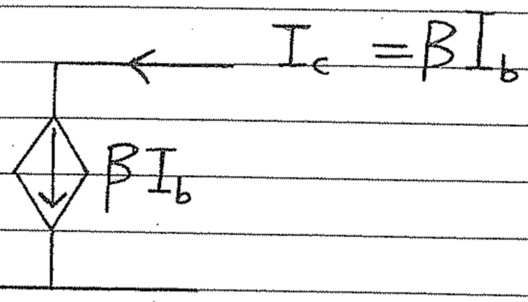
$$R_i = R_{ib_1} + R_{ib_2}$$

$$= 4(\beta+1)R_E + 2r_\pi$$

$\boxed{R_i \rightarrow \text{high}}$ #

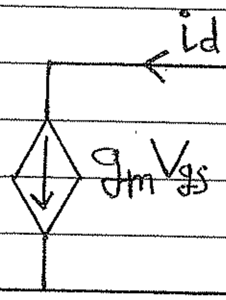
2) [A_v high] . #

BJT :



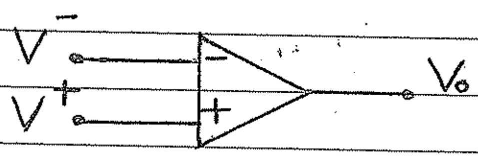
$\boxed{\text{Current - Controlled Current Source.}}$

FET :



$\boxed{\text{Voltage - Controlled Current Source.}}$

Op-Amp. :



$\boxed{\text{Voltage - Controlled Voltage Source.}}$

$$V_o = A(V^+ - V^-) \longrightarrow \boxed{V_o = AV_d}$$

V_d : differntial Voltage.

$$\boxed{V_d = V^+ - V^-}$$

OP - Amp. is very high gain multistage Voltage Amplifier.

Ideal C/C :-

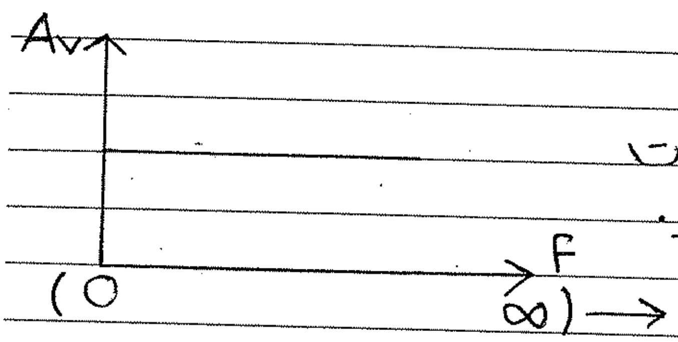
1) $A_o = \infty$

→ Open-loop Voltage gain.
(device without connection).

2) $R_{in} = \infty$. (biassing Current $I^+ = I^- = 0$)

3) $R_o = 0$.

4) Bandwidth (BW) $= \infty$.



* تكبر جميع الترددات بنفس المقدار.

5) Perfect balance :

$V_o = 0$ when $V^+ = V^-$

$V_o = A_o (V^+ - V^-)$.

NON Ideal C/C :- [Real op-Amp.]

		741 (BiPolar op-Amp.)	CA3140
1)	A_o	2×10^5	10^4
2)	R_i	2M Ω	10^6 MΩ
3)	R_o	60 Ω	
4)	Bw	1 MHz	5M
5)	V_{off}	10 μV	

V_{off} → Voltage offset.

مقدار الفولتية اللازمة وضعها على أحد أطراف الـ op.Amp. لتصبح ($V_o=0$).

\# الـ op.Amp الحديث مُصفر داخلياً.

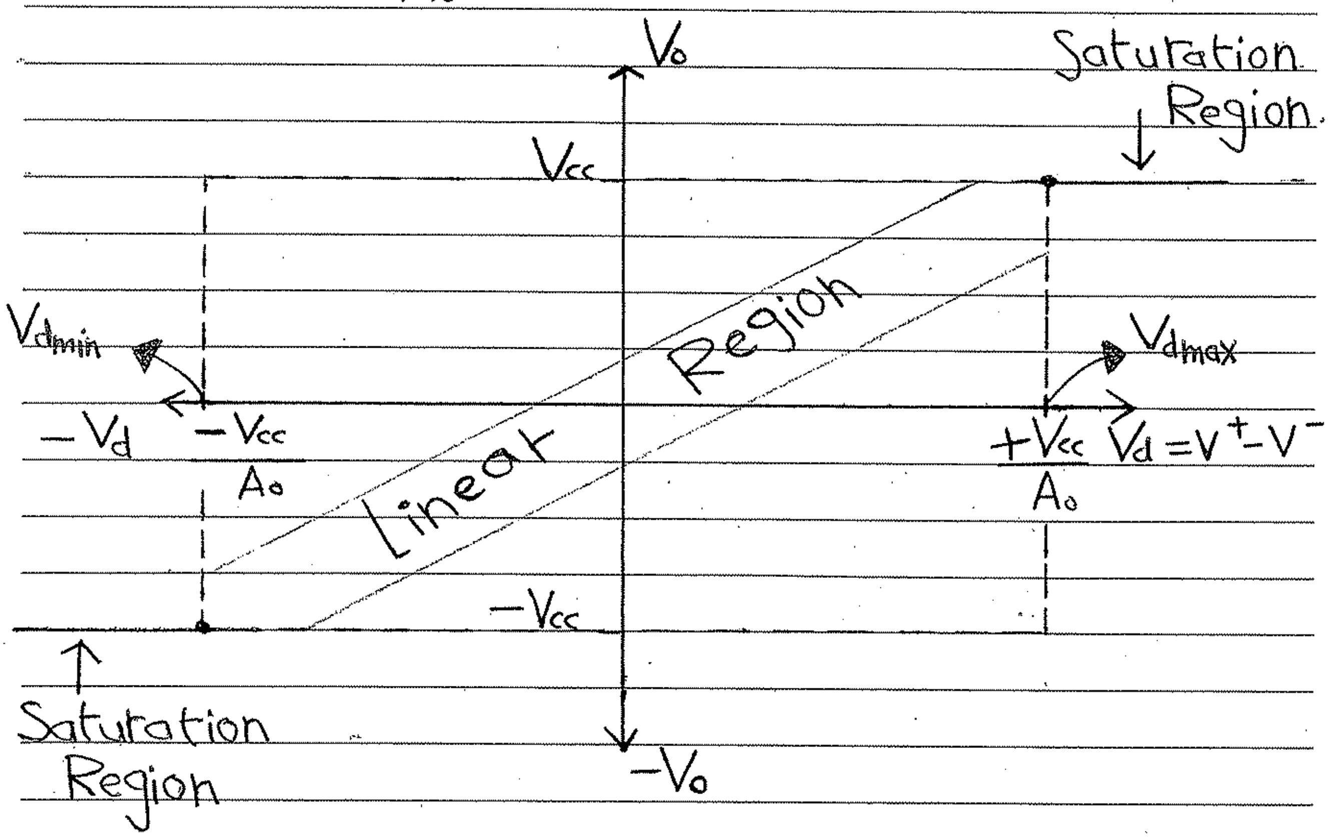
Transfer C/C :-

$$V_o = A_o(V^+ - V^-) = A_o \cdot V_d$$

$$V_{o_{max}} = \mp V_{cc}$$

$$= A_o \cdot V_d$$

$$\therefore V_{d_{max}} = \frac{\pm V_{cc}}{A_o}$$



Operating Regions :-

1) Linear Region :-

$V_o = A_o \cdot V_d$

$$\frac{-V_{cc}}{A_o} < V_d < \frac{+V_{cc}}{A_o}$$

2) Saturation Region :-

$V_o = \mp V_{cc}$

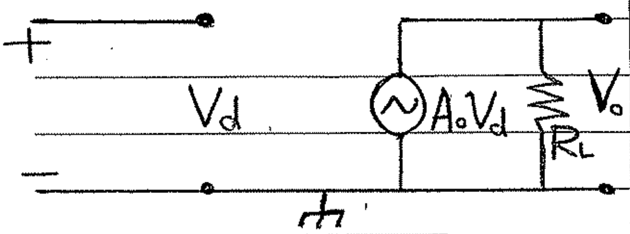
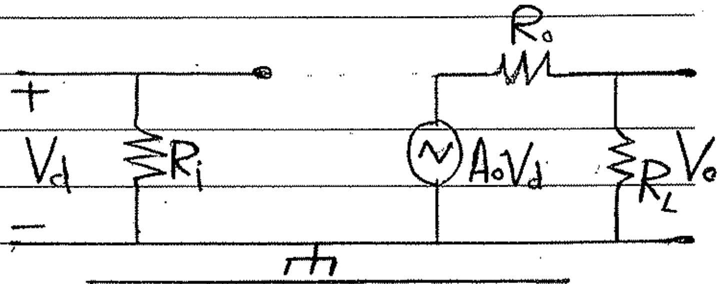
i] If $V_d > \frac{+V_{cc}}{A_o}$ then :-

$V_o = +V_{cc}$.

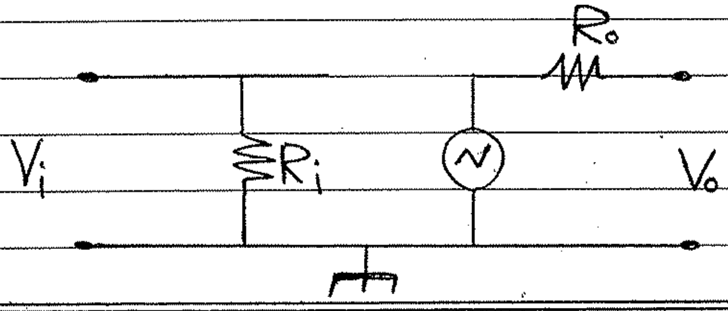
ii] If $V_d < \frac{-V_{cc}}{A_o}$ then :-

$V_o = -V_{cc}$.

✱ Eqnt. CCt. of OP-Amp. :-

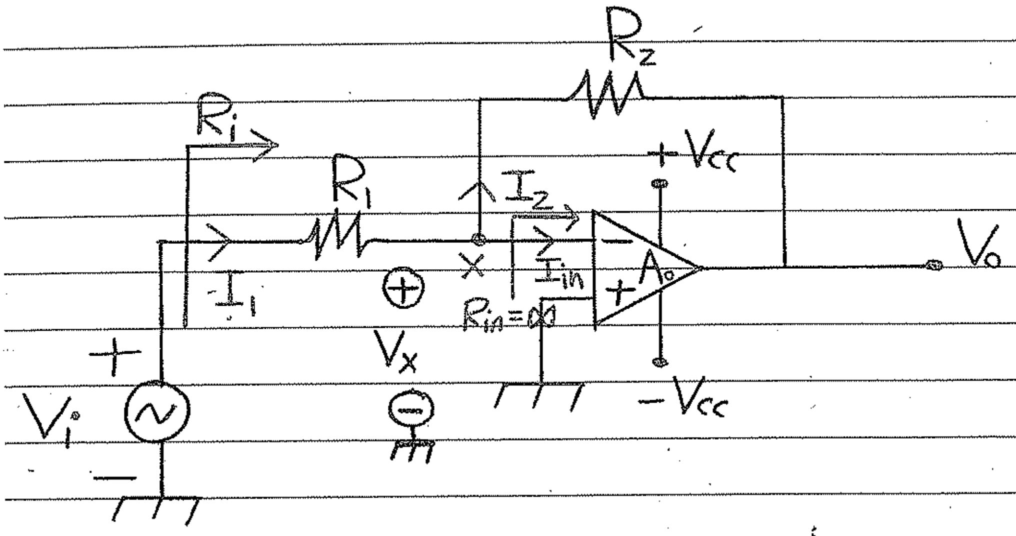
ideal	Real
	
$\boxed{V_o = A_o V_d}$	$\boxed{V_o = \frac{A_o \cdot V_d \, R_L}{R_L + R_o}}$
✱ V_o independant on R_L	✱ V_o depends on R_L.

Voltage Amp. In general:



Applications of op-Amp. :-

1) Inverting Amp. :-



A_o : Open loop cct.

KCL at node x :-

$$I_1 = I_2 + I_{in}$$

$$\frac{V_i - \cancel{V_x}^{\,0}}{R_1} = \frac{\cancel{V_x}^{\,0} - V_o}{R_2} + \cancel{I_{in}}^{\,0}$$

Assume Ideal op-Amp. :

→ $I_{in} = 0 \; (R_{in} = \infty)$.

→ $A_o = \infty$

$$V_o = A_o (V^+ - V^-) \quad \therefore V^+ - V^- = \frac{V_o}{A_o} = 0$$

$$V^+ = V^- = 0 \quad (\text{Virtual ground}).$$

$$V_x = V^- = V^+ = 0$$

$$\frac{V_i}{R_1} = -\frac{V_o}{R_2}$$

$$V_o = -\frac{R_2}{R_1} V_i$$

$$\frac{V_o}{V_i} = \boxed{A_v = -\frac{R_2}{R_1}}$$

$\hookrightarrow$ Closed Loop gain of the cct.

$$R_i = \frac{V_i}{I_1}$$; R_i for the cct.

$$\rightarrow -V_i + I_1 R_1 + V_x = 0$$

$$V_i = I_1 R_1$$

$$R_i = \frac{I_1 R_1}{I_1} \rightarrow \boxed{R_i = R_1}$$ #

EXA :-

1) Design an Inverting Amp. to have $A_v = -100$ and $R_i = 1\,k\Omega$.

2) Draw $V_o(t)$ when $V_{cc} = \mp 15\,V$ and V_i is : a) $0.1 \sin \omega t$ (V).

b) $0.2 \sin \omega t$ (V).

Sol.:

1) $R_i = R_1 = 1k\Omega$.

$$A_V = -\frac{R_2}{R_1} \Rightarrow -100 = -\frac{R_2}{1k} \Rightarrow R_2 = 100k\Omega.$$

2) a) $V_o = A_V \cdot V_i$ $\quad \boxed{A_V = \frac{V_o}{V_i}}$

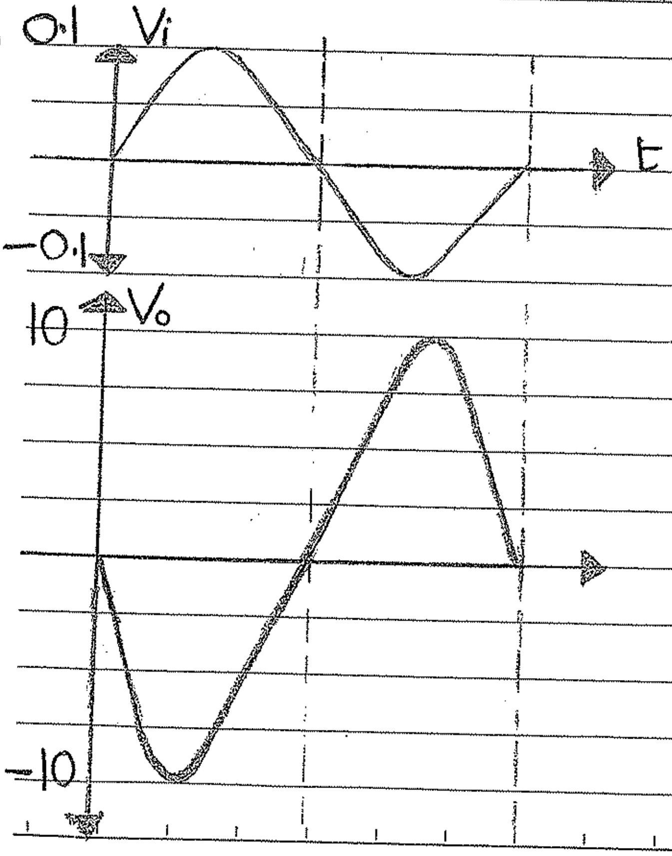
$= -100 \cdot (0.1 \sin \omega t)$

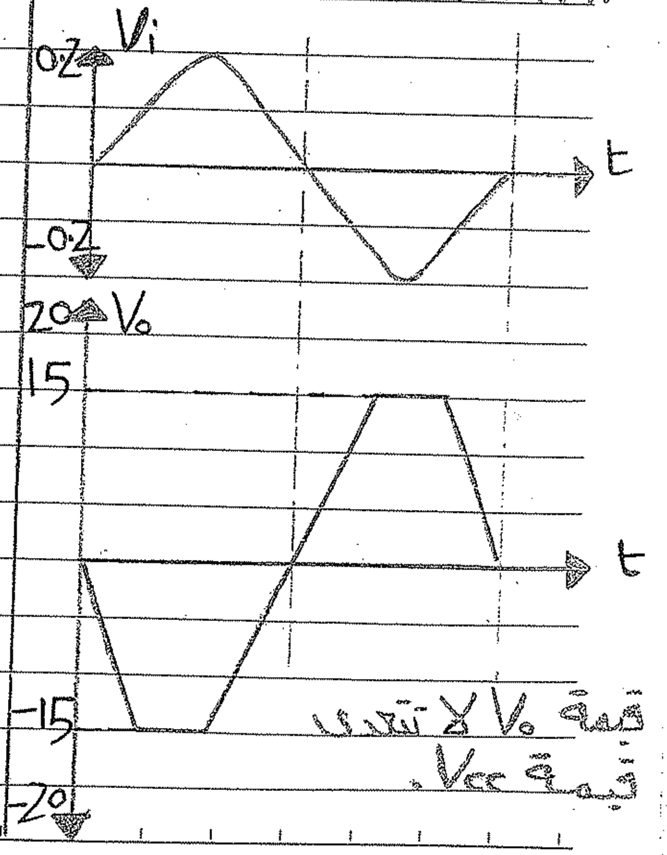
$= -10 \sin \omega t$ (V).

b) $V_o = A_V \cdot V_i$

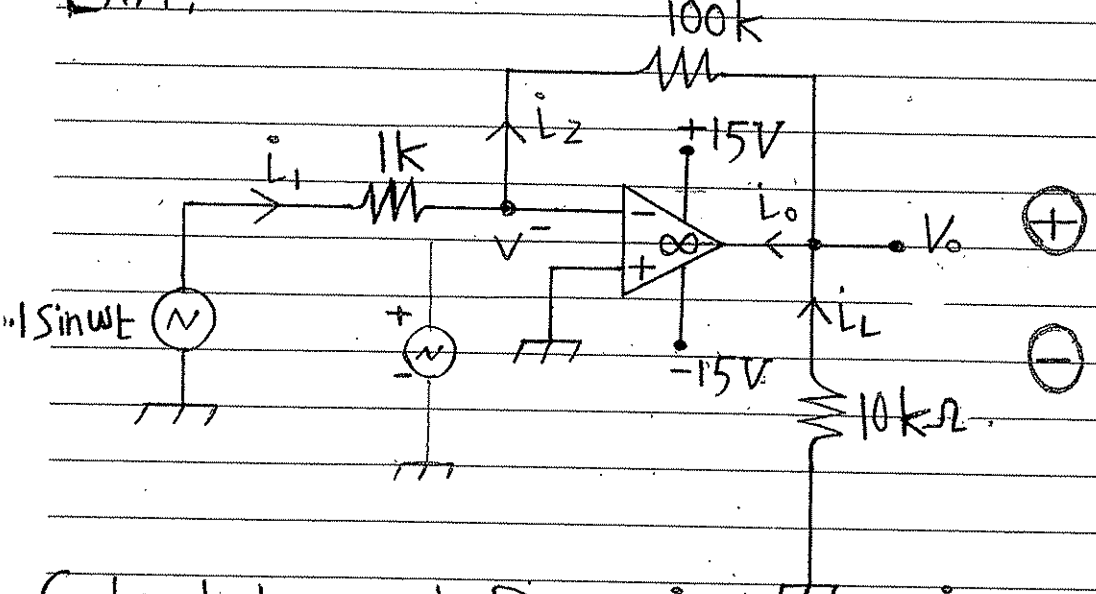
$= -100\,(0.2 \sin \omega t)$

$= -20 \sin \omega t$ (V).





EXA :-



Calculate and Draw i_1 , i_2 , i_L .

Sol. :-

$-V_i + i_1 R_1 + V^- = 0 \quad (V^- = V^+ = 0 \quad V.G)$

$i_1 = \frac{V_i}{R_1} = \frac{0.1 \text{ Sin wt } (V)}{1k} = 0.1 \text{ Sin wt mA}$. #

$i_1 = i_2 + \cancel{I_{in}}^{\,0}$

$i_1 = i_2 = 0.1 \text{ Sin wt mA}$. #

$V_o = -\frac{R_2}{R_1} V_i$

$= -\frac{100}{1} (0.1 \text{ Sin wt})$

$= -10 \text{ Sin wt } (V)$. #

$$i_L = \frac{0 - V_o}{R_L} = \frac{-(-10 \sin wt)}{10k} = 1 \sin wt \ (mA)$$ #.

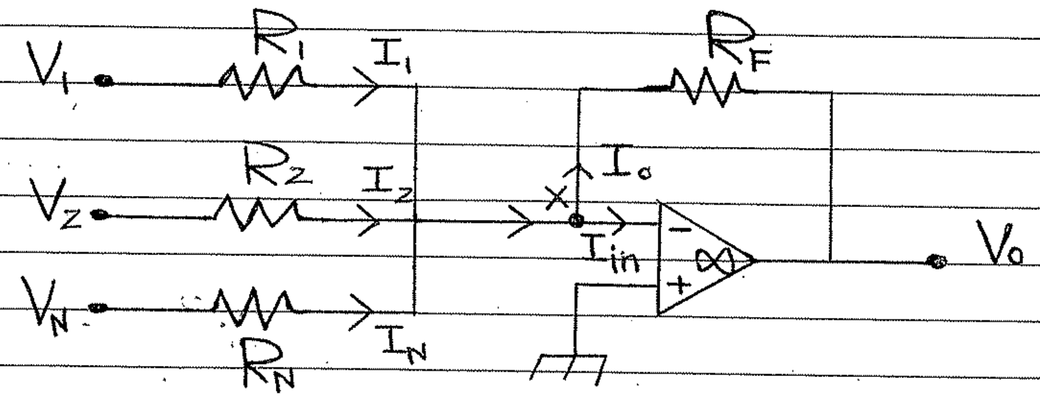
$$i_o = i_z + i_L = 1.1 \sin wt \ (mA).$$ #.

$\therefore$ Op_Amp. is Sink Current.

تسحب تيار

$* R_L \uparrow \ , \ i_L \downarrow \ , \ \underbrace{i_1 , i_z , V_o}_{\text{لا تتأثر}}$.

2) Inverting Summing Amp. :-



KCL at node X :-

$$I_1 + I_2 + \ldots I_N = I_o + I_{in}$$

$$\frac{V_1 - \cancel{V_x}^{\,0}}{R_1} + \frac{V_2 - \cancel{V_x}^{\,0}}{R_2} + \ldots \frac{V_N - \cancel{V_x}^{\,0}}{R_N} = \frac{\cancel{V_x}^{\,0} - V_o}{R_F} + \cancel{I_{in}}^{\,0}$$

But for ideal op_Amp. ;

$V_x = V^- = V^+ = 0$ (Virtual ground).

$I_{in} = 0$ $(R_i = \infty)$.

$$\rightarrow \frac{V_1}{R_1} + \frac{V_2}{R_2} + \ldots \frac{V_N}{R_N} = \frac{V_o}{R_F}$$

$$\therefore V_o = -\left(\frac{R_F}{R_1} V_1 + \frac{R_F}{R_2} V_2 + \ldots \frac{R_F}{R_N} V_N \right) \quad \#$$

Special Case : When $\boxed{R_1 = R_2 = R_N = R}$;

$$V_o = \frac{R_F}{R}\left(V_1 + V_2 + \dots V_N\right) \quad \#$$

※ $V_o = -(5V_1 + 10V_2 + 15V_3)$

$$\left[\frac{R_F}{R_1} = 5 \quad , \quad \frac{R_F}{R_2} = 10 \quad , \quad \frac{R_F}{R_3} = 15\right]$$

※ $V_o = -10\,(V_1 + V_2 + V_3)$

$$\left[\frac{R_F}{R_1} = \frac{R_F}{R_2} = \frac{R_F}{R_3} = \frac{R_F}{R} = -10\right]$$

$\boxed{\text{Singnals can be D.C or A.C}}$

{دع ابتسامتك اول ملامحك ؛ فهي لك صحة وفي الدين
صدقة وفي القلب سعادة .}

EXA.: For the CCt. Shown ;

$R_1 = 1k$, $R_2 = 2k$, $R_3 = 3k$; $R_F = 6k\Omega$

$V_1 = 1 V$ d.c

$V_2 = -2 V$ d.c

$V_3 = 2 \sin \omega t \ (V)$.

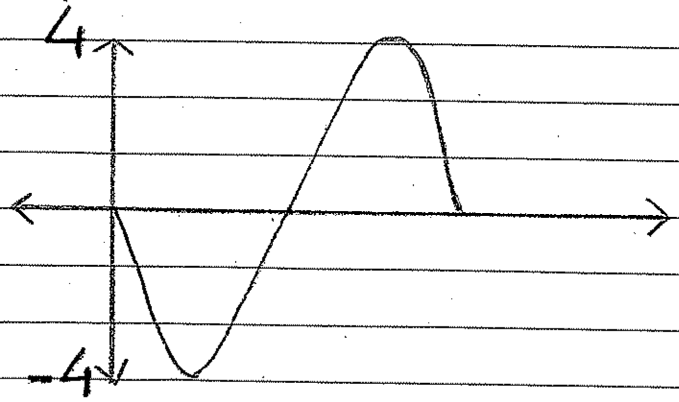
Calculate and Draw V_o ?

Sol.

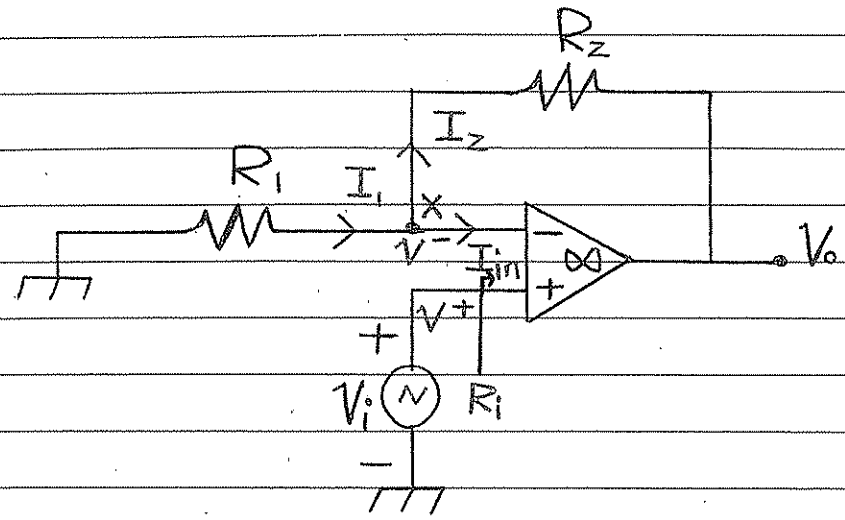
$$V_o = -\left(\frac{R_F}{R_1} V_1 + \frac{R_F}{R_2} V_2 + \frac{R_F}{R_3} V_3\right)$$

$$= -\left[\frac{6}{1}(1) + \frac{6}{2}(-2) + \frac{6}{3}(2\sin \omega t)\right]$$

$$= -\cancel{6} + \cancel{6} - 4\sin \omega t \ (V).$$



3) NON Inverting Amp. :-



At node X :-

$$I_1 = I_2 + I_{in}$$

$$\frac{0 - \cancel{V_x}^{V_i}}{R_1} = \frac{\cancel{V_x}^{V_i} - V_o}{R_2} + \cancel{I_{in}}^{0}$$

But for Ideal OP-Amp. :-

$$I_{in} = 0 \ (R_i = \infty)$$

$$V^+ = V^- = V_x = V_i \quad \text{(Virtual Short)}.$$

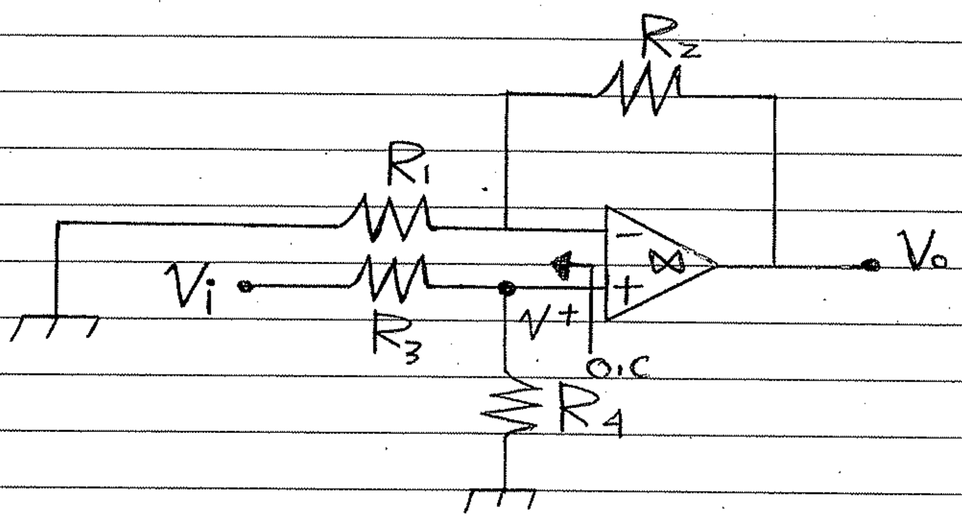
$$\frac{V_o}{R_2} = \frac{V_i}{R_1} + \frac{V_i}{R_2}$$

$$V_o = \left(1 + \frac{R_2}{R_1}\right) V_i$$

$$\frac{V_o}{V_i} = A_V = 1 + \frac{R_2}{R_1} \quad \#.$$

\# Close loop Voltage gain.

$R_i = \infty$.



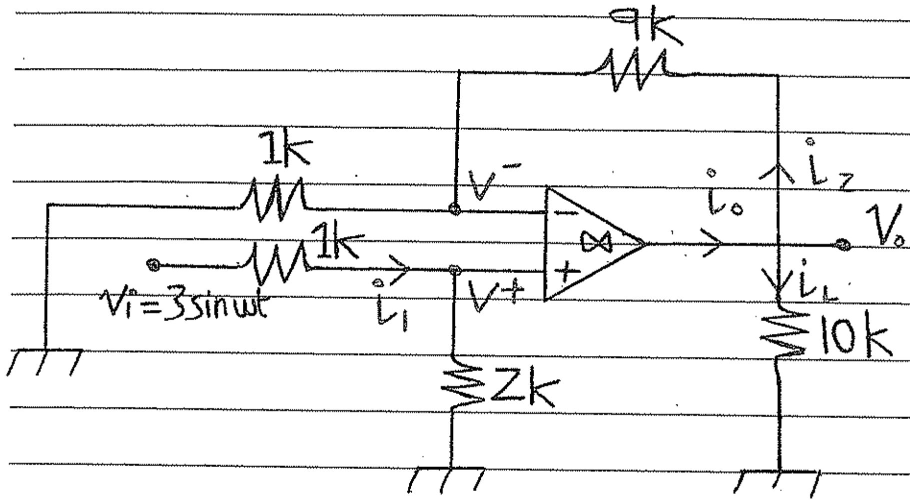
$$V_o = \left(1 + \frac{R_2}{R_1}\right) V^+$$

$$V^+ = V_i \frac{R_4}{R_4 + R_3}$$

$$V_o = \left(1 + \frac{R_2}{R_1}\right) V_i \frac{R_4}{R_3 + R_4}$$

$$\frac{V_o}{V_i} = A_V = \left(1 + \frac{R_2}{R_1}\right) \frac{R_4}{R_3 + R_4} \quad \#.$$

EXA. :- Assume ideal Op-Amp. :-



Calculate and Draw $V_o(t)$, $i_o(t)$, $i_L(t)$, $i_1(t)$, $i_2(t)$.

Sol. :- $V_o = \left(1 + \frac{9}{1}\right) V^+$

$V^+ = V_i \times \frac{2}{1+2} = \frac{2}{3} V_i$

$V^+ = \frac{2}{3}(3 \sin \omega t)$

$V^+ = 2 \sin \omega t \ (V)$.

$\therefore V_o = 10(2 \sin \omega t) = 20 \sin \omega t \ (V)$.

$i_L = \frac{V_o}{R_L} = 2 \sin \omega t \ (mA)$.

$i_2 = \frac{V_o}{9+1} = 2 \sin \omega t \ (mA)$.

$i_o = i_2 + i_L$

$= 2\sin(\omega t) + 2\sin(\omega t) = 4\sin \omega t \ (mA).$

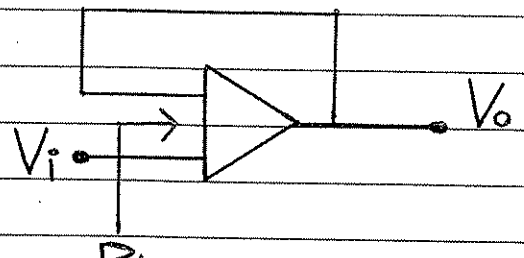
$i_1 = \frac{V_i}{1+2} = \sin \omega t \ (mA).$ #

OP-Amp $\longrightarrow$ Source Current.

4) Voltage - Follower

[Buffer] :-

* Special case of non-Inverting Amp. :

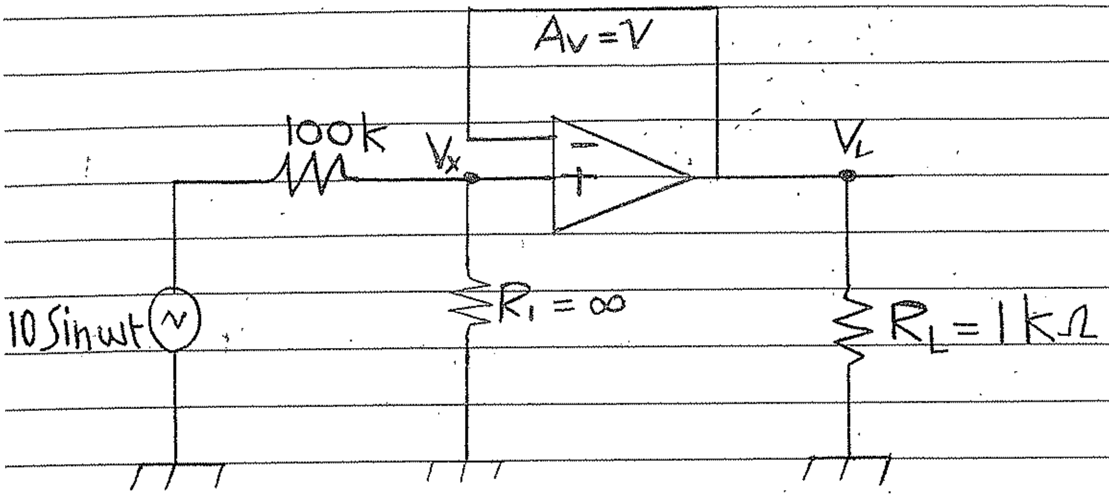


$A_V = \frac{V_o}{V_i} = 1 + \frac{\cancel{R_2}^{\,0}}{R_1} = 1$

$V_o = V_i$

$A_V = 1$, $\theta = 0^\circ$, $R_i = \infty$, $R_o = 0$.

#



$$V_L = 10 \frac{1}{100+1} = 0.1 \sin \omega t \ (V).$$

$\boxed{\text{Sever loading effect}}$.

To solve this problem ; we use Buffer :-

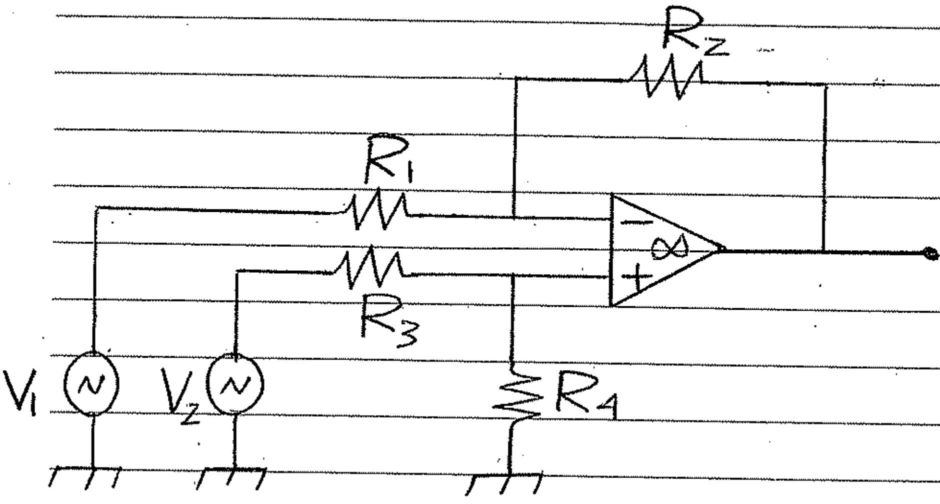
$$V_x = V_i \cdot \frac{R_{in}}{R_{in}+R_s} \simeq V_i$$

$V_x = V_L = V_i = 10 \sin \omega t \ (V)$. $\boxed{\text{No Loading}}$.

So, The main usage of Buffer to Cancel Loading Effect.

※ Buffer better than Common Collector.

5) Difference Amp. :-

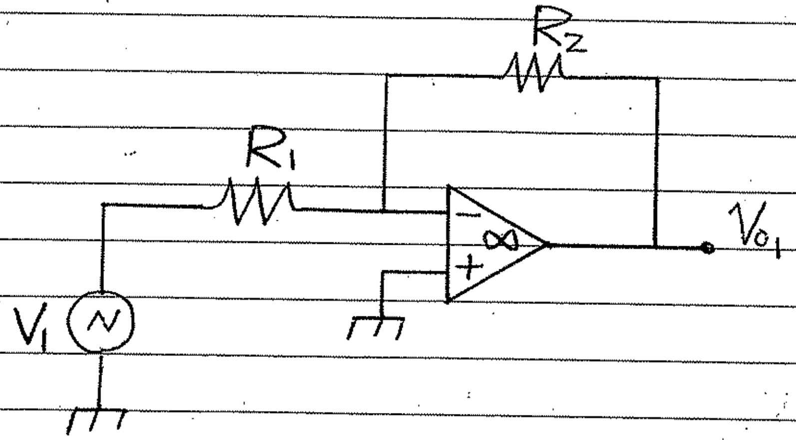


$V_o = A_v (V_2 - V_1)$.

By using Superposition principle :-

1) Effect of V_1 ($V_2 = 0$) :-

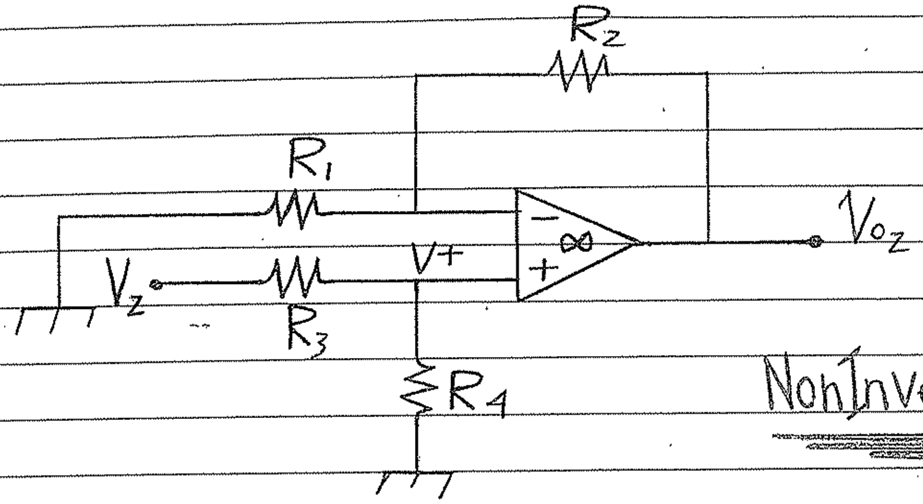
When $V_2 = 0$ (Short cct.) , $V^+ = 0 \cdot \frac{R_4}{R_4 + R_3} = 0$



Inverting

$$\boxed{V_{o_1} = -\frac{R_2}{R_1} V_1}$$

2) Effect of V_2 ($V_1 = 0$) :-



Non Inverting

$$V_{o2} = \left(1 + \frac{R_2}{R_1}\right) V^+ \quad ; \quad V^+ = V_2 \cdot \frac{R_4}{R_3 + R_4}$$

$$V_{o2} = \left(1 + \frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3 + R_4}\right) V_2 \quad \#$$

$$V_o = V_{o1} + V_{o2}$$

$$= \left(1 + \frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3 + R_4}\right) V_2 - \frac{R_2}{R_1} V_1$$

$$= \left(1 + \frac{R_2}{R_1}\right)\left(\frac{\frac{R_4}{R_3}}{1 + \frac{R_4}{R_3}}\right) V_2 - \frac{R_2}{R_1} V_1$$

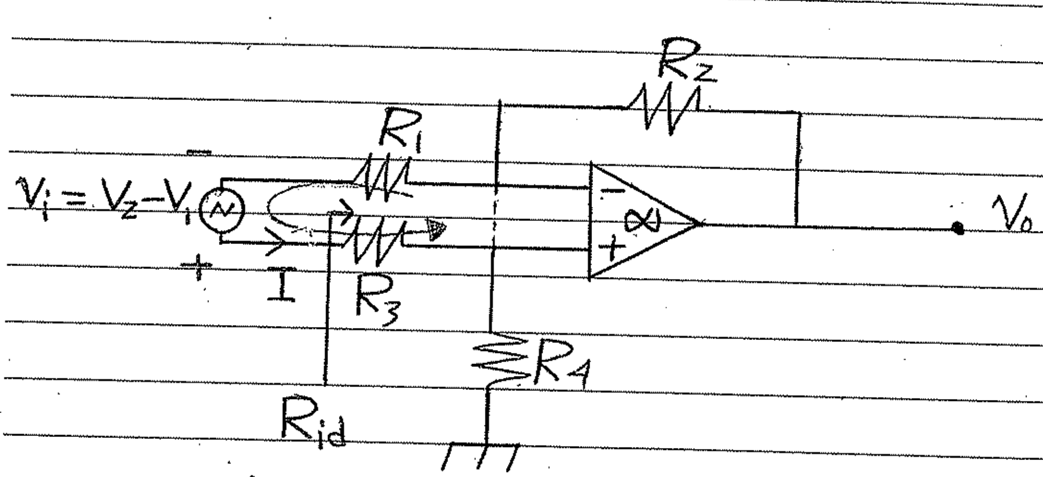
Choose $\frac{R_4}{R_3} = \frac{R_2}{R_1}$, then :

$$V_o = \cancel{\left(1 + \frac{R_2}{R_1}\right)}\left(\frac{\frac{R_2}{R_1}}{\cancel{1+\frac{R_2}{R_1}}}\right) V_2 - \frac{R_2}{R_1} V_1$$

$$= \frac{R_2}{R_1} V_2 - \frac{R_2}{R_1} V_1$$

$$= \frac{R_2}{R_1} \left(V_2 - V_1 \right).$$

$$\therefore A_{vd} = \frac{V_o}{V_2 - V_1} = \frac{R_2}{R_1} \quad \#$$



$$R_{id} = \frac{V_i}{I}$$

$$-V_i + IR_3 + IR_1 = 0$$

$$V_i = I(R_3 + R_1)$$

$$\frac{V_i}{I} - R_3 + R_1 = R_{id}. \quad \#$$

EXA.: Design a Difference Amp. to have

$R_i = 20\,k\Omega$. $A_{vd} = 50$.

Sol.

$$A_{vd} = \frac{R_2}{R_1} = \frac{R_4}{R_3}$$

$$R_{id} = R_1 + R_3$$

Choose $R_1 = R_3$, $R_2 = R_4$; Then:

$$R_{id} = 2R_1 = 2R_3$$

$$\therefore R_1 = R_3 = \frac{20}{2} = 10\,k\Omega$$

$$50 = \frac{R_2}{10} \longrightarrow R_2 = 500\,k\Omega$$

$$R_4 = R_2 = 500\,k\Omega$$ #

إذا كانت قيمة

R_i عالية

أو A_{vd} عالية

أو كلاهما عالي

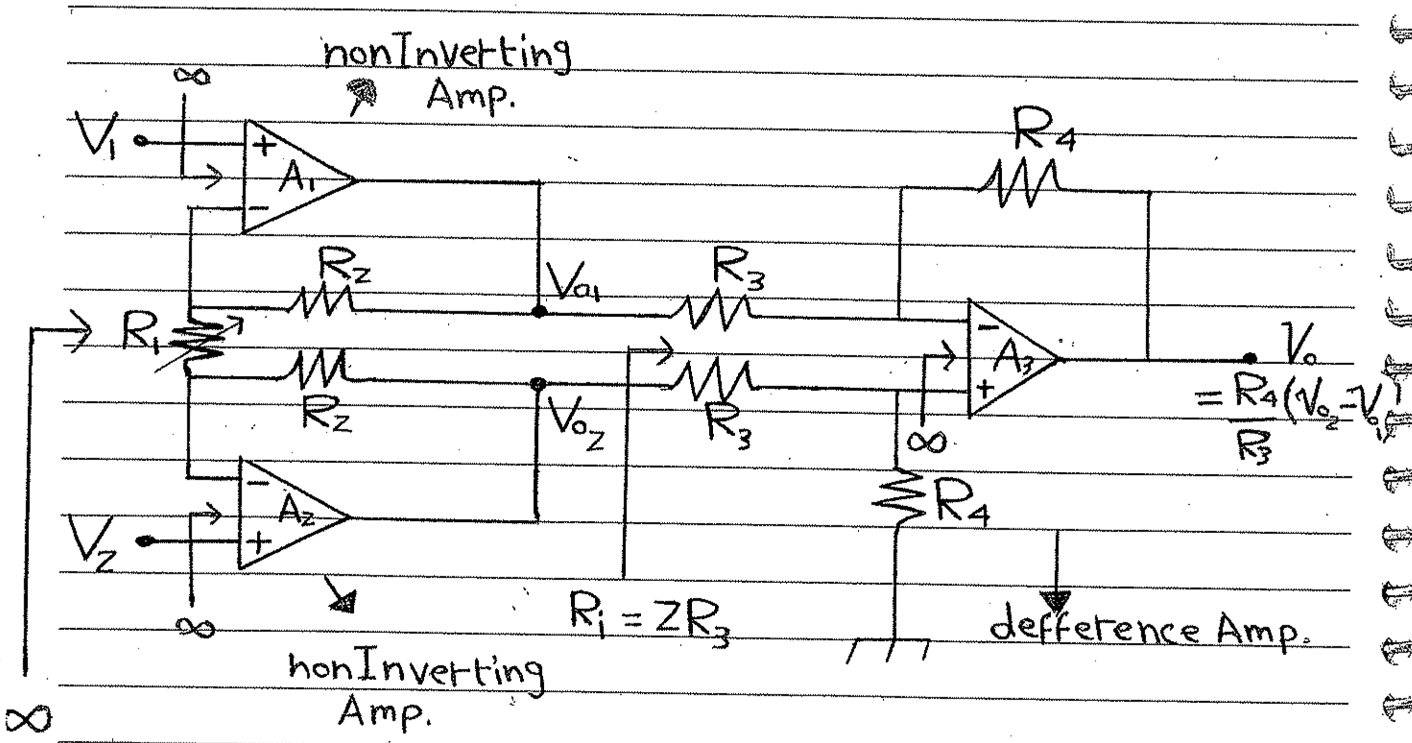
يجب أن نقبل بقيم عالية جداً لـ R_4 و R_3 ،

وهذا غير مرغوب في عملية الـ Design .

الـ Design يتطلب استخدام مقاومات ذات ابعاد جيدة ليست عالية ولا قليلة . [$k\Omega$ مناسبة] .

لحل مشكلة القيم العالية لـ R_3, R_4 :-

6) Instrumentation Amp. :-



* Instrumentation Amp. used to achieve high Input Resistance ; high, adjustable Single element dependant gain using resonable Values of Resistors.

A_3 : Defference Amp.

A_1 & A_2 : Non Inverting Amp.

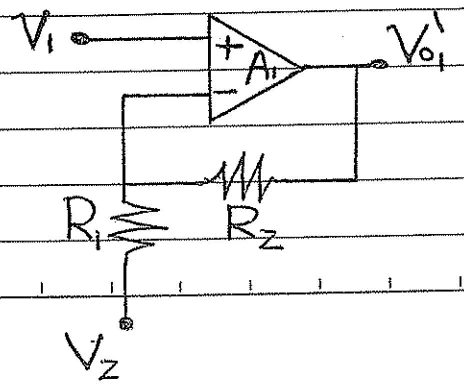
$$V_o = \frac{R_4}{R_3}\left(V_{o_2} - V_{o_1}\right)$$

V_{o_1} ?

Using Supperposition :-

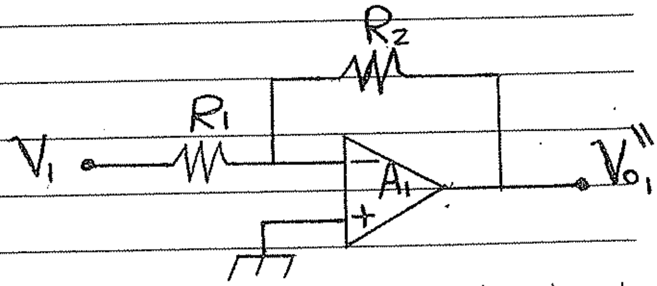
1) Effect of V_1 ($V_2 = 0$):

$$V_{o_1}' = \left(1 + \frac{R_2}{R_1}\right)V_1$$



2) Effect of V_2 ($V_1 = 0$):

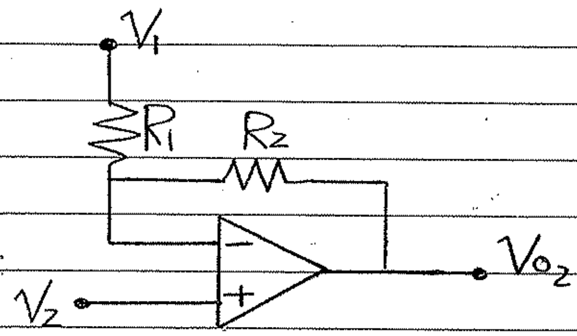
$$V_{o_1}'' = -\frac{R_2}{R_1}V_2$$



$$V_{o_1} = V_{o_1}' + V_{o_1}''$$

$$\boxed{V_{o_1} = \left(1 + \frac{R_2}{R_1}\right) V_1 - \frac{R_2}{R_1} V_2}$$

V_{o_2} ?



$$\boxed{V_{o_2} = \left(1 + \frac{R_2}{R_1}\right) V_2 - \frac{R_2}{R_1} V_1}$$

$$V_o = \frac{R_4}{R_3}\left[\left(1 + \frac{R_2}{R_1}\right)V_2 - \frac{R_2}{R_1}V_1 - \left(\left(1+\frac{R_2}{R_1}\right)V_1 - \frac{R_2}{R_1}V_2\right)\right]$$

$$V_o = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{R_1}\right)(V_2 - V_1)$$

$V_o = A_{dI}(V_2 - V_1)$; where:

$$A_{dI} = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{R_1}\right)$$

$$R_{i_3} = 2R_3$$

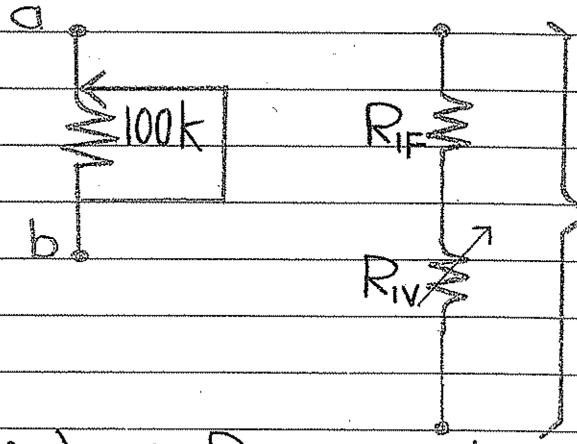
EXA.:- Design an Instrumentation Amp. to have a gain ranging from $(5 \rightarrow 500)$, The max. available Resistance is $100\,k\Omega$.

Sol.

$$A_{dI} = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{R_1}\right)$$

Choose R_1 to be Variable Resistance.

$\boxed{\text{If } R_1 = 0 \rightarrow A_{dI} \Rightarrow \infty \rightarrow \text{OP-Amp. In Saturation.}}$



$R_1 = R_{1F} + R_{1V}$

$A_{dI}(\min) \rightarrow R_1 \max$

$A_{dI}(\max) \rightarrow R_1 \min$

Choose R_{1V} to be $100\,k\Omega$ potentiometer.

$R_{1\,min} = R_{1F}$

$R_{1\,max} = R_{1F} + 100$

$$5 = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{R_1}\right) \quad \text{---} \; 1$$

$$500 = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{R_1}\right) \quad \text{---} \; 2$$

let $\frac{R_4}{R_3} = 2$

نختار رقم اقل من (5) ولا تكون عنده قيمة $1 + \frac{2R_2}{R_1}$ تساوي صفر أو سالبة .

From 1 :

$$5 = 2\left(1 + \frac{2R_2}{100 + R_{1F}}\right)$$

$$1.5 = \frac{2R_2}{100 + R_{1F}} \longrightarrow 2R_2 = 150 + 1.5R_{1F} \quad \text{---} \; 3$$

From 2 :

$$500 = 2\left(1 + \frac{2R_2}{R_{1F}}\right)$$

$$249 = \frac{2R_2}{R_{1F}} \longrightarrow 2R_2 = 249R_{1F} \quad \text{----} \; 4$$

Equate 3 & 4 :-

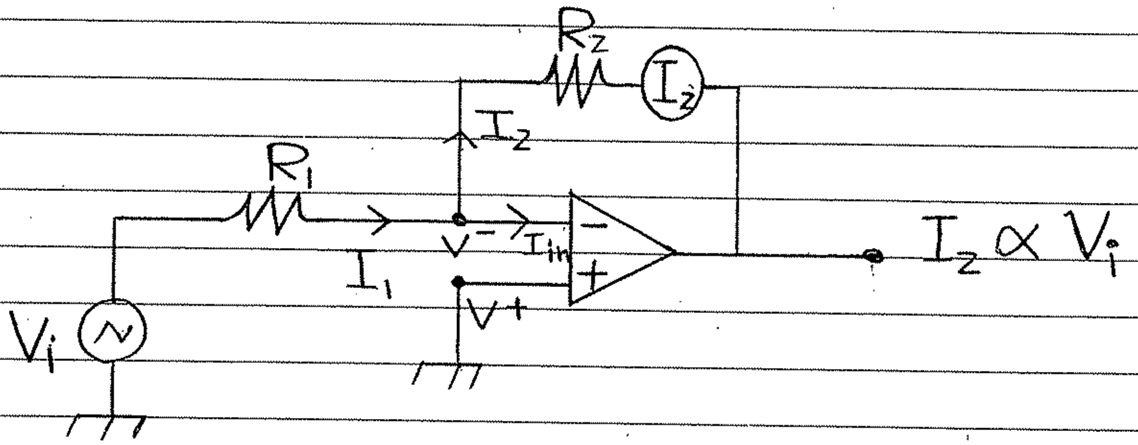
$$249 R_{1F} = 150 + 1.5 R_{1F}$$

$$247.5 R_{1F} = 150 \longrightarrow R_{1F} = 0.61 k\Omega.$$

from 4 : $R_2 = \frac{249 \times 0.61}{2} = 74.5 k\Omega.$

$\frac{R_4}{R_3} = 2 \rightarrow$ Choose $R_3 = 1k\Omega$, then $R_4 = 2k\Omega$.

7) Voltage -to- Current Converter :-



$$I_1 = I_{in} + I_2$$

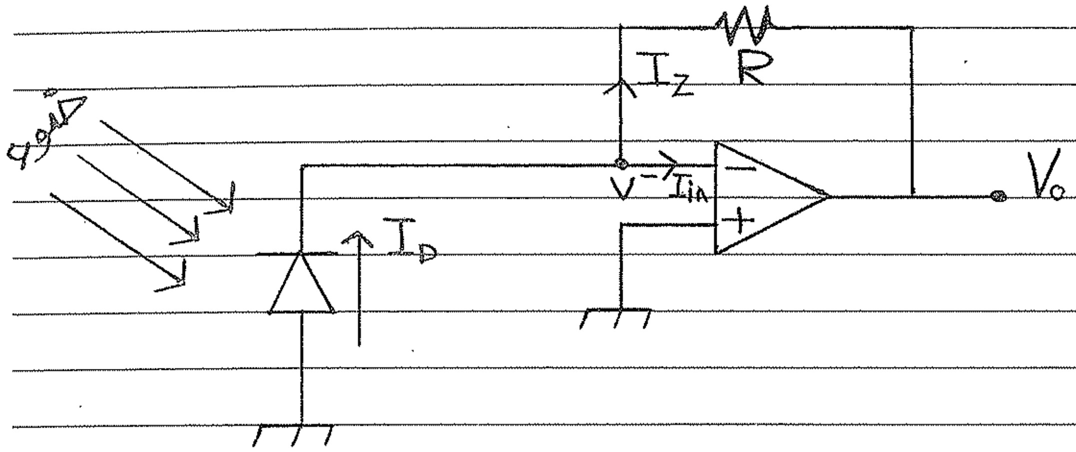
$$\frac{V_i - \cancel{V^-}^{\,0}}{R_1} = \cancel{I_{in}}^{\,0} + I_2$$

$V^- = V^+ = 0$ (Virtual ground)
$I_{in} = 0$
} Ideal OP-Amp

$$\frac{V_i}{R_1} = I_2$$

i.e I_2 is proportional to V_i and propor-tional constant is $\frac{1}{R_1}$.

8) Current-to-Voltage Converter :



$$I_D = I_{in} + I_Z$$

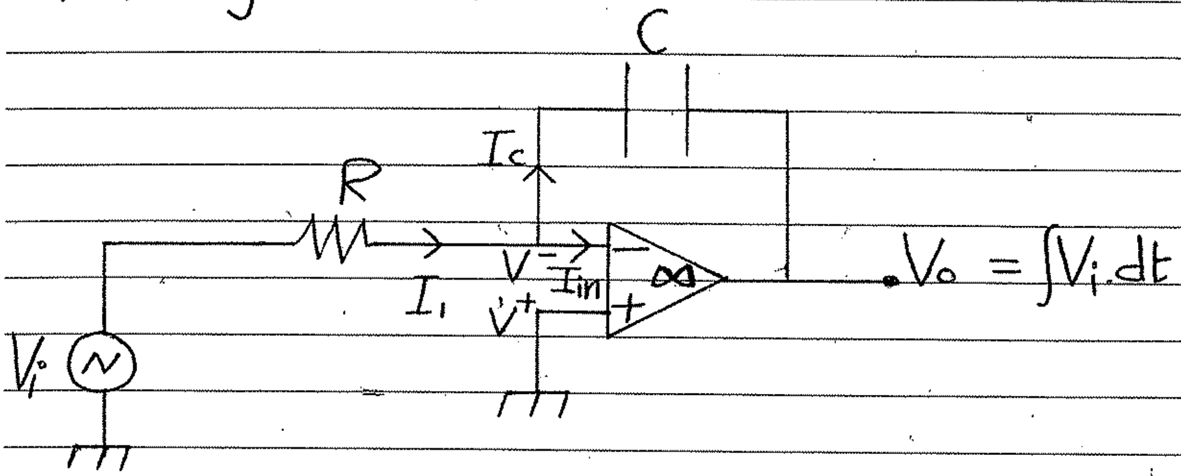
$$= \cancel{I_{in}}^{0} + \frac{\cancel{V^-}^{0} - V_o}{R}$$

$$V_o = -I_D R$$

$$V_o \propto I_D$$

i.e V_o is proportional to I_D and proportional Costant is $-R$.

9) Integrator :-



$$I_1 = I_c + I_{in}$$

$$\frac{V_i - \cancelto{0}{V^-}}{R} = C\frac{dV_c}{dt} + \cancelto{0}{I_{in}}$$

$$\# \; V_c = \cancelto{0}{V^-} - V_o$$

$V^- = V^+ = 0$ (Virtual ground).

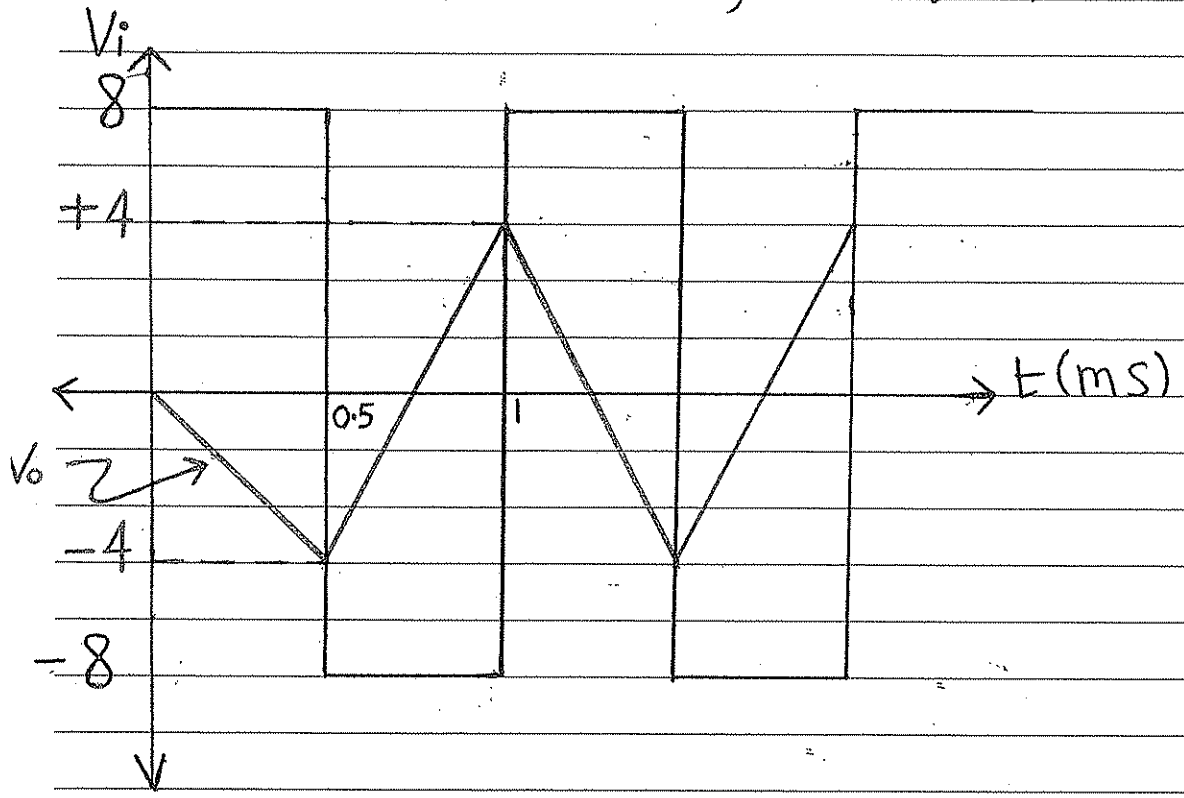
$I_{in} = 0$ $(R_i = \infty)$

$$\rightarrow \frac{V_i}{R} = -C\frac{dV_o}{dt}$$

$$\int dV_o = \int -\frac{V_i}{RC} . dt$$

$$\boxed{V_o = -\frac{1}{RC}\int V_i . dt}$$

EXA.: For $R = 1k\Omega$, $C = 1\mu F$



1) $t: (0 \longrightarrow 0.5)$ ms , $V_i = 8V$.

$$V_o = \frac{1}{10^3 \times 10^{-6}} \cdot 8t \Big]_0^{0.5ms}$$

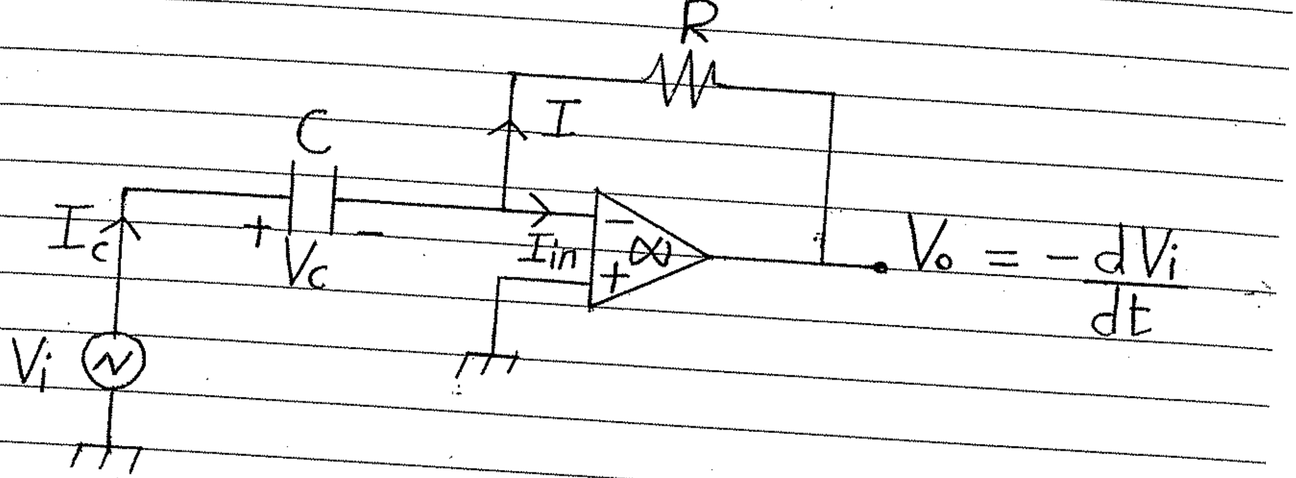
$$= -10^3 (8 \times 0.5) \times 10^{-3} = -4V.$$

2) $t: (0.5 \longrightarrow 1)$ ms , $V_i = -8V$.

$$V_o = \frac{1}{10^3 \times 10^{-6}} \int -8\, dt = -10^3 \cdot 8t \Big]_{0.5}^{1ms}$$

$$= +4V.$$

10) Differentiator :-



$$I_c = I + I_{in}$$

$$C\frac{dV_c}{dt} = \frac{\cancel{V^-}^{\,0} - V_o}{R} + \cancel{I_{in}}^{\,0}$$

$$V_c = V_i - \cancel{V^-}^{\,0}$$

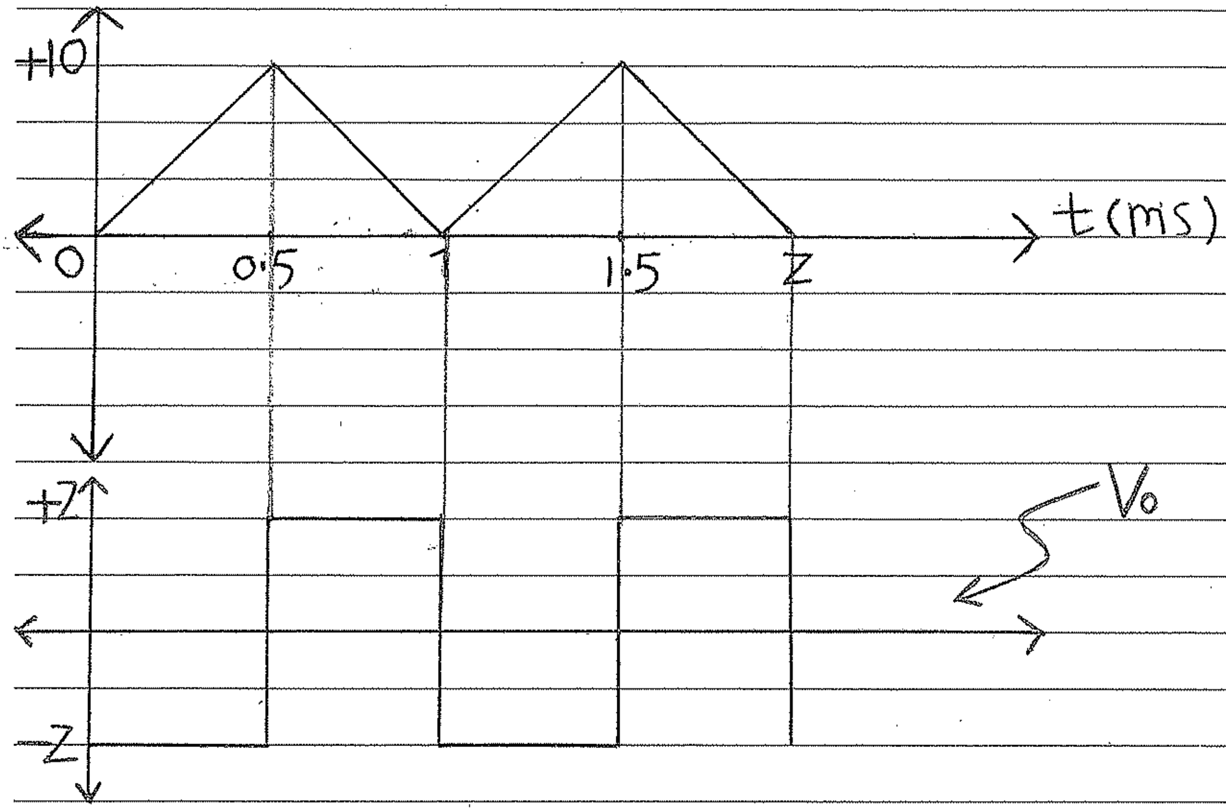
$$V^- = V^+ = 0 \quad \text{(Virtual ground)}$$

$$I_{in} = 0 \quad (R_i = \infty)$$

$$\rightarrow C\frac{dV_i}{dt} = -\frac{V_o}{R}$$

$$\boxed{V_o = -RC\frac{dV_i}{dt}}$$

EXA.: For $R = 1k\Omega$, $C = 0.1\mu F$.



1) t: (0 ⟶ 0.5) ms

$$V_o = -RC \frac{\Delta V_i}{\Delta t}$$

$$\frac{\Delta V_i}{\Delta t} = \frac{(10-0)V}{(0.5-0)ms} = 20 \times 10^3 = 2 \times 10^4 \, V/s.$$

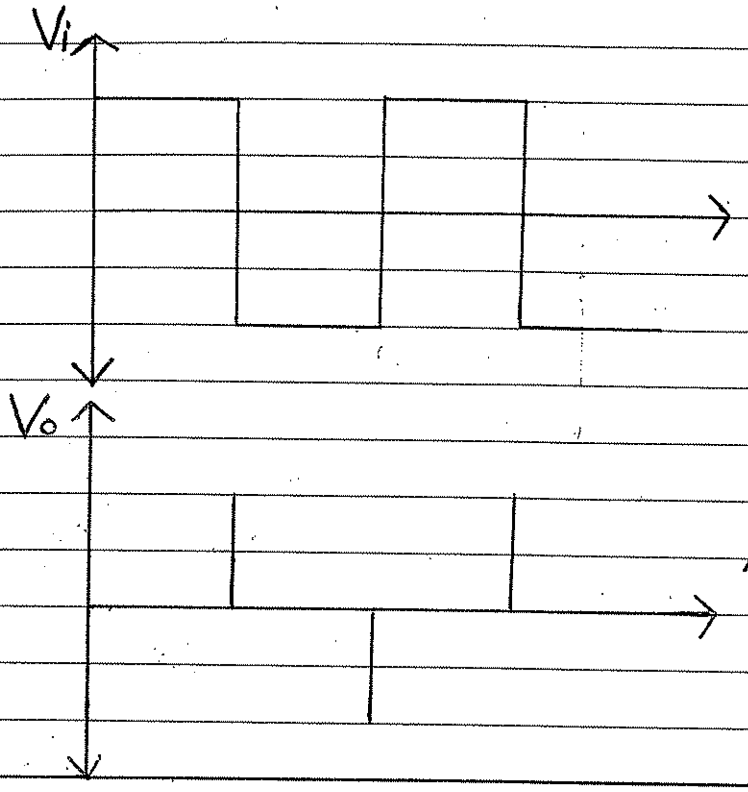
$$V_o = -1 \times 10^3 \times 10^{-7} \times 2 \times 10^4 = -2V$$

2) t: (0.5 ⟶ 1) ms

$$\frac{\Delta V_i}{\Delta t} = \frac{(0-10)V}{(1-0.5)ms} = -2 \times 10^4 \, V/s.$$

$$V_o = -10^3 \times 10^{-7} \times (-2 \times 10^4) = +2V$$

Case:



"Trigger "موجات إبريّة

Integrator
Differentiator

} تأثير الموجات #

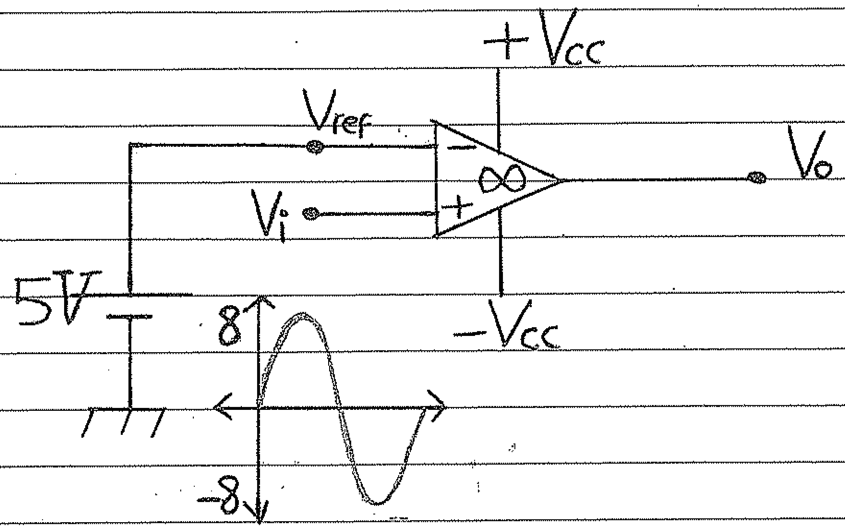
*Differentiator:
→ high freq. → C: Short CCt. → OP-Amp. : Saturation.

↲ لتفادي هذه المشكلة نضع R_x مع الـ C على التوالي.

*Integrator:
→ Low Freq. → C: OPen CCt. → OP-Amp. : Saturation.

↲ لتفادي هذه المشكلة نضع R_x مع الـ C على التوازي.

II) Voltage Comparator :-



i) OP-Amp. works in open loop mode.

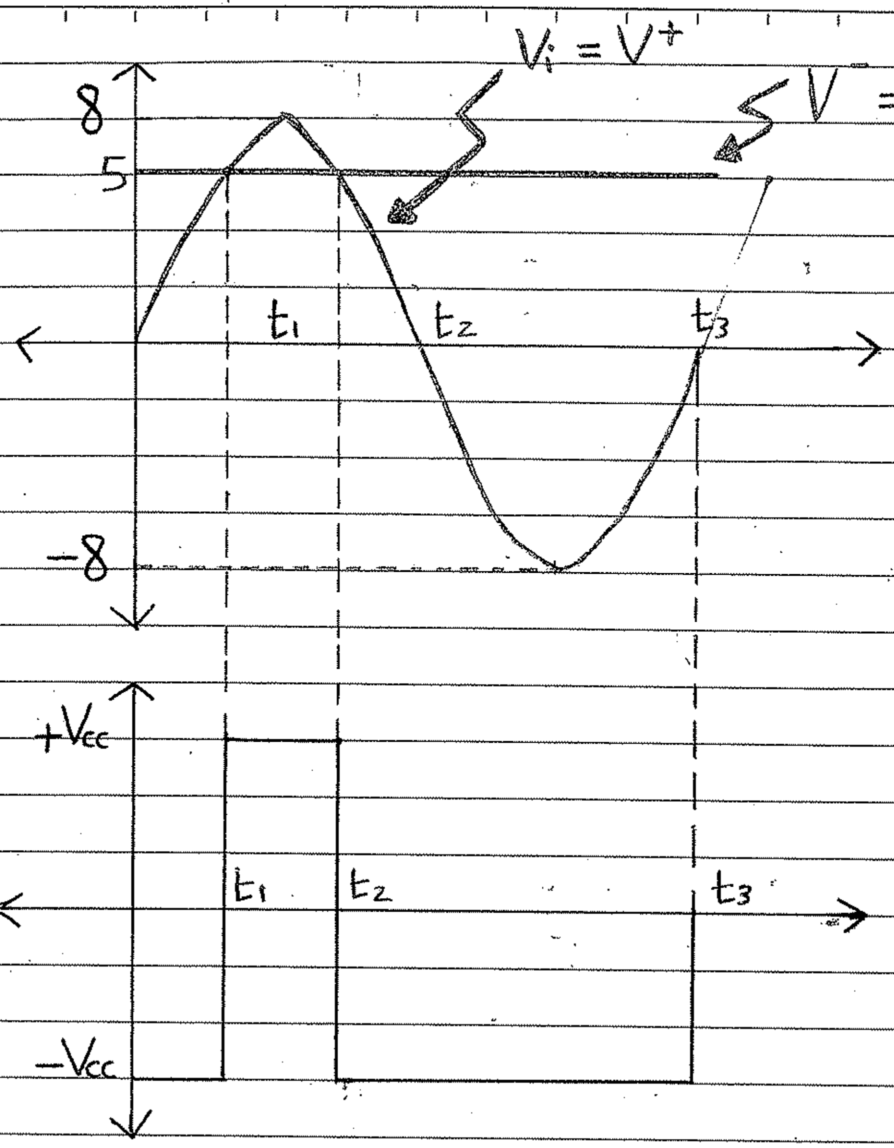
ii) $V_o = \mp V_{cc}$

$$V_o = \underbrace{A_o}_{\to \infty} (V^+ - V^-)$$

#1] if $V^+ > V^- \rightarrow V_o = +V_{cc}$.

#2] if $V^+ < V^- \rightarrow V_o = -V_{cc}$.

نرسم V_i (V^+) ⟵ نرسم V_{ref} (V^-) ⟵ نقارن للحصول على V_o

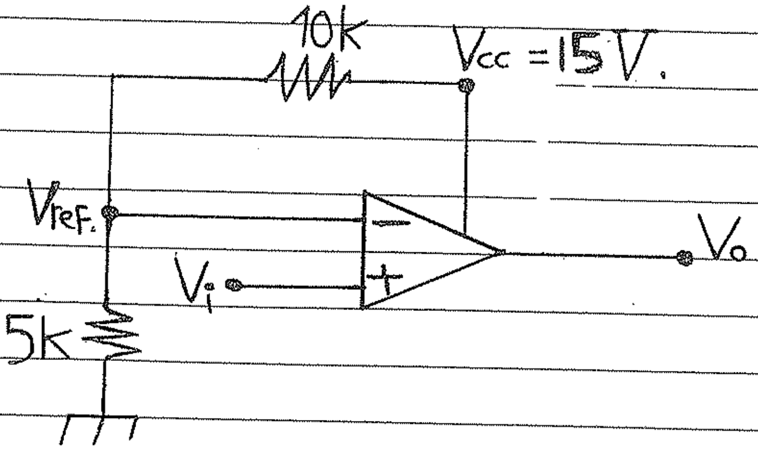


From $0 \rightarrow t_1$; $V^+ < V^- \longrightarrow \boxed{V_o = -V_{cc}}$

From $t_1 \rightarrow t_2$; $V^+ > V^- \longrightarrow \boxed{V_o = +V_{cc}}$

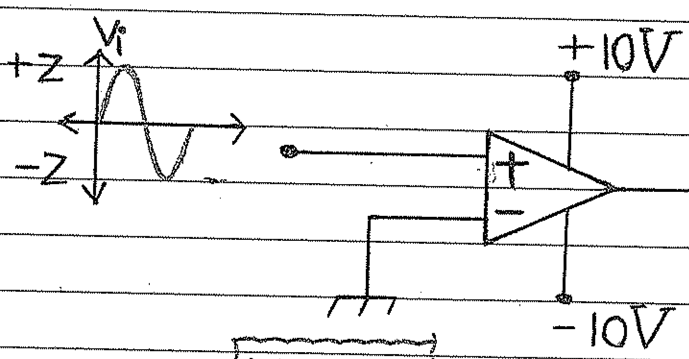
From $t_2 \rightarrow t_3$; $V^+ < V^- \longrightarrow \boxed{V_o = -V_{cc}}$

Case:

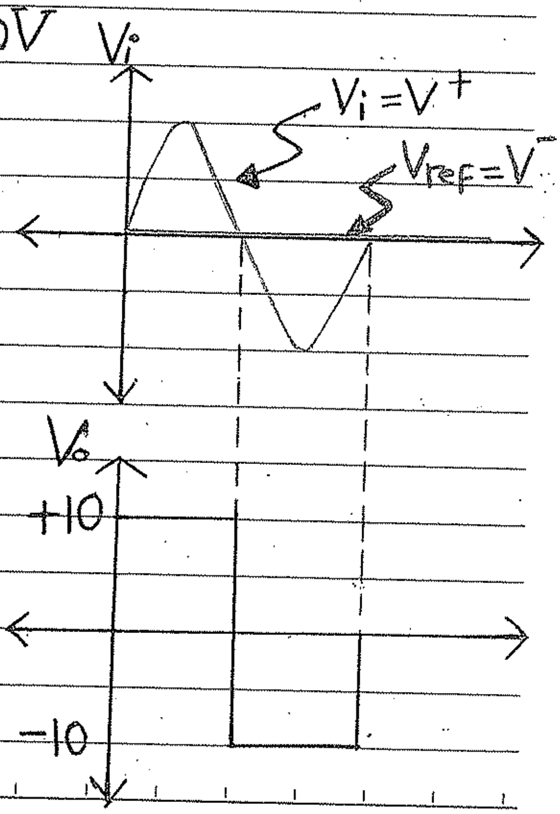


$$V_{ref} = \frac{15 * 5}{15} = 5\,V \quad \text{(Voltage dividor)}$$

Case:



$\boxed{V_{ref} = 0}$



IF $V_{ref} = 0$, then the Circuit is called:

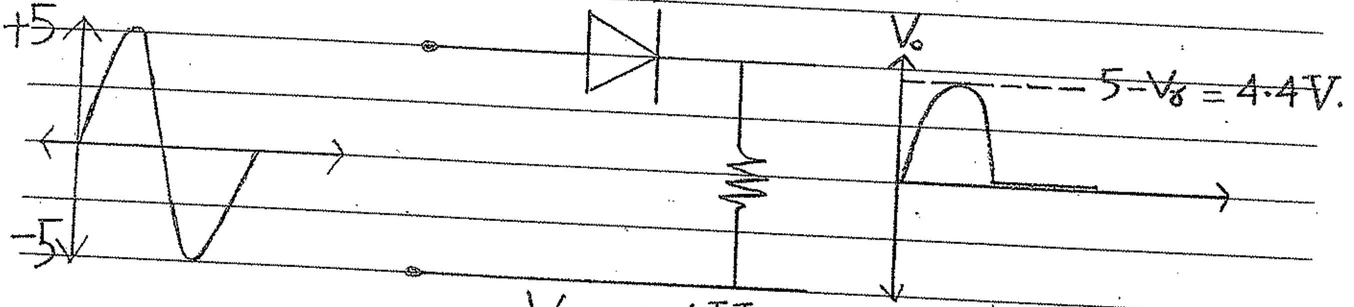
{Zero Crossing detector}.

→ is a Voltage Comparator.

NON Linear Applications :

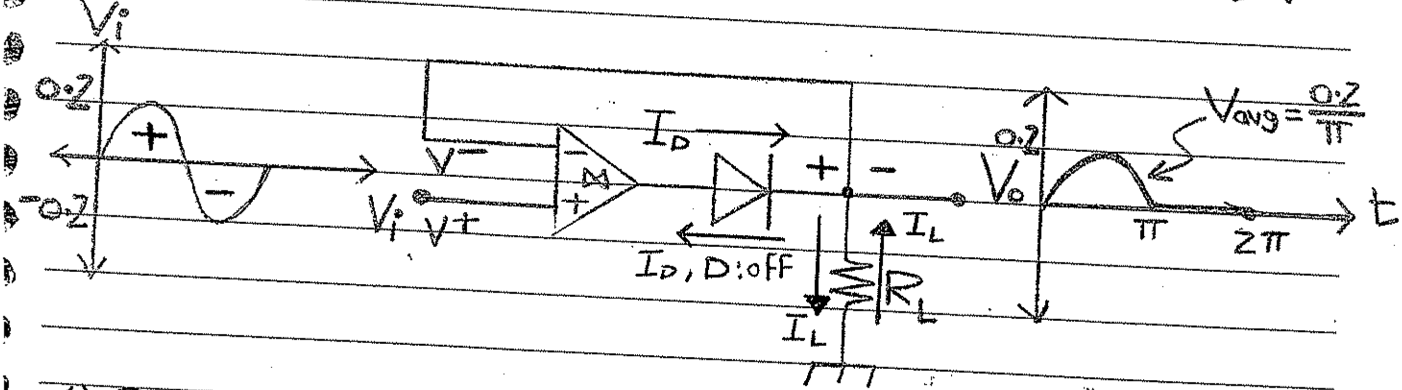
1] Precision rectifier :-

precision rectifier Used to rectify Signals with peak Value < V_γ .



$V_\gamma = 0.6V$.

هذه الحالة عندما تكون [$V_i > V_\gamma$] ، أما عندما تكون [$V_i < V_\gamma$] :



1) During (+Ve) H.C of V_i ; $V_o \rightarrow (+Ve)$;

and I_L اتجاهه ↓ , So Diode will be ON Clossed-loop.

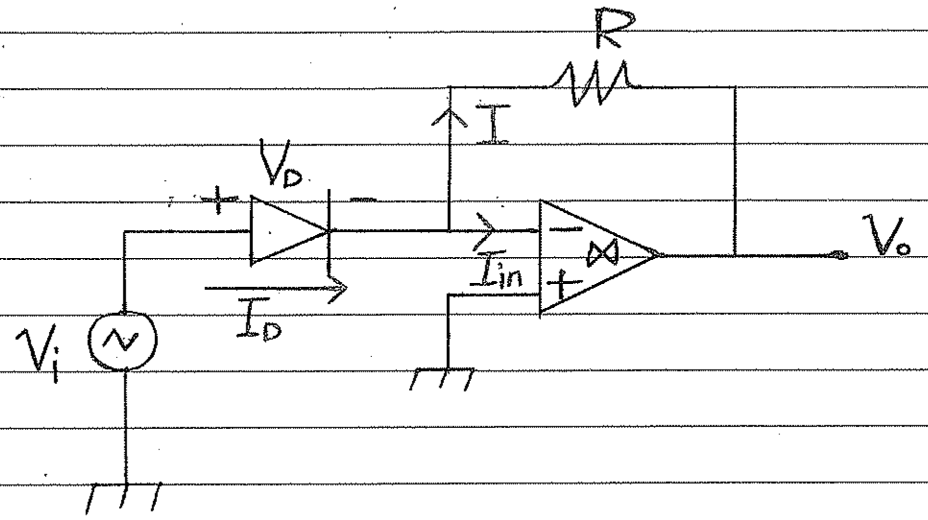
$I_D = I_L \longrightarrow \boxed{V_o = V_i}$ #.

2) During (−Ve) H.C of V_i ; $V_o \rightarrow (-Ve)$;

and $I_L \uparrow$ વધારો , So Diode will be OFF , Open loop.

$I_D = \ominus \rightarrow \boxed{V_o = 0}$ #.

2] EXponential Amp. :



$I_D = I + I_{in}$

$$I_s e^{\frac{V_D}{nV_T}} = \frac{V^- - V_o}{R} + I_{in}$$

$V_D = V_i - V^-$

But ; $V^- = V^+ = 0$ (Virtual ground)

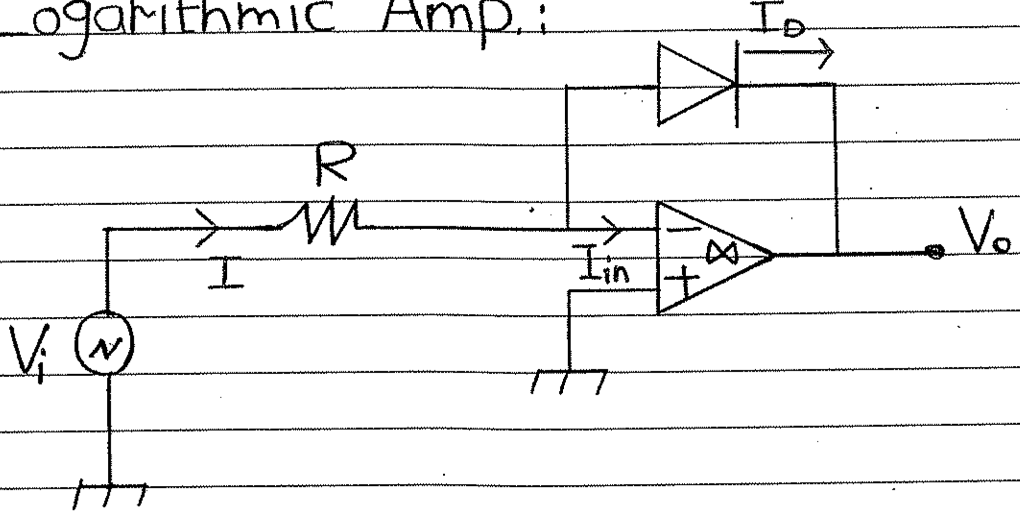
$I_{in} = 0$

$$I_S e^{\frac{V_i}{nV_T}} = -\frac{V_o}{R}$$

$$\boxed{V_o = -R\, I_S\, e^{\frac{V_i}{nV_T}}}$$

$[V_o]$ exponentialy linear with $[V_i]$.

3] Logarithmic Amp.:



$$I = I_{in} + I_D$$

$$\frac{V_i - V^-}{R} = I_{in} + I_S e^{\frac{V_D}{nV_T}}$$

$V_D = V^- - V_o$

But ; $V^- = V^+ = 0$ (Virtual ground)

$$I_{in} = 0$$

$$\frac{V_i}{R} = I_s e^{\frac{-V_o}{nV_T}}$$

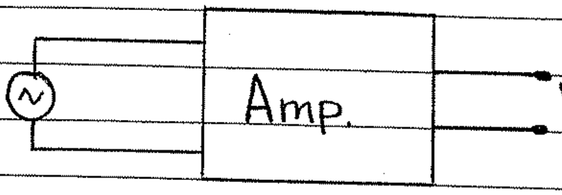
$$\frac{V_i}{I_s R} = e^{\frac{-V_o}{nV_T}}$$

$$\frac{-V_o}{nV_T} = \ln \frac{V_i}{I_s R}$$

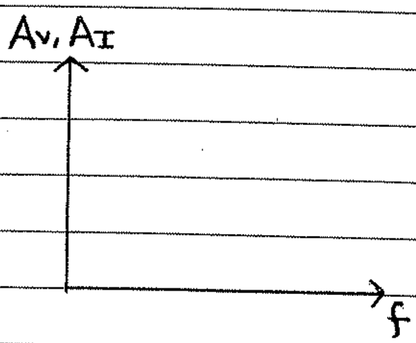
$$\boxed{V_o = -nV_T \ln \frac{V_i}{I_s R}}$$

Chapter (7) :- Frequency Response of Amp. :-

$V_s = 2\sin 2\pi f t$



$V_o = A_v \cdot V_s$
$= A_v (2\sin 2\pi f t)$



$$A_v = \frac{V_o}{V_s} = \frac{V_o}{2\sin 2\pi f t}$$

※ قيمة V_o تختلف باختلاف ال (f) لـ V_s.

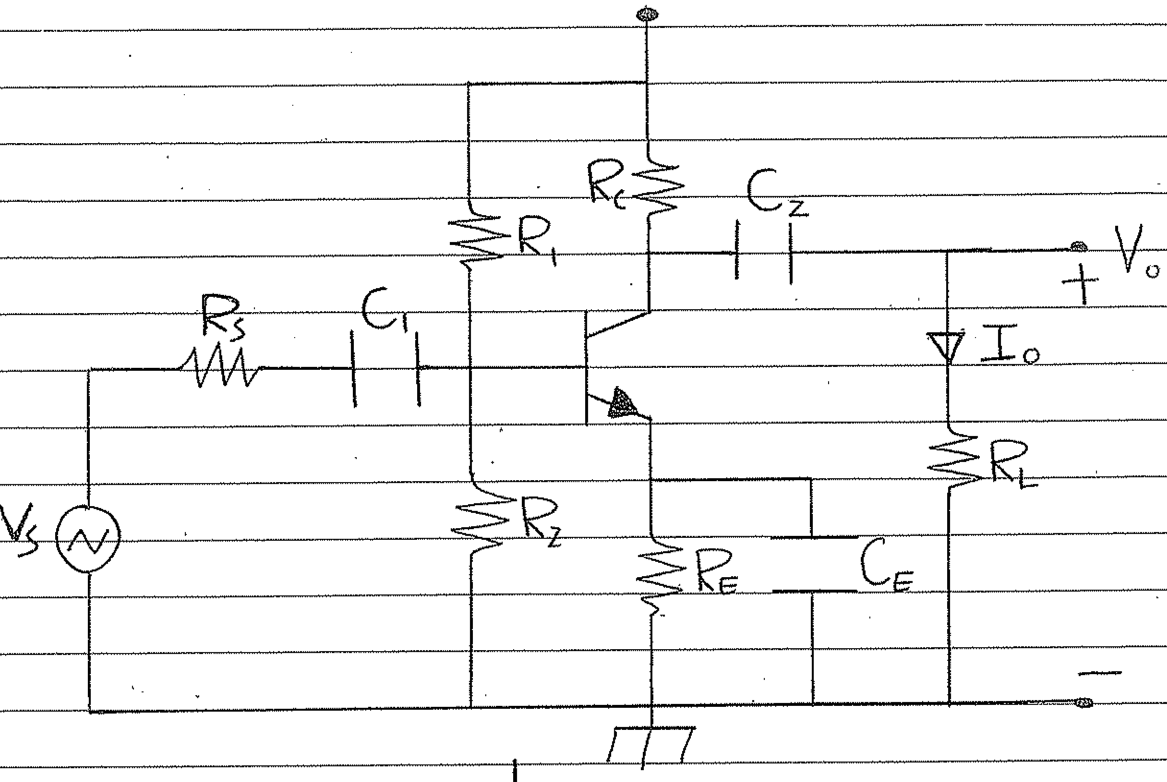
Frequency Response of Amp. Is a plot of Amp. gain (A_v or A_I) Versus frequency.

The gain Can be unitless $\left[A_v = \frac{V_o}{V_s} , A_I = \frac{I_o}{I_s}\right]$ or in dB where:

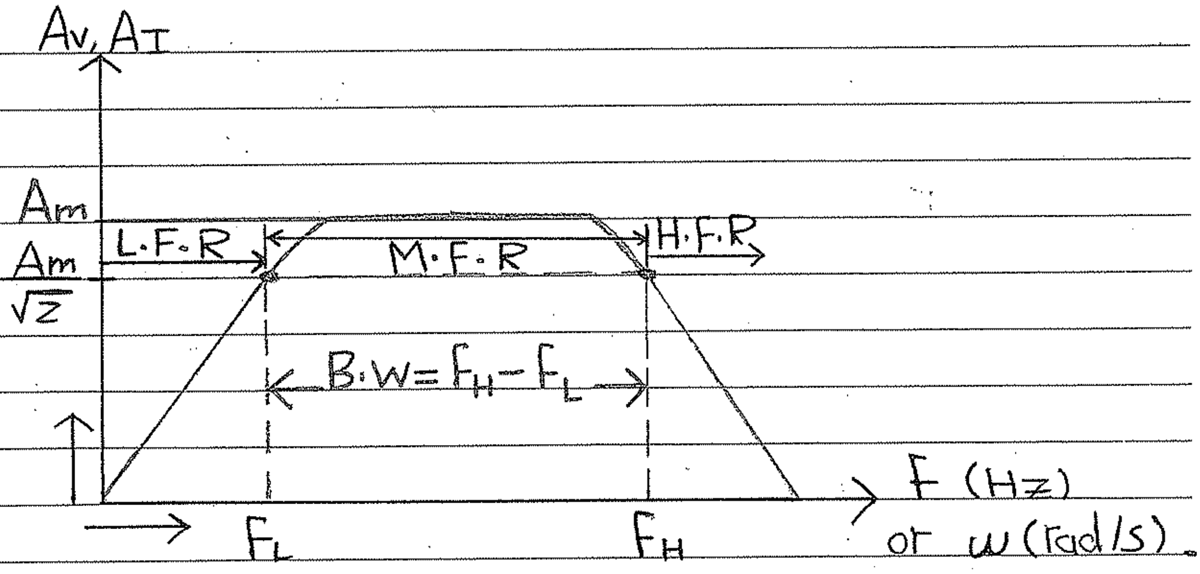
$$A_v(dB) = 20 \log \frac{V_o}{V_s}$$

$$A_I(dB) = 20 \log \frac{I_o}{I_s}$$

The freq. can be in Hz or angular freq. ω (rad/s).



R_C
C_2
R_1
V_o
+
R_s
C_1
I_o
R_L
V_s
R_2
R_E
C_E
−



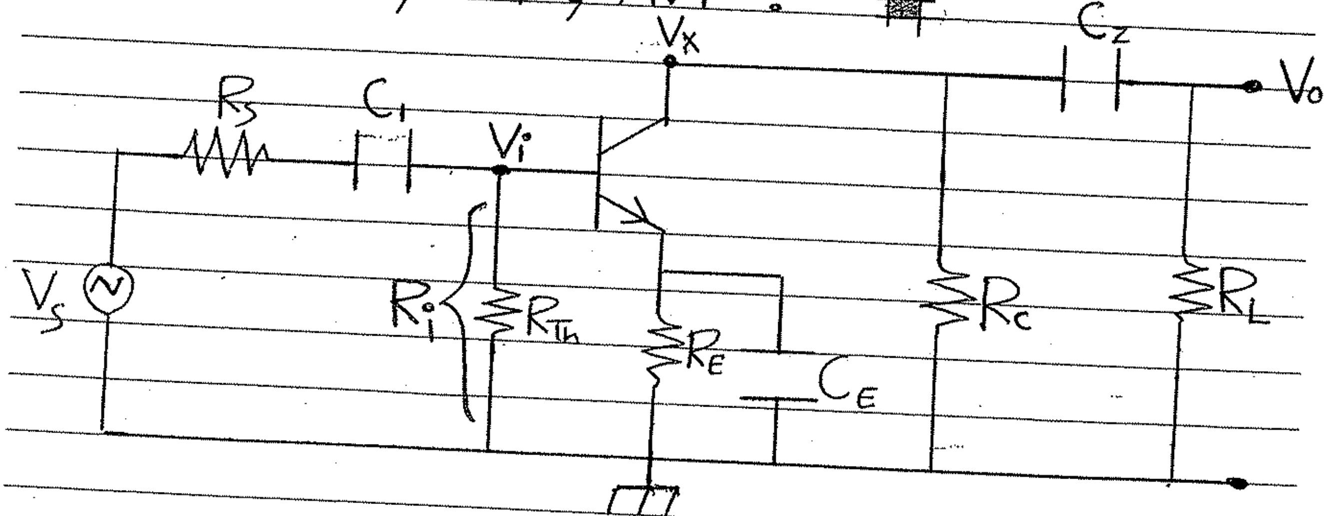
A_v, A_I
A_m
L.F.R
M.F.R
H.F.R
$\frac{A_m}{\sqrt{2}}$
$B.W = F_H - F_L$
F (Hz)
or ω (rad/s)
F_L
F_H

1] For any Amp. Contain at least one Coupling or bypass Cap. ; the typical freq Response is Shown.

2] The typical freq. Resp. Contains three regions [L.F.R, M.F.R, H.F.R].

i) Low Frequency region (L.F.R) :-

The gain if freq. dependant Such that as $f\uparrow$, $A_v\uparrow$ due to the effect of Coupling and bypass Cap.s where $f\uparrow$, $(X_{C_1}, X_{C_2})\downarrow$ and Since they are in the series path of Signal So as $X_C\downarrow$, $V_o\uparrow$, $A_v\uparrow$.



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

$$V_i = \frac{V_s \cdot R_i}{R_i + R_s + X_{c_1}} \quad \text{V.D.R}$$

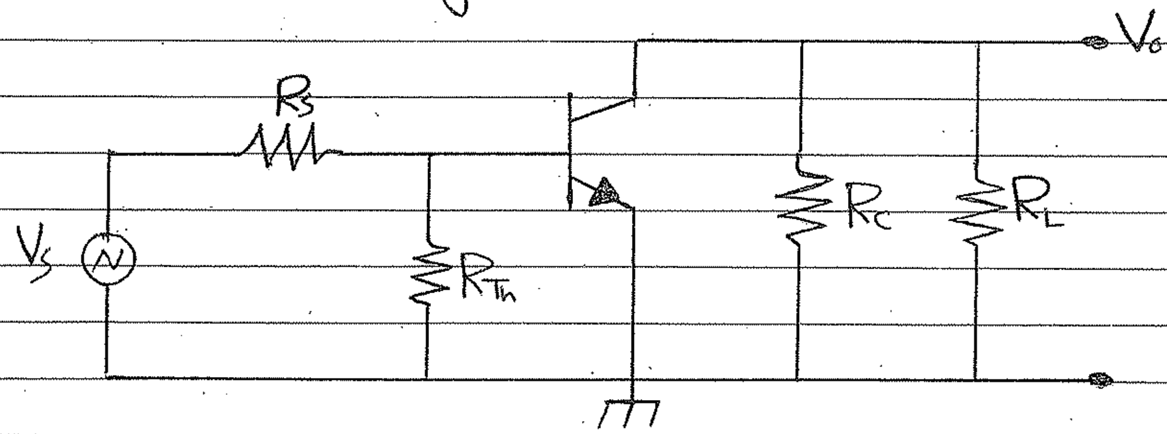
$$V_x = k \cdot V_i$$

$$V_o = \frac{V_x \cdot R_L}{R_L + X_{c_2}} \quad \text{V.D.R}$$

IF $F\uparrow$, $(X_{c_1} \& X_{c_2})\downarrow$, $V_i\uparrow$, $V_x\uparrow$, $V_o\uparrow$, $(A_V = \frac{V_o}{V_s})\uparrow$.

ii) Meduim Frequency Region (M.F.R) :-

All Cap.s are considered Short CCt. and the CCt. behavies as apure Resistive Amp with a certain gain (A_m).



$$A_V = -g_m (R_c // R_L) \frac{R_i}{R_i + R_s} \quad \#.$$

This Regn. extends From $F_L \rightarrow F_H$ over a Band Width (B.W) $= F_H - F_L$.

{Useful range of Amp. Operation}.

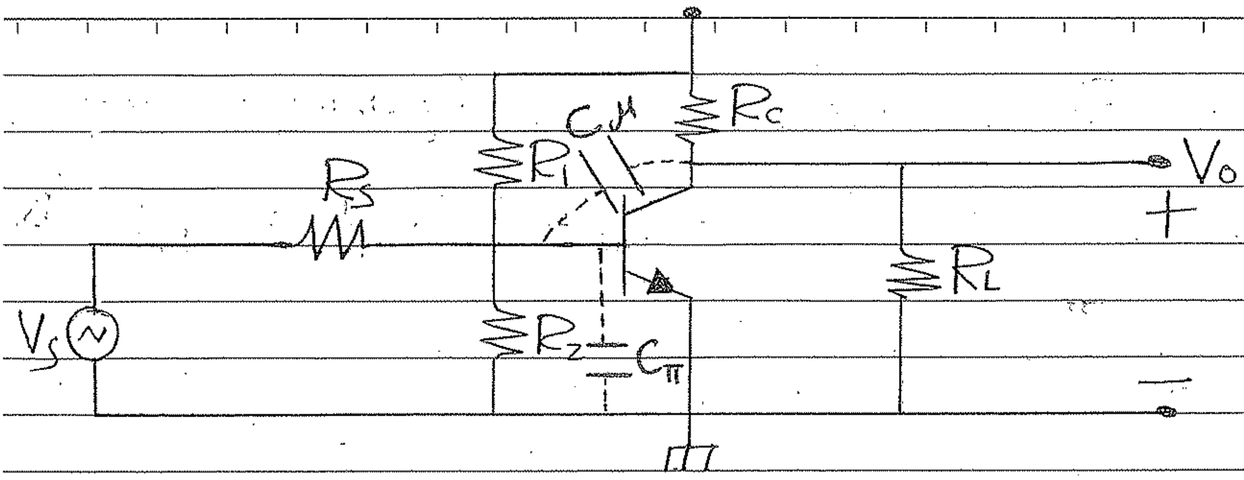
iii) High Frequency Regn. :-

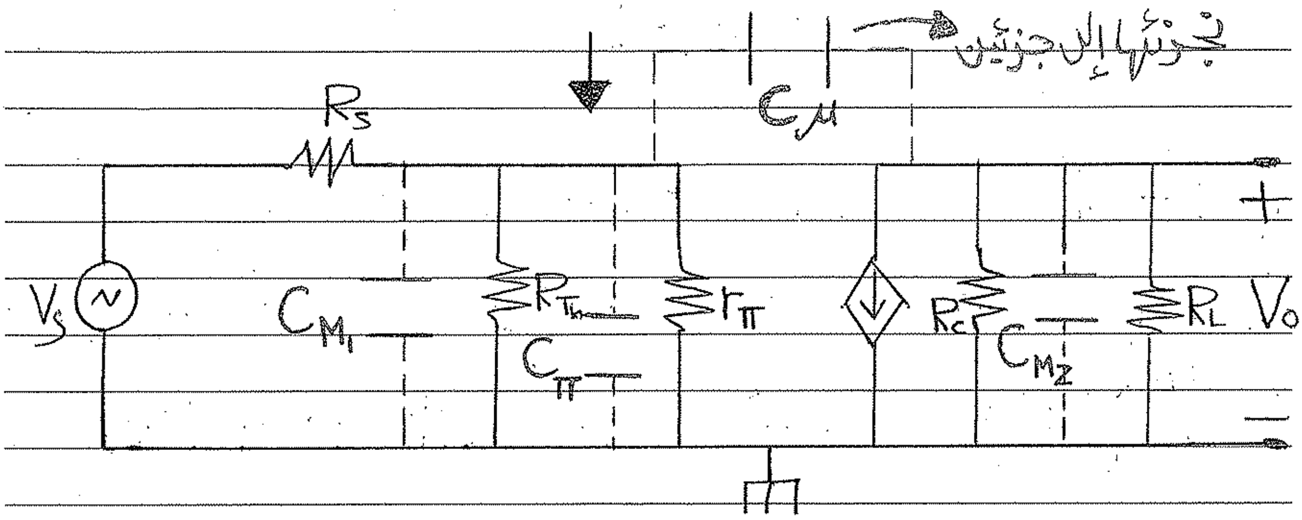
All Caps are Short cct. ; but New Aray Caps appear effectivily (No physical existance) Called: C_μ : Jn. Cap.

C_π : diffusion Cap.

Their effect is in parallel with Input and output side.

as F↑ their reactances X_C decrease ; decreasing V_o and A_v.

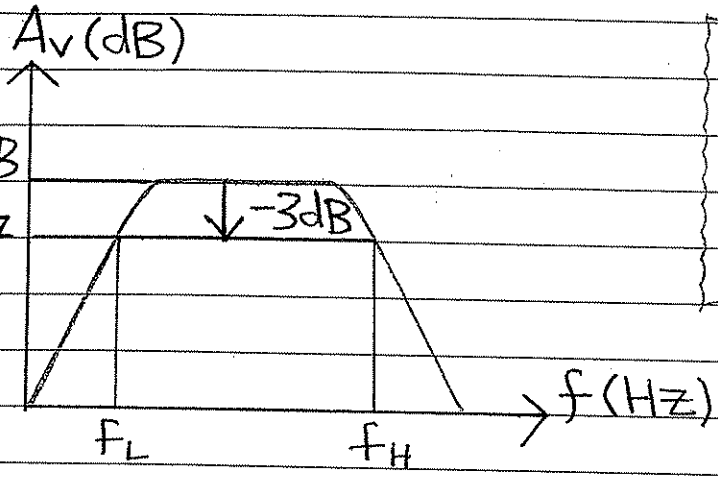




$$V_o = -g_m V_\pi \left(R_C \parallel R_L \parallel X_{CM_2} \right)$$

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

as $f\uparrow$, $X_{CM_2}\downarrow$, $V_o\downarrow$, $A_v\downarrow$.



$A_v = \frac{V_o}{V_s}$ → ثابت

اذا قسمت A_v على $\sqrt{2}$

نقسم V_o ايضاً على $\sqrt{2}$

The boundaries between L.F.R, M.F.R, & H.F.R are Called :-

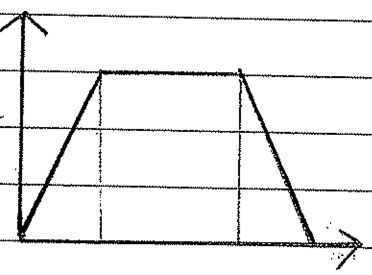
1) Cut off frequencies.

\# f_L → Low-Cut off freq.

\# f_H → high-Cut off freq.

2) −3dB frequencies.

3) Break frequencies.



4) half - Power frequencies :-

$$P_{FL} = P_{FH} = \frac{1}{2} P_{MF}$$

$$P = \frac{V_o^2}{R} \quad (MF)$$

at (F_L) and (F_H) :-

$$V_{of_L} = V_{of_H} = \frac{V_o}{\sqrt{2}}$$

$$\therefore P_{LF} = P_{HF} = \left(\frac{V_o}{\sqrt{2}}\right)^2 / R$$

$$= \frac{V_o^2}{2} / R \quad ; \frac{V_o^2}{R} = P_{MF}$$

$$= \frac{1}{2} P_{MF} .$$

Ele. 2

EXA:- Given : $\beta = 100$, $V_{BE} = 0.7\,V$, $V_A = \infty$

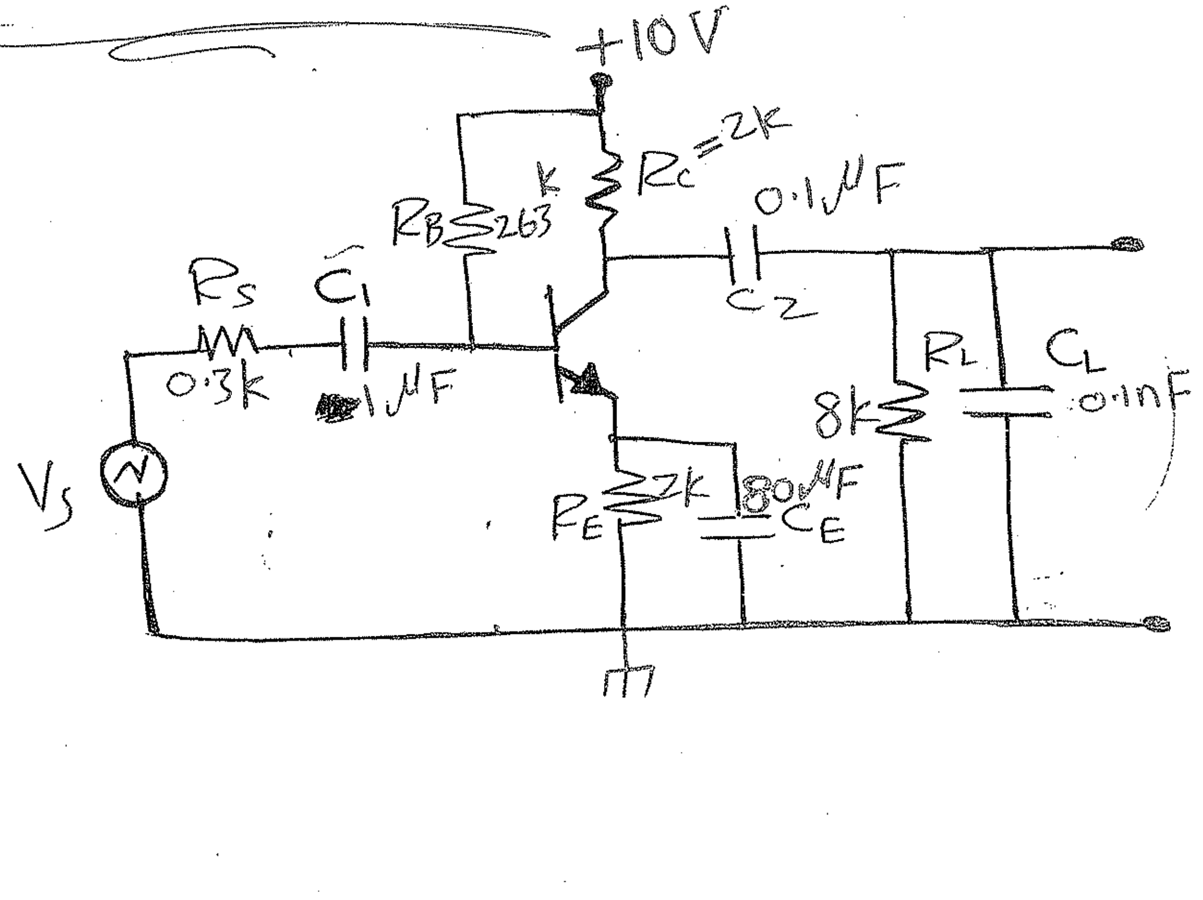
$C_\mu = 2pF$, $C_\pi = 10\,pF$

1) Draw M.F. Equevelnt cct. and find A_{vm}

2) " L.F. Eqnt. cct and find f_L.

3) " H.F. " " " find f_H.

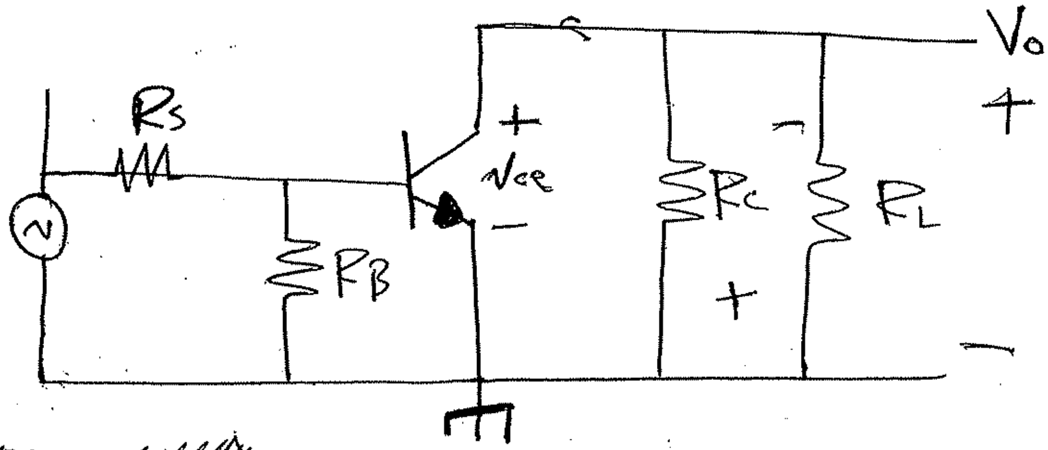
4) Sketch freq. Resp. (A_v(dB) versus freq).

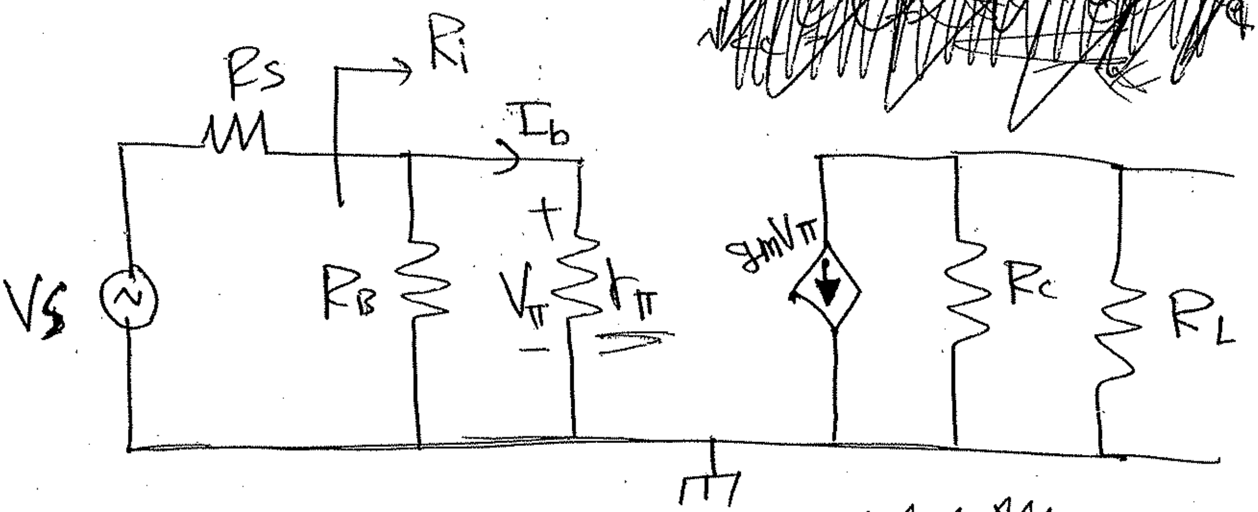


① In M.F.R :-

$C_1, C_2, C_E \longrightarrow S.C$

$C_L, C_\pi, C_\mu \longrightarrow O.C$



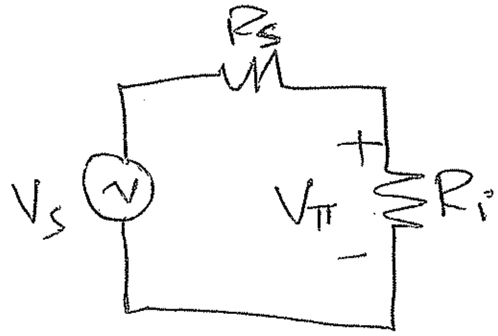


$$-A_{vm} = \frac{V_o}{V_s} = \frac{V_o}{V_\pi} * \frac{V_\pi}{V_s}$$

$$V_o = -g_m V_\pi (R_C \| R_L)$$

$$\frac{V_o}{V_\pi} = -g_m (R_C \| R_L)$$

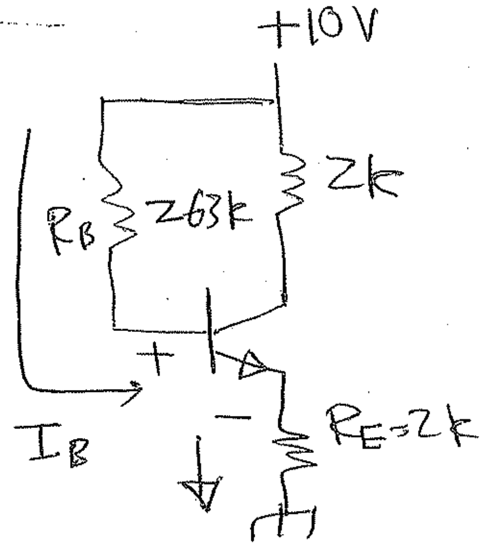
$$\frac{V_\pi}{V_s} = \frac{R_i}{R_i + R_s}$$



$$R_i = r_\pi \| R_B$$

$$A_{vm} = -g_m (R_C \| R_L) \frac{R_i}{R_i + R_s}$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}}$$ D.C. analysis.



$$-10 + I_B\, 263 + V_{BE} + (\beta+1) I_B R_E = 0$$

$$I_B = \frac{(10 - 0.7)V}{263 + 101 * 2}$$

$$= \frac{9.3}{465} = 0.02\,mA.$$

$$I_{CQ} = 100 * 0.02 = 2\,mA.$$

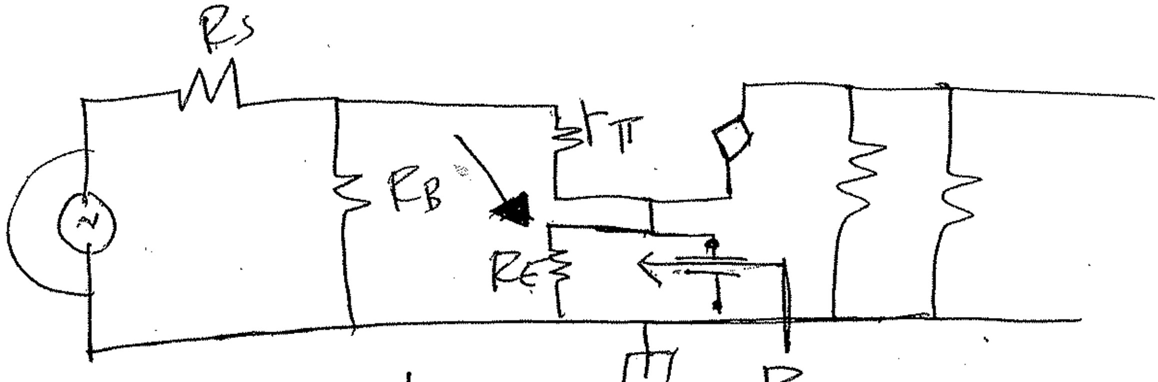
$$f_{l_2} = \frac{1}{2\pi C_2 R_{eq_2}} \quad ; R_{eq_2} = R_{Th} \text{ seen by } C_2.$$

$$R_{eq_2} = R_C + R_L = 2 + 8 = 10k\Omega.$$

$$f_{L2} = \frac{1}{2\pi * 0.1 * 10^{-6} * 10^4} = \frac{10^3}{2\pi}$$

$$= \boxed{160\ Hz}.$$

(iii) Effect of C_E ($C_1, C_2 \rightarrow$ S.C) :-



$$f_{l_3} = \frac{1}{2\pi C_E R_{eq.3}}$$

$R_{eq_3} = R_{Th}$ seen by C_E.

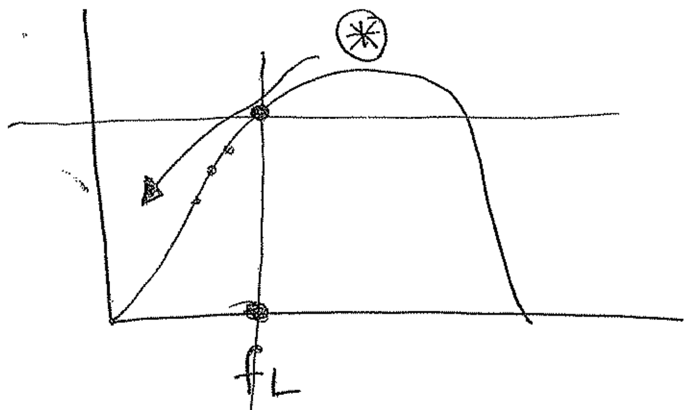
$$R_{eq_3} = \left(\frac{(R_S \parallel R_B) + r_\pi}{\beta + 1}\right) \parallel R_E$$

$$= \frac{0.3 \parallel 263 + 1.3}{} \parallel 2k = \boxed{15\Omega} \quad \boxed{6}$$

$$f_{L3} = \frac{1}{2\pi \times 80 \times 10^{-6} \times 15}$$

$$= \frac{10^6}{160 * 15 * \pi} = \underline{133\ Hz.}$$

#

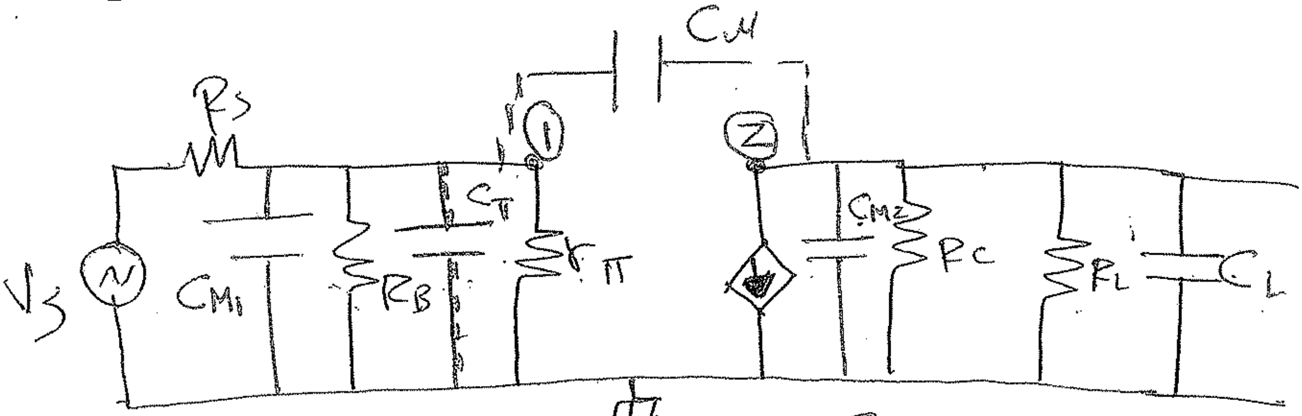


$\underline{f_{L(eff)}}$ = The highest Value.

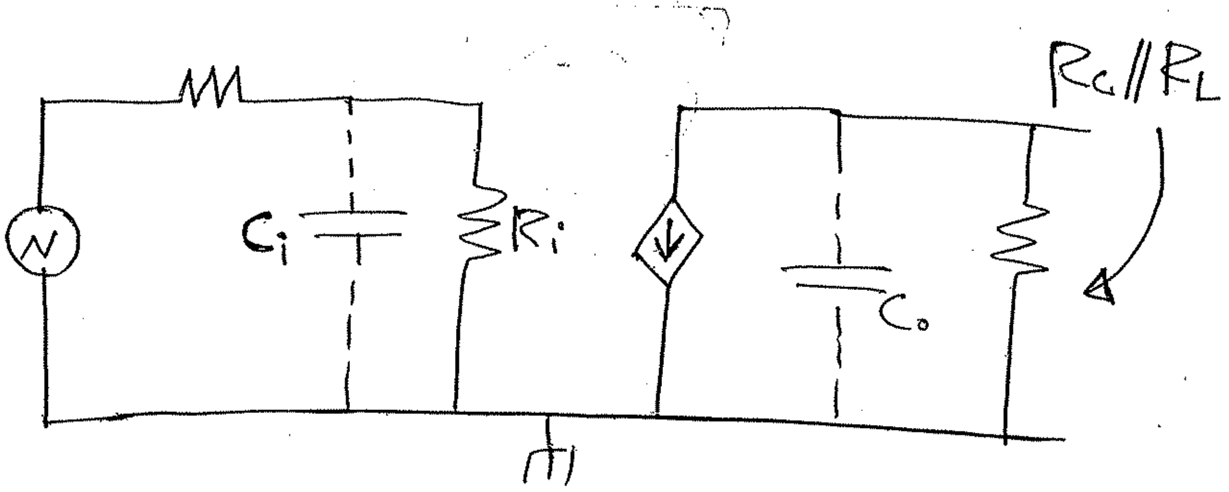
$= \underline{160\ Hz.}$

---

③ $\underline{H.F.R}$: [$C_{11}, C_2, C_E \rightarrow S.C$
$C_\mu, C_\pi, C_L \rightarrow$ exist].



H.F.S.S.A.C Eqnt. cct. $\boxed{7}$



$$C_i = C_\pi + C_{M_1}$$

$$C_o = C_L + C_{M_2}$$

$$C_{M_1} = C_\mu (1-k)$$

$$C_{M_2} = C_\mu \left(1-\frac{1}{k}\right)$$

$$k = \frac{V_2}{V_1} = \frac{V_o}{V_i} = \frac{V_o}{V_\pi} = \frac{-g_m \cancel{V_\pi} (R_c \| R_L)}{\cancel{V_\pi}}$$

$$k = -g_m (R_c \| R_L)$$
$$= -78\,(2\|8) = \underline{-120}\ \#.$$

C.E, C.S $\rightarrow$ K سالبة

$$f_{Hi} = \frac{1}{2\pi C_i R_{eq_1}}$$

R_{eq_1} = R_{Th} seen by C_i

$$R_{eq_1} = (R_s \parallel R_i) = 0.3 \parallel 1.2$$
$$= 0.28 \text{ k}\Omega.$$

$$C_i = C_{M1} + C_\pi$$

$$C_{M1} = 2(1-(-120)) = 242 \text{ p.F}$$

$$C_i = 242 + 10 = \underline{\underline{252 \text{ p.F}}}$$

$$f_{Hi} = \frac{1}{2\pi * 252 * 10^{-12} * 0.28 * 10^{3}}$$

$$= \frac{10^9}{150\pi} \approx 2\text{MHZ}.$$

$$f_{H_o} = \frac{1}{2\pi C_o R_{eq_2}}$$

R_{eq_2} = R_{Th} seen by C_o.

$$R_{eq_2} = R_C \parallel R_L = (2 \parallel 10)$$
$$= 1.6\ k\Omega.$$

$$C_o = C_{M_2} + C_L$$

BJT: $k >> 1$

$$C_{M_2} = C_\mu \left(1 - \frac{1}{k}\right)$$

If $\underline{\underline{k >> 1}}$:- $C_{M_2} \simeq C_\mu$
$= 2PF.$

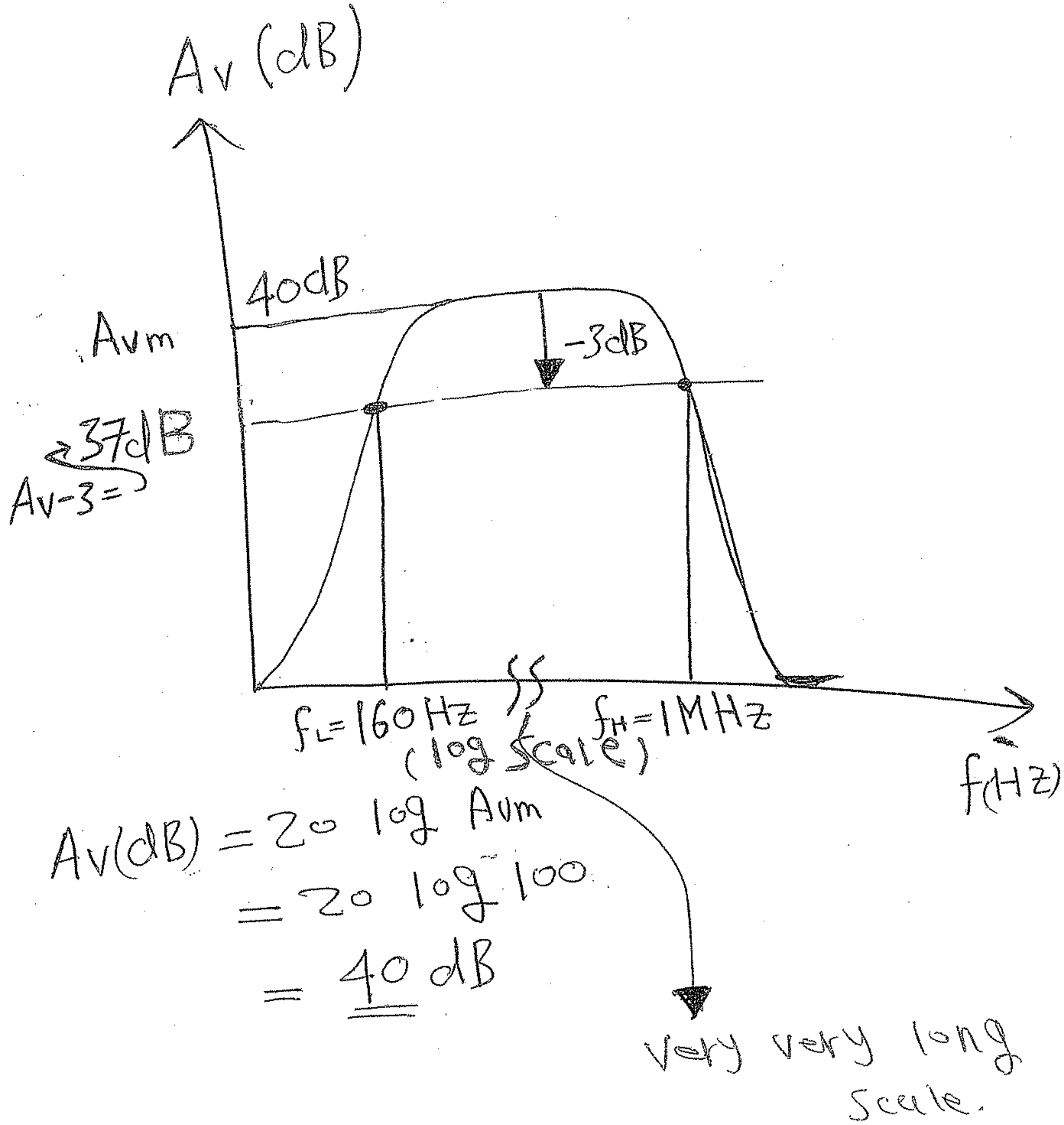
$$C_o = 2\cancel{Pf} \; 0.1\,nf = 102\ p.F.$$

$$f_{H_o} = \frac{1}{2\pi * 102 * 10^{-12} * 1.6 * 10^{3}}$$

$$= \frac{10^7}{3.2\pi} = 1\,MHz \;\#.$$

$f_{H_{eff}}$ is the lowest value

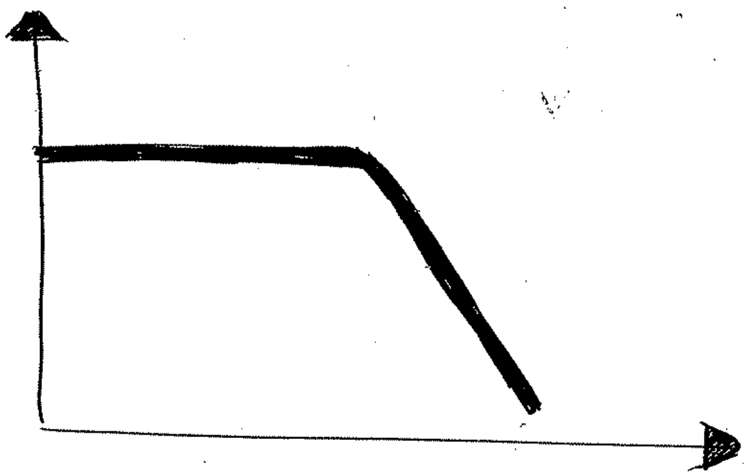
$f_{..} = 1\,MHZ$ #. $\boxed{10}$



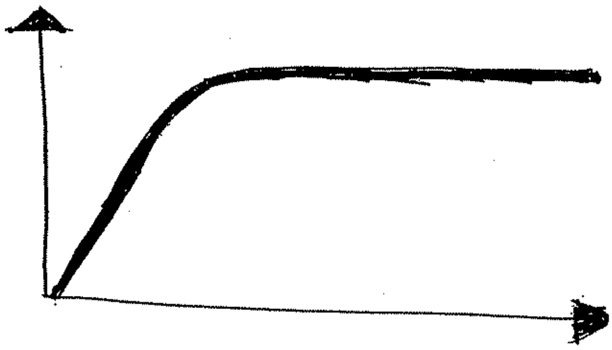
$$A_v(dB) = 20 \log A_{vm}$$
$$= 20 \log 100$$
$$= \underline{\underline{40}} \text{ dB}$$

\#

$C_1, C_2, C_E \longrightarrow \underline{\underline{\infty}}$



$\underline{\underline{C_L = 0}}$



$C \Rightarrow \infty \quad : \quad \underline{\underline{S.C}}$

$C \Rightarrow 0 \quad : \quad \underline{\underline{OC}}$

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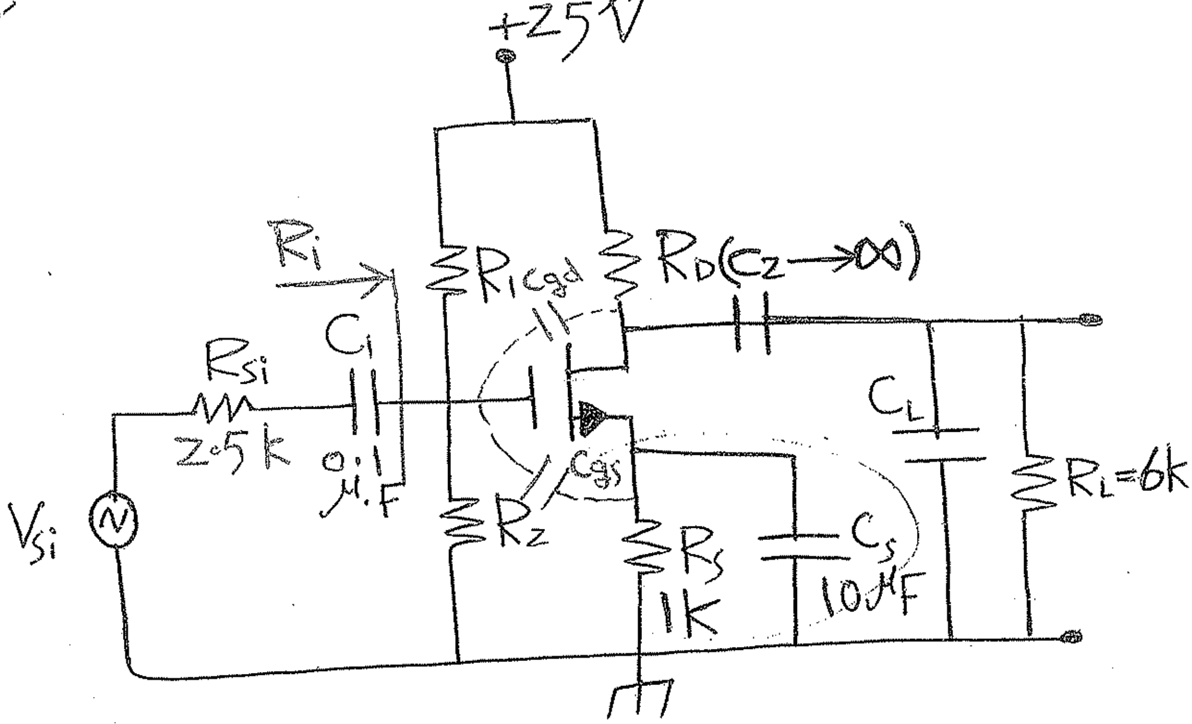
Freq. Resp. For C.S Amp. :-



Given : $I_D = 5mA$

$K_n = 1.25 \, mA/V^2$, $V_{TN} = 1V$, $\lambda = 0$

$C_{gs} = 20 \, pF$; $C_{gd} = 5 \, pF$

1) Design the cct. to give $A_v = \frac{V_o}{V_{si}} = -8$

(Find R_D, R_1, R_2) (let $R_i = 10k\Omega$).

2) Calculate f_L, f_H

3) Calculate C_L required to give $f_H = 30 \, kHz$

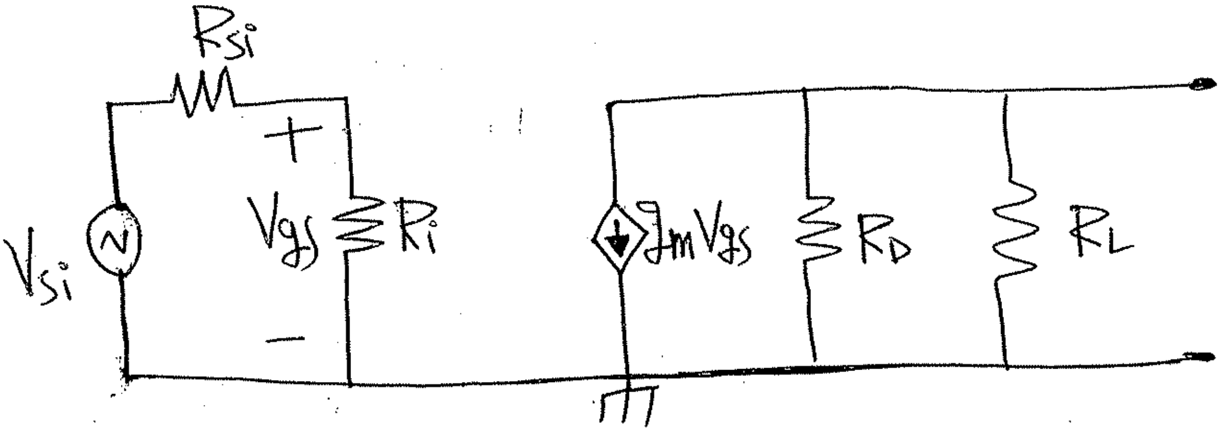
4) Sketch freq. Resp.

II

Sol.

R_D ? M.F. Eqvt. cct.

$C_1, C_S \rightarrow S.C$, $C_{gd}, C_{gs}, C_L \rightarrow O.C.$



$$A_v = \frac{V_o}{V_{si}} = \frac{V_o}{V_{gs}} * \frac{V_{gs}}{V_{si}}$$

$$V_o = -g_m V_{gs} (R_D // R_L)$$

$$\frac{V_o}{V_{gs}} = -g_m (R_D // R_L)$$

$$V_{gs} = \frac{V_{si} R_i}{R_i + R_{si}} \Longrightarrow \frac{V_{gs}}{V_{si}} = \frac{R_i}{R_i + R_{si}}$$

$$A_v = -g_m \underbrace{(R_D // R_L)}_{R_L'} \frac{R_i}{R_i + R_{si}}$$

$g_m = 2\sqrt{k_n I_D} = 2\sqrt{1.25 * 5}$ 174

$= 5 \frac{mA}{V}$

$-8 = -5 R_L' \frac{10}{2.5+10}$

$-8 = -4 R_L' \rightarrow R_L' = 2k\Omega$

$= R_D \parallel 6k$

$\Rightarrow R_D = 3k\Omega$ #

R_1 & R_2 (from D.C):

$R_1 V_G = \frac{25 R_2 R_1}{R_2 + R_1} \rightarrow R_i$

$R_1 = \frac{25}{V_G} R_i$

$V_{GS} = V_G - V_S$

$V_G = V_{GS} + V_S$

3

$$V_{GS} = V_{TN} \mp \sqrt{\frac{I_D}{k_n}}$$

$$= 1 \mp \sqrt{\frac{5}{1.25}} = 1 \mp \sqrt{4}$$

$$= 3V \text{ or } -1V$$

$$V_S = I_D \cdot R_S = 5 * 1 = 5V.$$

$$V_G = 3 + 5 = 8V.$$

$$R_1 = \frac{25}{8} * 10 = \underline{31.25\ k\Omega}.$$

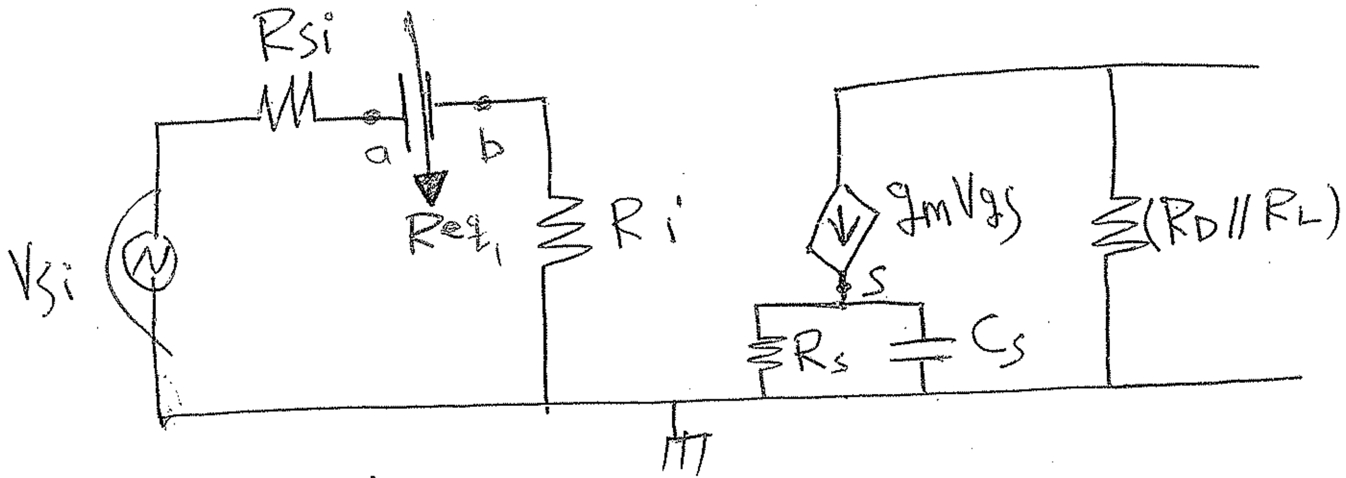
$$R_2 = \frac{R_1 * R_i}{R_1 - R_i} = \frac{31.25 * 10}{31.25 - 10}$$

$$= \frac{312.5}{21.25} = 14.75k.$$

f_L ? → (L.F. Eqnt. cct.)

(C_i, C_s → exist), (C_{gs}, C_{gd}, C_L) → O.C

(C_2 → S.C)



$$f_{L1} = \frac{1}{2\pi C_1 Req_1}$$

$$Req_1 = R_{si} + R_i = 12.5\,k\Omega$$

$$f_{L1} = \frac{1}{2\pi * 1 * 10^{-7} * 12.5 * 10^3} = \frac{10^4}{25\pi}$$

$$= 127\,Hz$$

$$F_{Ls} = \frac{1}{2\pi C_s \cdot Req_2} = \frac{1}{2\pi\, C_s \cdot R_s}$$

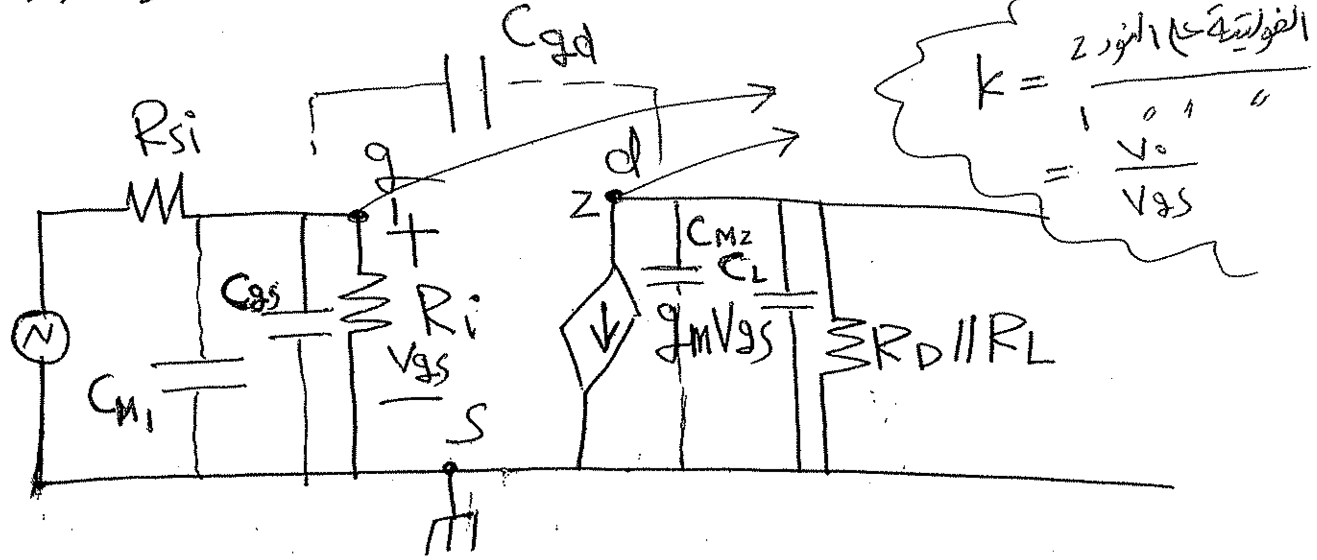
$$= \frac{1}{2\pi * 10^{-5} * 1 * 10^3}$$

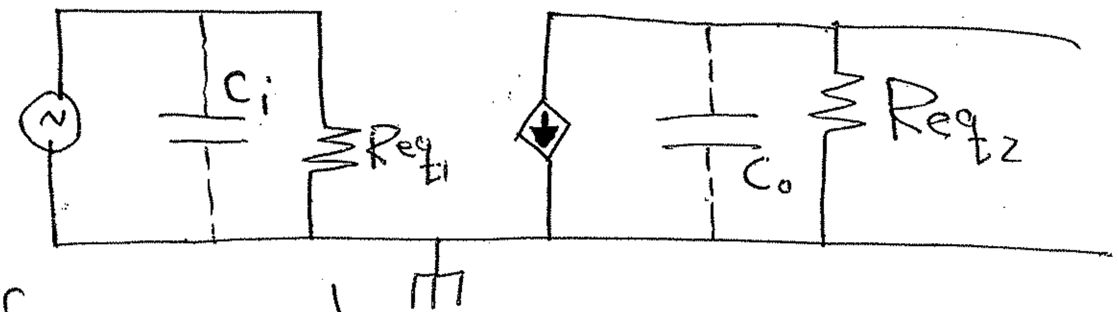
$$= \frac{100}{2\pi} = 16\,Hz$$

$\boxed{5}$

f_H ? $\longrightarrow$ (H. F. Eqnt. cct.)

$(C_1, C_S, C_2 \longrightarrow S.C)$ و $(C_{gs}, C_{gd}, C_L \rightarrow$ exist$)$





$$f_{H_i} = \frac{1}{2\pi C_i R_{eq_{t1}}}$$

$$C_i = C_{M_1} + C_{gs}$$

$$C_{M_1} = C_{gd}(1-k)$$

$$k = \frac{V_o}{V_{gs}} = \frac{-g_m \cancel{V_{gs}} (R_D // R_L)}{\cancel{V_{gs}}}$$

$$k = -g_m (R_D // R_L) = -5 * 2 = \underline{\underline{-10}}$$

$$C_{M_1} = 5\,(1-(-10)) = 55 \text{ P.F.}$$

$$C_i = 20 + 55 = 75 \text{ P.F.}$$

$$R_{eq_{t1}} = R_{si} \,||\, R_i = 2.5 \,||\, 10 = 2k\Omega.$$

$$f_{Hi} = \frac{1}{2\pi * 10^3 * 75 * 10^{-12}} = \frac{10^9}{300\pi}$$

$$= 1.1 \text{ MHz.}$$

$$f_{Ho} = \frac{1}{2\pi R_{eq_{t2}} C_o}$$

$$\Rightarrow R_{eq_{t2}} = R_D \,||\, R_L = 2k\Omega.$$

$$\Rightarrow C_o = C_{M2} + C_L \Rightarrow C_{M2} = C_{gd}\left(1 - \frac{1}{k}\right)$$

$$= 5\left(1 - \left(\frac{-1}{10}\right)\right)$$

$$= 5.5 \text{ P.F.}$$

given $f_{Ho} = 30\text{kHz}$ $\therefore$

$$C_o = \frac{1}{2\pi R_{eq_{t2}} \cdot 30 * 10^3} = \frac{1}{2\pi * 3 * 10^4 * 2 * 10^3}$$

$$= \frac{10^{-7} * 10^{12}}{12\pi} \text{ F}$$

$$= \frac{10^5}{12\pi} \text{ P.F} = 2600 \text{ PF}$$

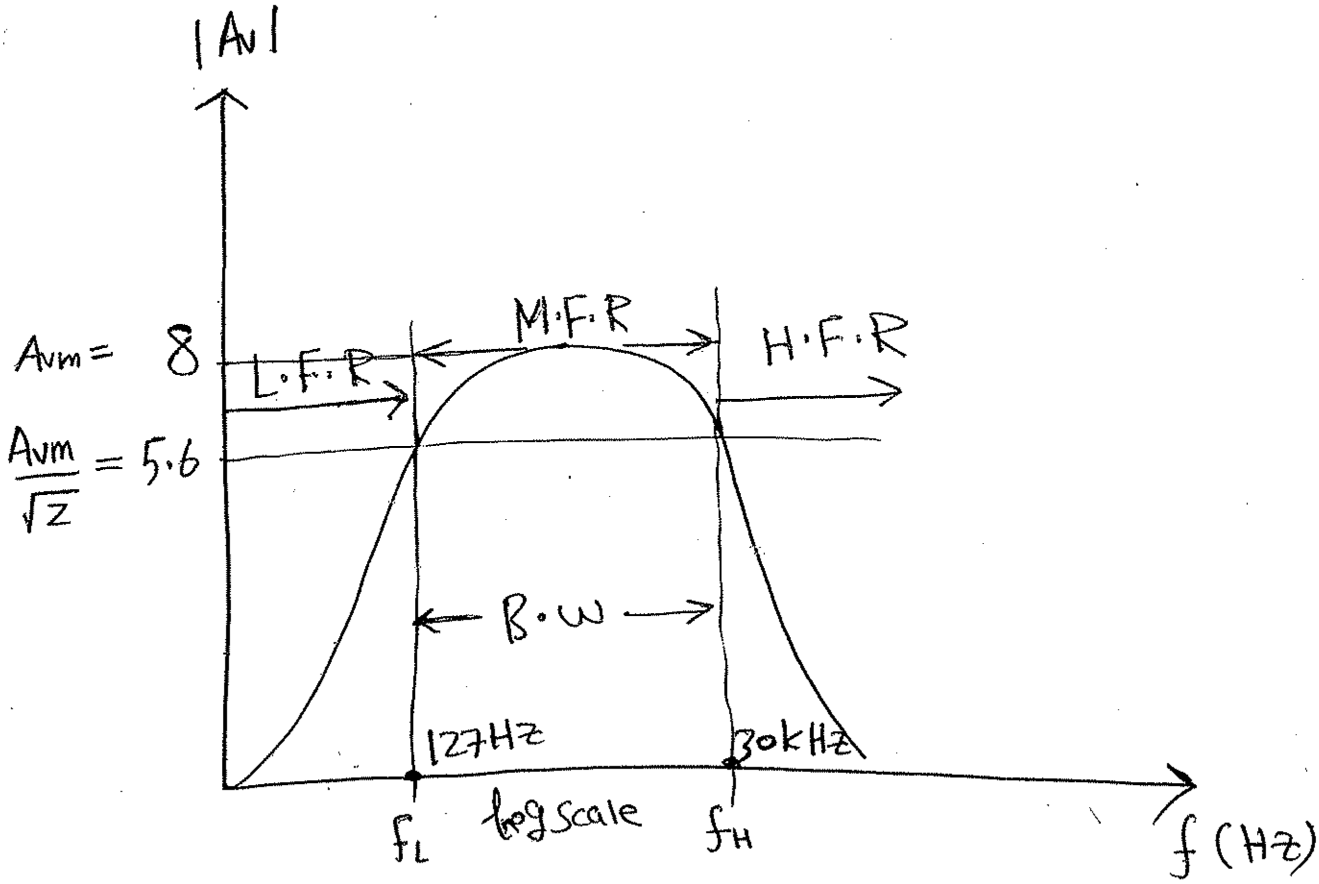
$\boxed{7}$

$C_L = 2600 - 5.5$

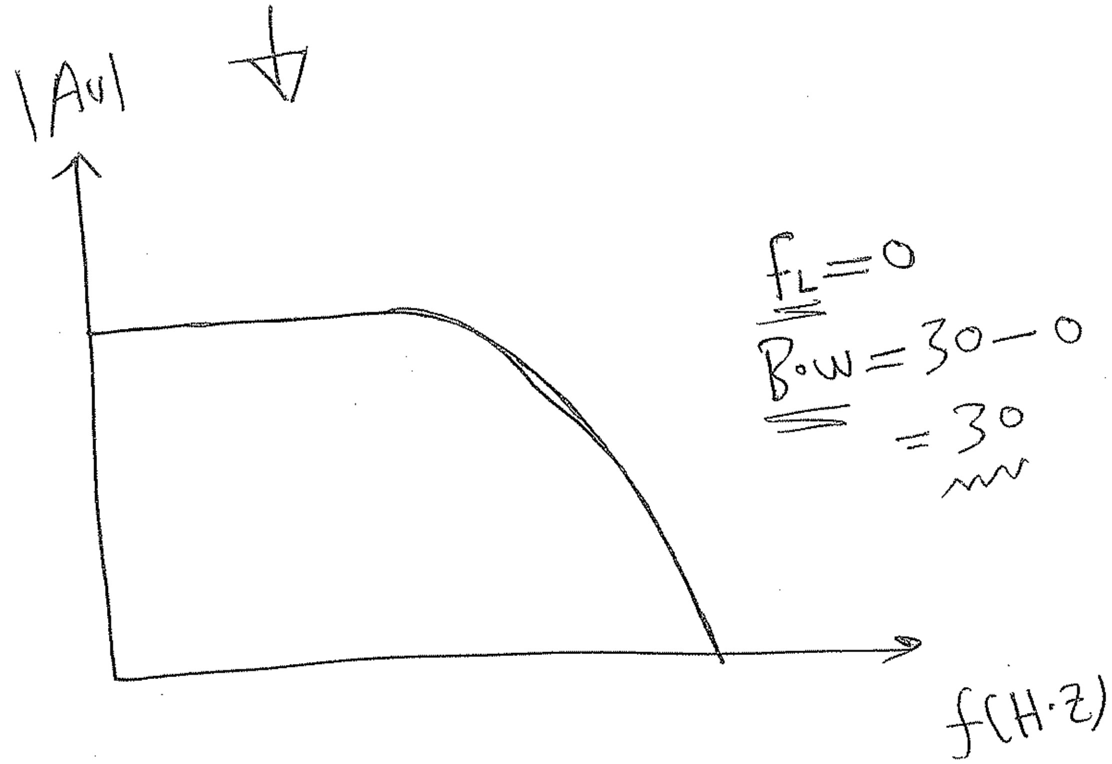
$= 2594.5 \ P.F.$

$C \rightarrow 0 \rightarrow (X_C \rightarrow \infty) \rightarrow$ open cct.

$C \rightarrow \infty \rightarrow (X_C \rightarrow 0) \rightarrow$ Short cct.



مش موجودة C_2 و C_s و C_1 قصر



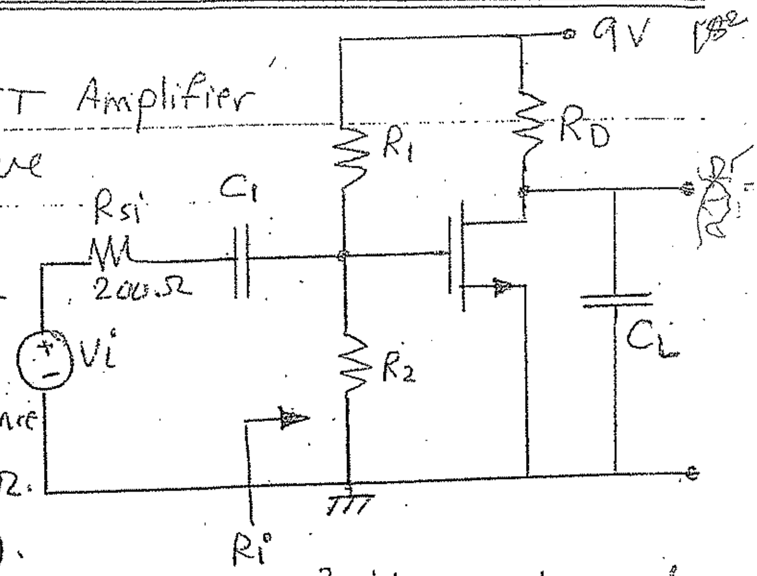
$f_L = 0$

$B.W = 30 - 0$

$= 30$

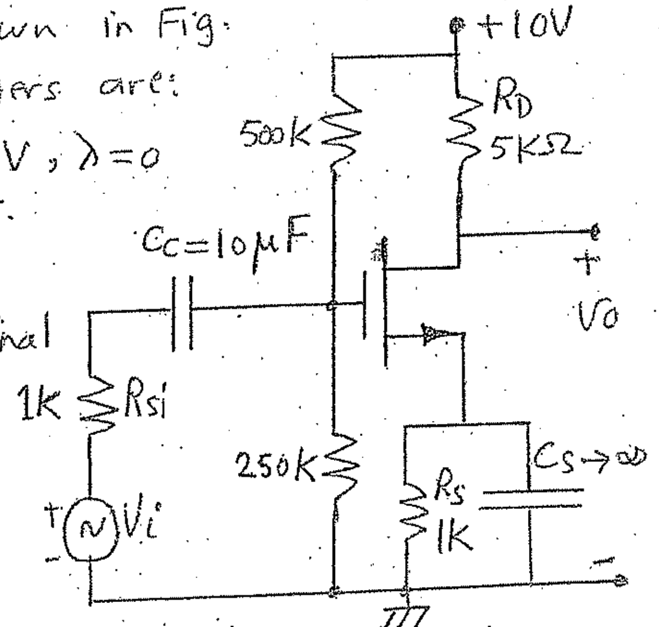
Sheet No. 1 Frequency Response Dr. Hadi AL-ITHA

Q1: Design the MOSFET Amplifier shown in Fig. to have a midband voltage-gain of 10 and $f_L = 200\,HZ$, $f_H = 3\,KHZ$. The Amplifier input Resistance must not exceed $36\,K\Omega$. (Find R_1, R_2, C_1, C_L, R_D).



* Use a MOSFET with $K_n = 0.3\,mA/V^2$, $V_T = 1V$ biased at $I_{DQ} = 0.2\,mA$.

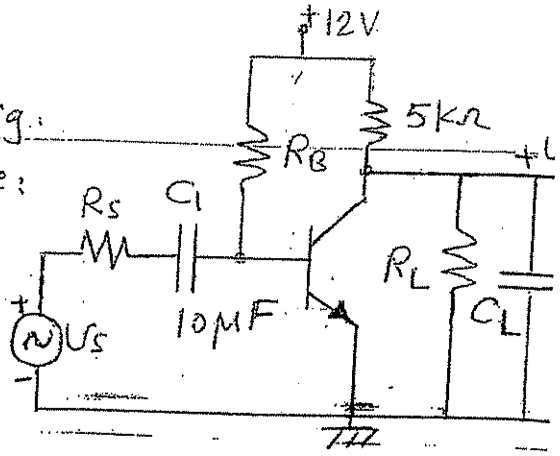
Q2: For the circuit shown in Fig. The MOSFET parameters are:
$K_n = 1\,mA/V^2$, $V_{TN} = 2V$, $\lambda = 0$
$C_{gs} = 5\,pF$, $C_{gd} = 1\,pF$



1) Draw the Small-Signal Equivalent cct. at low-, Medium- and high-frequency.
2) Calculate f_L and f_H, B.W and the midband voltage-gain.
3) Sketch the frequency Response of the Amp. indicating $|A_{vm}|_{dB}$ versus frequency.

Q3: For the circuit shown in Fig.: the transistor parameters are: $\beta = 100$, $V_{BE} = 0.7V$, $V_A = \infty$, Neglect transistor internal capacitances,

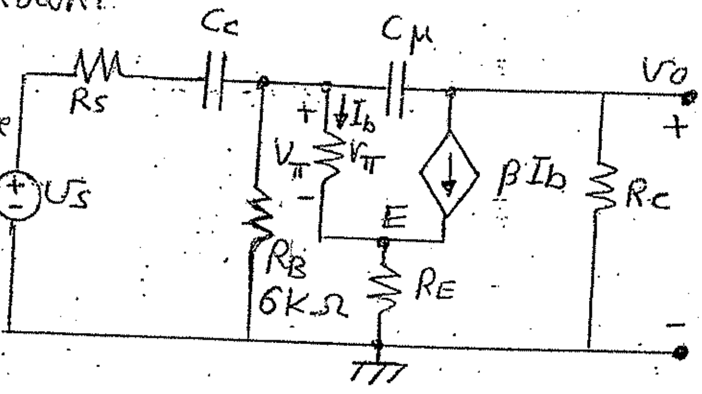
1) Draw the low-, Midband. and high-Frequency Eqnt. circuits.
2) Calculate $|A_m|_{dB}$, f_L and f_H.
3) Sketch the frequency Resp.



$R_B = 1M\Omega$
$R_L = 500k\Omega$
$C_L = 10pF$
$R_S = 1K\Omega$

Q4: For the Eqnt. circuit shown: $R_S = 4K\Omega$, $R_E = 400\Omega$, $R_C = 2K\Omega$ and the device has $g_m = 70mA/V$, $r_\pi = 2K$, $\beta = 100$. $C_\mu = 5pF$.

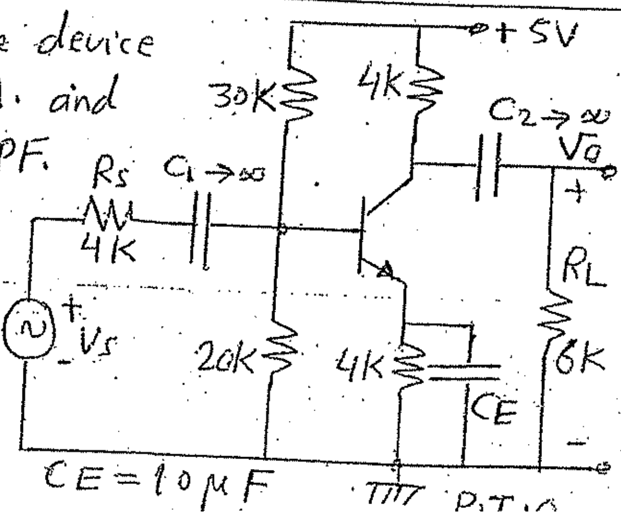
1) Calculate C_c required to give $f_L = 35 HZ$.



2) Calculate A_m, f_H and sketch the frequency Resp.

Q5: For the circuit shown the device is biased at $I_{CQ} = 0.32mA$. and has $V_A = 200V$, $\beta = 120$. $C_\mu = 1PF$. unity-gain freq. $f_T = 600MHZ$.
$(f_T = \frac{g_m}{2\pi(C_\mu + C_\pi)})$.

1) Calculate f_L; f_H, $|A_m|_{dB}$.
2) Sketch the freq. Response.



$C_E = 10\mu F$

P.T.O