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The following topics will be studied:

1) BJT Amplifiers (CH. 6)
2) MOSFET Amplifiers. (CH. 4)
3) Operational Amplifier (CH. 9)
4 Amplifier frequency Response. (CH. 7)

BJT Amplifiers

Amplifier: It is a linear circuit used to magnify A.c input signal. Any amplifier contains:

D.c Sources: To bias the BJT in F.A.M with a certain operating point (V_{CEQ}, I_{CQ}).

A.c Source: to apply the required A.c input.

Resistors: for biasing and for voltage and current controlling.

Capacitors: D.c blocking, A.c coupling.

Single-Stage BJT Amp's.

The are three basic S.S. Amplifiers according to the Common terminal.

a) Common-Emitter Amplifier

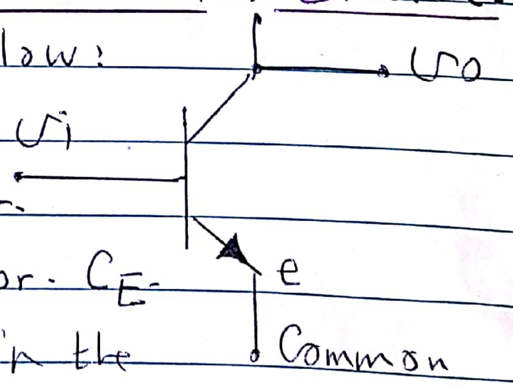
E → Comm. Terminal, input to base, V_o from C. and can be classified as follow:

i- Basic C.E Amp.

ii- C.E with Emitter resistor.

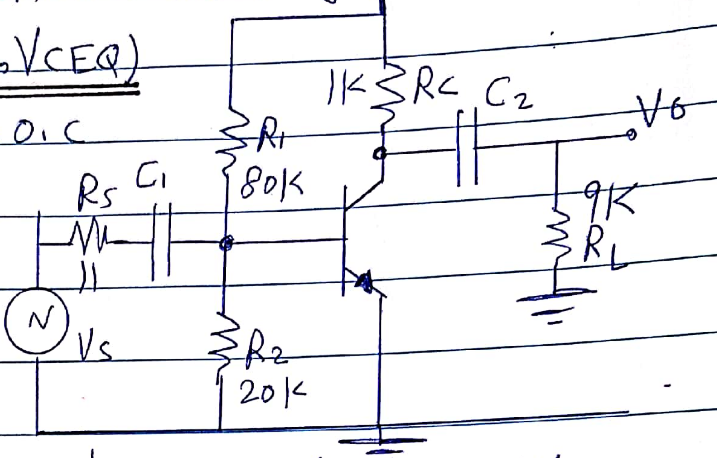
iii- C.E with bypass Capacitor. C_E.

each cct. will be discussed in the following:



i) Basic Common-Emitter Amp

The BJT must be biased in F.A.M to be used as an Amp. So we must first perform D.C analysis and be sure that the BJT is in F.A.M, then start A.C analysis. Assume the cct. shown in Fig. $+V_{CC} = 5V$:



* Determine Q-pt (Find I_{CQ}, V_{CEQ})

* For D.C analysis all Caps → O.C

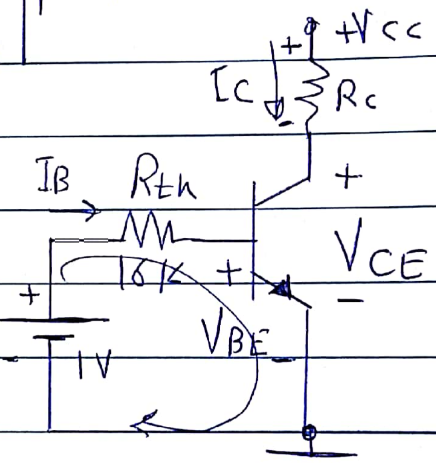
$R_{th} = R_1 // R_2 = 16\,K\Omega$

$V_{th} = \frac{V_{CC} R_2}{R_1 + R_2} = \frac{5 \times 20}{100} = 1V$

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

$I_B = \frac{(V_{th} - V_{BE})}{R_{th}} = \frac{(1 - 0.6)V}{16k} = 25\,\mu A$ | $\beta = 100$, $V_{BE} = 0.6V$

$I_C = \beta I_B = 100 \times 25 = 2.5\,mA$



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

$\therefore V_{CE} = 5 - 2.5 \times 1 = 2.5V$

Since $I_B > 0$

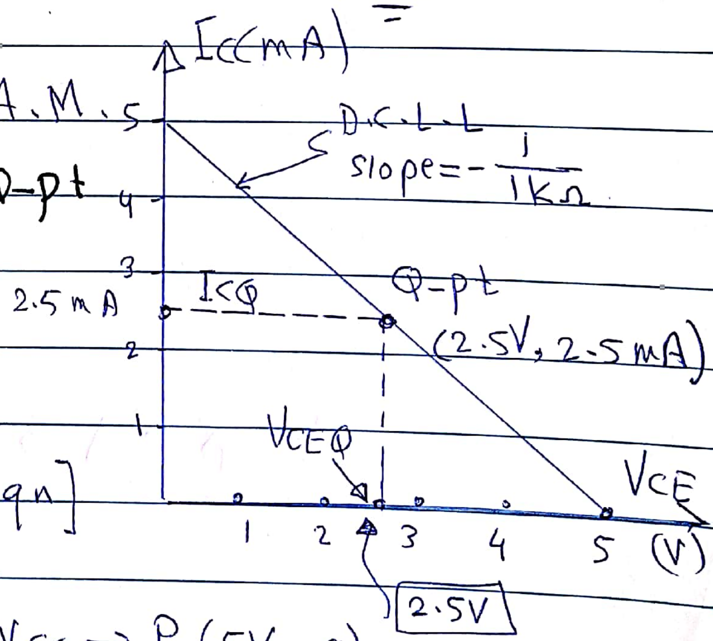
$\therefore$ B-E Jn. is Forward

and Since $V_{CE} > V_{BE}$

$\therefore$ B-C Jn. is reverse.

So the BJT is in F.A.M.

* Draw D.C.L.L indicating Q-pt and slope of D.C.L.L.



Write D.C.L.L eqn.

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

$V_{CE} = V_{CC} - I_C R_C$ [D.C.L.L eqn]

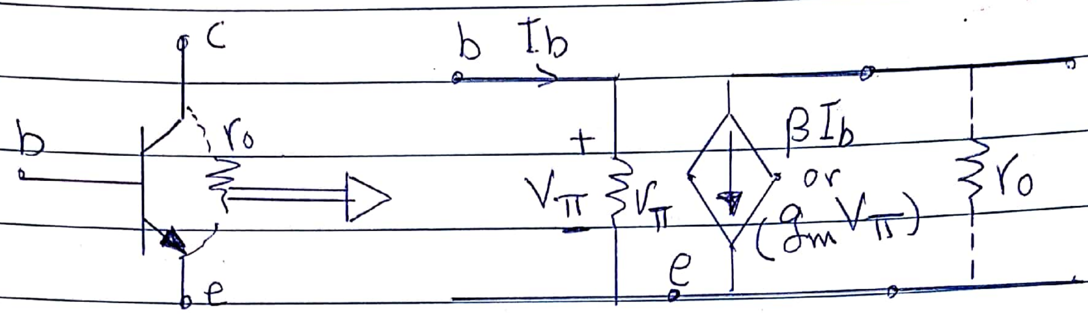
$\therefore$ Slope of D.C.L.L $= -\frac{1}{R_C}$

from eqn: i) For $I_C = 0$, $V_{CE} = V_{CC} \Rightarrow P_1(5V, 0)$.

for $V_{CE} = 0$, $I_C = \frac{V_{CC}}{R_C} = \frac{5V}{1k} = 5mA$ $P_2(0, 5mA)$.

A.C Analysis

To perform A.C Analysis, the BJT must be replaced by it model (equivalent cct.) called [hybrid-π] model



In this model: r_π : base-emitter resistance

and is given by: $\boxed{r_\pi = \frac{\beta V_T}{I_{CQ}}}$

$\beta \to$ given , V_T = thermal voltage, $V_T = 0.026V = 26mV$

I_{CQ}: Collector Current.

g_m: Transconductance (mA/V)

and given by: $\boxed{g_m = \frac{I_{CQ}}{V_T}}$

and If the BJT output resistance is considered (r_o), then it will added as shown (between C & e).

and it is given by: $\boxed{r_o = \frac{V_A}{I_{CQ}}}$

where: V_A: is Early Voltage it is given ($50V \to 300V$)

*NOTE: If $V_A = \infty$ or NOT given, then $r_o = \infty$.

EXAMPLES: For the cct. shown calculate

A_v: Voltage-gain $\to A_v = \frac{V_o}{V_s}$

A_I: Current gain $\to A_I = \frac{I_o}{I_s}$

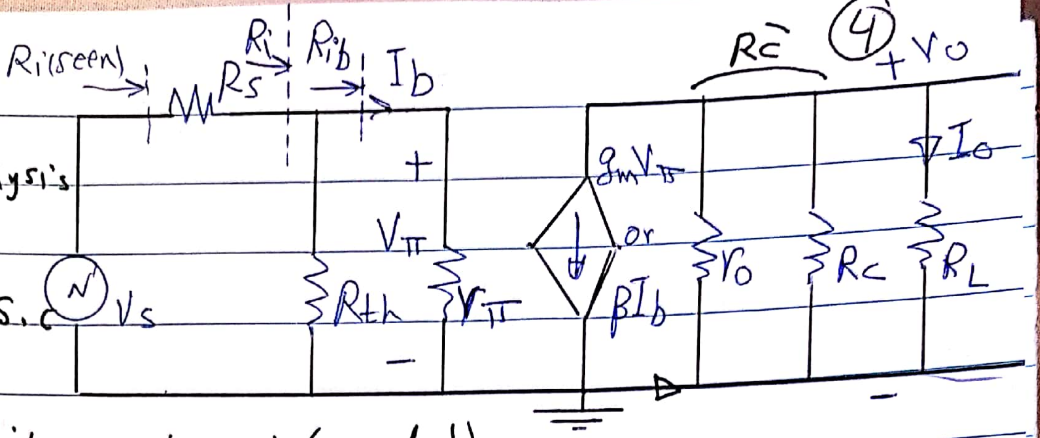
R_{in}: Input Resistance.

R_o: output "

* The A.C equivalent cct. is shown in the next page

* The A.C analysis is shown next page.

* For A.C analysis:
* all Caps → S.C
* all D.C Sorces → S.C
* The BJT is replaced by its eqvl. cct (model).



① Small-signal voltage-gain: $A_V = \frac{V_o}{V_s} = \frac{V_o}{V_\pi} \times \frac{V_\pi}{V_s}$

$V_o = -g_m V_\pi \bar{R_L} \Rightarrow \boxed{\frac{V_o}{V_\pi} = -g_m \bar{R_L}}$ where $\bar{R_L} = r_o \| R_c \| R_L$

$V_\pi = \frac{V_s \cdot R_i}{R_i + R_s} \Rightarrow \boxed{\frac{V_\pi}{V_s} = \frac{R_i}{R_i + R_s}}$ where $R_i = r_\pi \| R_{th}$ "using voltage division Rule"

$$\boxed{\therefore A_V = -g_m \bar{R_L} \frac{R_i}{R_i + R_s}}$$

(−) means 180° phase-shift between Vo and Vs

$g_m = \frac{I_{CQ}}{V_T} = \frac{2.5 mA}{26 mV} = 96.154\ mA/V$

$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{100 \times 26 mV}{2.5 mA} = 1.04 K\Omega$, $r_o = \frac{V_A}{I_{CQ}} = \frac{100V}{2.5 mA} = 40k$

$R_i = r_\pi \| R_{th} = 1.04 \| 16K = 0.976 K\Omega$

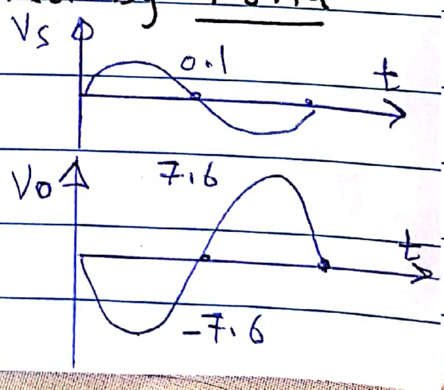
$\therefore \frac{V_o}{V_\pi} = -96.154 (40 \| 1 \| 9) = -96.154 \times 0.88 = \boxed{-84.6}$

$\frac{V_\pi}{V_s} = \frac{R_i}{R_i + R_s} = \frac{0.976}{0.976 + 0.1} = 0.9$

$\therefore A_V = -84.6 \times 0.9 = -76.14$

i.e. $V_o = -76.14 V_s \Rightarrow V_s$ is amplified by 76.14 and inverted by 180°.

[If (For exA: $V_s = 0.1 \sin \omega t$ V then $V_o = -7.614 \sin \omega t$ V")]



2 Small-Signal Current-gain $A_I = \frac{I_o}{I_s} = \frac{I_o}{I_b} \times \frac{I_b}{I_s}$

Using Current-division Rule "CDR" [From eqnt. cct),

$I_o = -\beta I_b \frac{R_C'}{R_C' + R_L} \rightarrow \boxed{\frac{I_o}{I_b} = -\frac{\beta R_C'}{R_C' + R_L}}$ where $R_C' = r_o // R_C$

$I_b = \frac{I_s \cdot R_{th}}{R_{th} + r_\pi}$ (CDR) $\rightarrow \boxed{\frac{I_b}{I_s} = \frac{R_{th}}{R_{th} + r_\pi}}$

$\therefore A_I = -\frac{\beta R_C'}{R_C' + R_L} \cdot \frac{R_{th}}{R_{th} + r_\pi}$ $\quad R_C' = R_C // r_o = 1 // 40 = 0.975K$

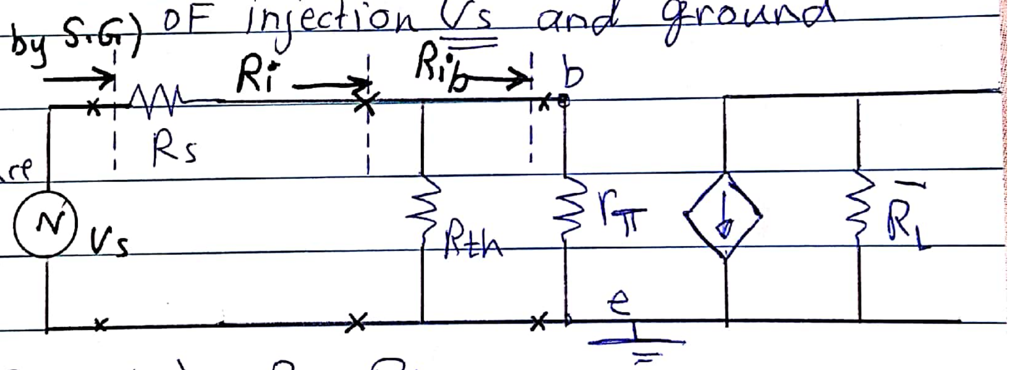
$\boxed{A_I} = -\frac{100 \times 0.9756}{0.9756 + 9} \cdot \frac{16}{16 + 1.04} = \boxed{-9.183}$

this means that "I_s is amplified by 9.183 and Inverted by 180°."

3 Input Resistance R_i: "The resistance between the node of injection V_s and ground"

$R_i = (R_{th} // r_\pi)$

R_{ib}: Input resistance Seen by the base



R_i(seen by Signal Generator) $= R_s + R_i$

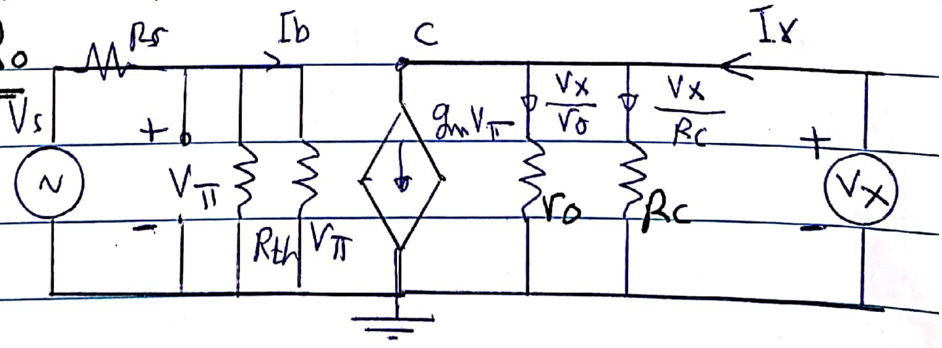
So $R_{ib} = r_\pi = 1.04 K\Omega$

$R_i = R_{th} // r_\pi = 0.976 K\Omega$

R_i(Seen by S.G) $= 0.1 + 0.976 = 1.076 K\Omega$

4 output Resistance: R_o

$R_o = \frac{V_x}{I_x}\Big|_{V_s = 0}$



Write KCL at Node ©:

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

but when $V_s = 0 \Rightarrow V_\pi = 0 \Rightarrow g_m V_\pi = 0$

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

$\therefore \boxed{R_o = R_C // r_o}$

OR: we can say: when $V_s = 0, V_\pi = 0$ or $I_b = 0$, So the current source $g_m V_\pi = \beta I_b = 0$ i.e it is open

So we can write $\boxed{R_o = r_o // R_C}$

$R_o = 1K // 40K = 0.9756 K\Omega$

Av and AI Relation:

We can find Av interms of AI and Vise-Versa

i) Av interms of AI:

$$A_V = \frac{V_o}{V_s} = \frac{I_o R_L}{I_s(R_s + R_i)} = A_I \frac{R_L}{R_s + R_i}$$

ii) AI interms of Av:

$$A_I = I_o / I_s = \frac{(V_o / R_L)}{(V_s / R_s + R_i)} = \frac{V_o}{V_s} \frac{R_s + R_i}{R_L} = A_V \frac{R_s + R_i}{R_L}$$

Be Carful!!! $V_o = I_o . R_L$ and $I_o = V_o / R_L$

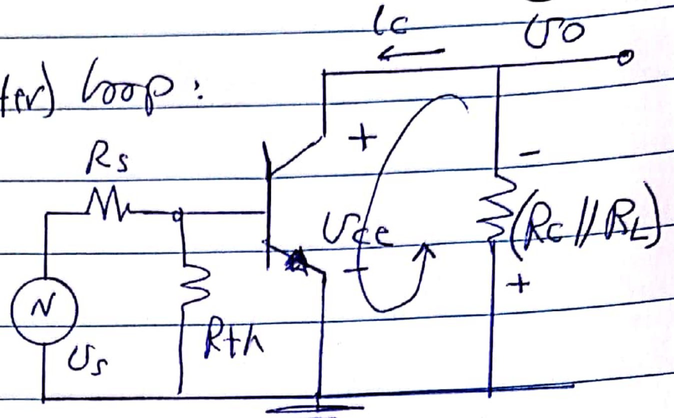
A.C. Load-line: a straight line drawn on transistor output characteristics relates a.c voltage and current (V_{ce}, i_c) with cct. elements. It intersects with D.C.L.L at Q-pt. and has a certain slope.

* The intersections with V_{ce} & i_c axis represent the max. values for i_c and V_{ce} for the cct.

Write KVL For (collector-emitter) loop:

$v_{ce} + i_c (R_C // R_L) = 0$

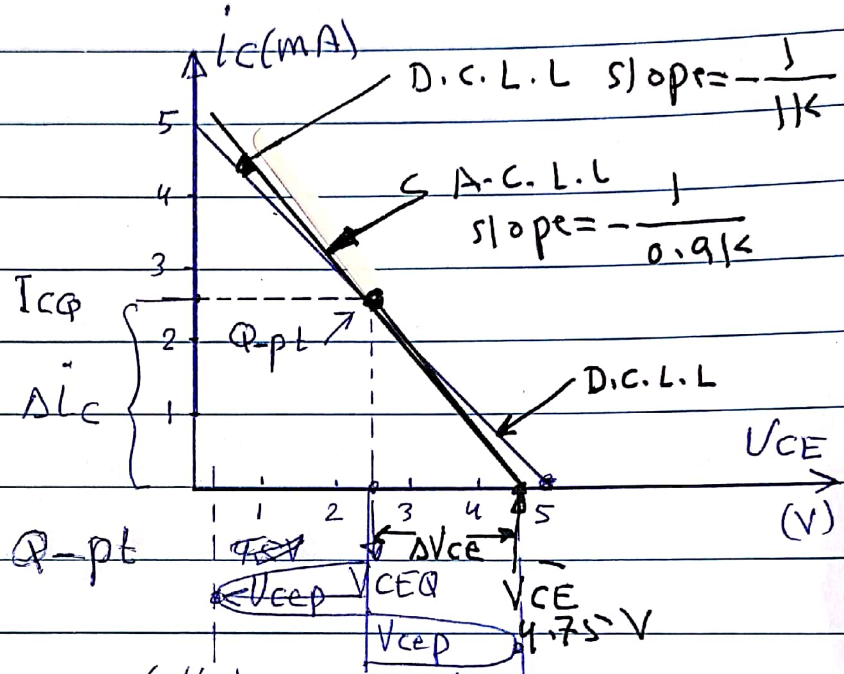
$\therefore \boxed{v_{ce} = -i_c (R_C // R_L)}$ A.C.L.L eqn.



A.C circuit

Slope of A.C.L.L $= -\dfrac{1}{(R_C // R_L)}$

* It is a straight line passing through Q-pt. and has a slope $= -\dfrac{1}{R_C // R_L}$



* To Find another pt

(slope) $= \dfrac{1}{(R_C // R_L)} = \dfrac{\Delta i_c}{\Delta V_{ce}}$

$\therefore \Delta V_{ce} = \Delta i_c (R_C // R_L)$

Since it passes through Q-pt

So $\Delta i_c = I_{CQ}$

$\therefore \Delta V_{ce} = I_{CQ} (R_C // R_L) = 2.5(1//9) = 2.25V$

$\overline{V_{CE}} = \Delta V_{ce} + V_{CEQ} = 2.5 + 2.25 = 4.75V$

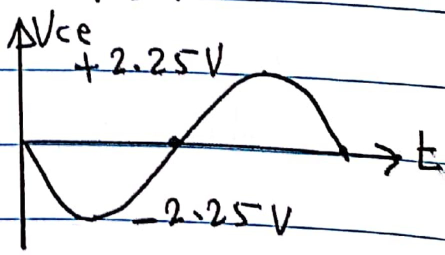
$\therefore$ We have two pts. and we can draw A.C.L.L

* **Maximum peak-to-peak Symmetrical Swings:**

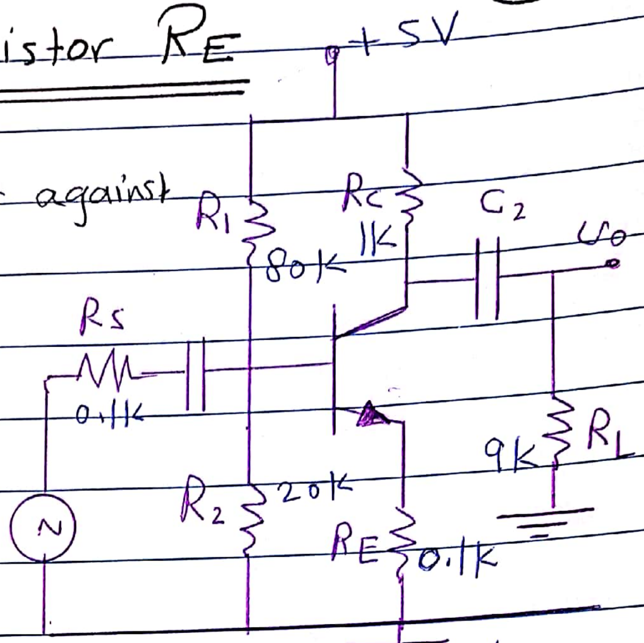
It is the Max. (p-to-p) Symmetrical v_{ce} Voltage without distortion. i.e $v_{ce}(peak) = \Delta V_{ce} = I_{CQ}(R_C // R_L) = 2.25V$

So $v_{ce}(p\text{-}p)_{max} = 2\Delta V_{ce} = 4.5V$ as Shown.

i.e For this cct.: the Max. peak-to-peak v_{ce} Voltage without distortion and Symmetrical is 4.5V



ii) C.E with Emitter Resistor R_E

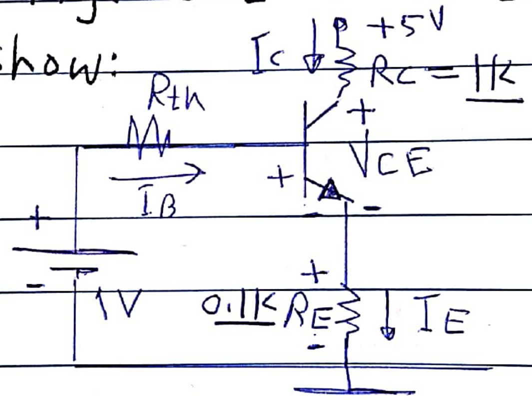


"R_E is used to stabilize Q-pt against β Variation".

Consider the Basic-C-E cct. disscused befor "without R_E" with $\beta = 100$, $I_{CQ} = 2.5mA$, $V_{CEQ} = 2.5V$. the BJT was in FAM.

* When $\beta = 200$, then $I_{CQ} = 5mA$, $V_{CE} = 0$, the BJT will be in Saturation mode and Can't be Used as an Amp.*

* IF R_E is Connected as in this Fig. "C.E with R_E" the D.C analysis will be as show:



$R_{th} = 80 // 120 = 16K\Omega$

$V_{th} = \frac{5 \times 20}{100} = 1V$

$-V_{th} + I_B R_{th} + V_{BE} + I_E R_E = 0$

but $I_E = (\beta + 1) I_B$

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

$\beta = 200$, $V_{BE} = 0.6V$

For $\beta = 200$

$\therefore I_B = \frac{(1 - 0.6)V}{16 + 201 \times 0.1} = 0.011 mA$, $I_{CQ} = \beta I_B = 2.216mA$

$I_{EQ} = (\beta + 1) I_B = 2.227mA$

$V_{CEQ} = 5 - I_C R_C - I_E R_E = 5 - 2.216 - 0.2227 = 2.561V$

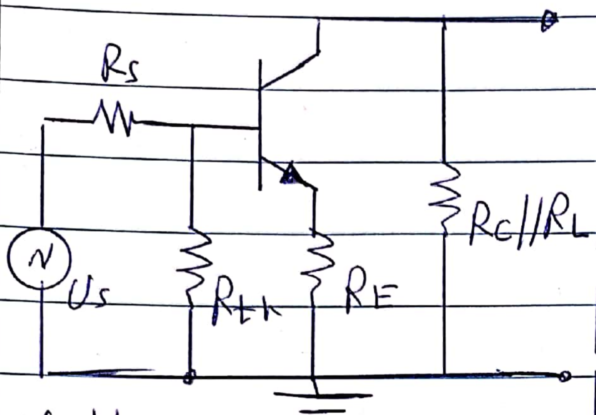
* The BJT is in F.A.M !!!

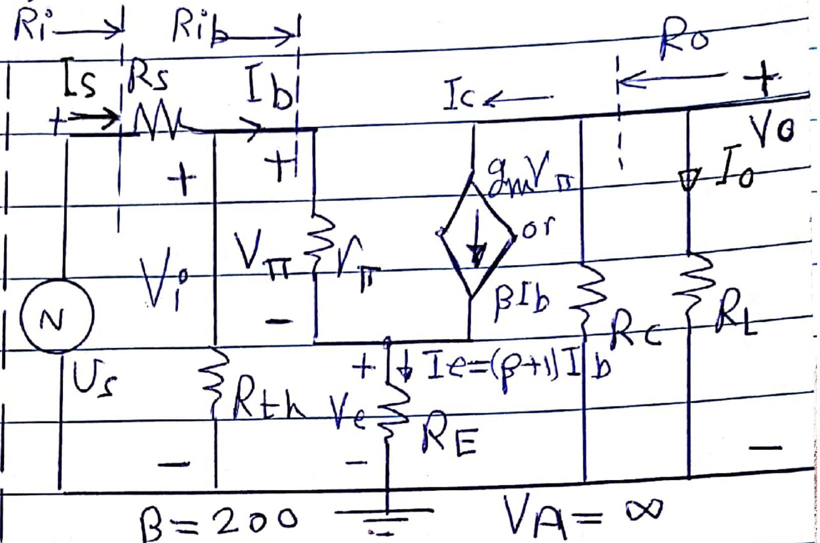
i.e R_E stabilize Q-pt and the BJT is in FAM even when $\beta = 200$.

A.C Analysis of C.E with R_E

Calculate A_V, A_I, R_{ib}, R_i and R_o

* For A.C Analysis: Caps → S.C, D.C Sources → S.C





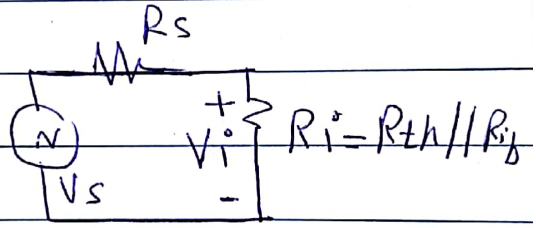
$\beta = 200$ $V_A = \infty$

Voltage gain:

$$A_V = \frac{V_o}{V_s} = \frac{V_o}{V_i} \times \frac{V_i}{V_s}, \quad V_o = -\beta I_b (R_C // R_L)$$

$$-V_i + V_\pi + V_e = 0 \Longrightarrow V_i = V_\pi + V_e = I_b(r_\pi + (\beta+1)R_E)$$

$$\therefore \frac{V_o}{V_i} = \frac{-\beta(R_C//R_L)}{r_\pi + (\beta+1)R_E}$$



$V_i = (V_s \cdot R_i) / R_i + R_s$ (VDR)

$$\therefore \frac{V_i}{V_s} = \frac{R_i}{R_i + R_s} \quad \text{where } R_i = R_{th} // R_{ib}$$

$$\boxed{\therefore A_V = \frac{-\beta(R_C//R_L)}{r_\pi + (\beta+1)R_E} \cdot \frac{R_i}{R_i + R_s}}$$

this means that "R_E reduces A_V"

However: $R_i = R_{th} // R_{ib}$

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

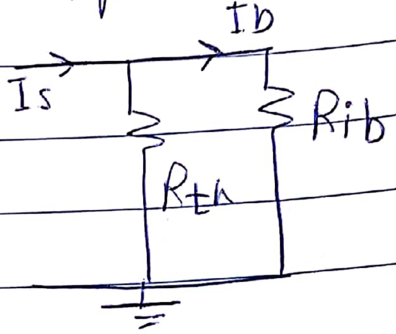
$\therefore R_i = R_{th} // R_{ib} = 16 // 22.446 = 9.341\ k\Omega$

$$A_V = \frac{-200 \times 0.9}{2.346 + 20.1} \cdot \frac{9.341}{9.341 + 0.1} = \boxed{-7.934}$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{200 \times 26}{2.216\ mA} = 2.346\ k\Omega$$

$R_{ib} = 2.346 + 201 \times 0.1 = 22.446\ k\Omega$

$R_o = \frac{V_x}{I_x}\Big|_{V_s=0}$ when $V_s=0$, $I_b=0$, $\beta I_b = 0 \rightarrow$ o.c



∴ $R_o = R_C = 1K\Omega$.

$A_I = \frac{I_o}{I_s} = \frac{I_o}{I_b} \times \frac{I_b}{I_s}$

$I_o = -\frac{\beta I_b R_C}{R_C+R_L} \rightarrow \frac{I_o}{I_b} = \frac{-\beta R_C}{R_C+R_L}$

$I_b = \frac{I_s \cdot R_{th}}{R_{th}+R_{ib}}$ (CDR) $\rightarrow \frac{I_b}{I_s} = \frac{R_{th}}{R_{th}+R_{ib}}$

$\boxed{∴ A_I = \frac{-\beta R_C}{R_C+R_L} \cdot \frac{R_{th}}{R_{th}+R_{ib}}} = \frac{-200\times 1}{1+9} \cdot \frac{16}{16+22.46} = \boxed{-8.32}$

OR: $\boxed{A_I} = \frac{I_o}{I_s} = \frac{(V_o/R_L)}{V_s/R_s+R_i} = A_V \frac{R_s+R_i}{R_L} = \boxed{-8.32}$

* Compare to Basic C.E Amp., C.E with R_E has the following ~~effects~~ characteristics:
* Stabilize Q-pt against β-Variation (D.C) Advantages
* Reduce Av & AI (Disadvantages)
* Increase Ri (Advantages).
* Stabilize Av & AI against β-Variation (Advantages)

as in the following.

Consider the eqn. For $A_V = \frac{-\beta(R_C//R_L)}{r_\pi + (\beta+1)R_E} \cdot \frac{R_{in}}{R_{in}+R_s}$

* IF $r_\pi << (\beta+1)R_E$ & $\beta >> 1$ & $R_i >> R_s$, then

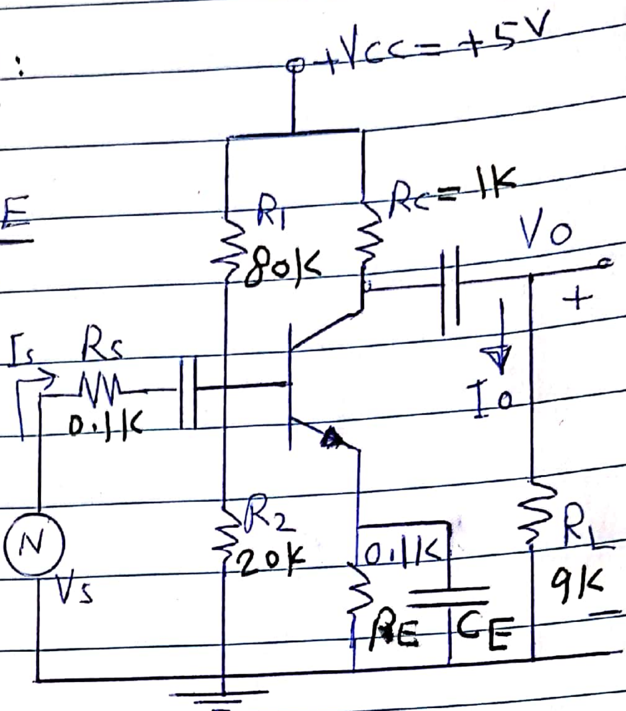
$\boxed{A_V \simeq -\frac{(R_C//R_L)}{R_E}}$. This means Av is approximatly becomes independant on β.

* For this cct. $A_V = -\frac{(9//1)}{0.1} \simeq \boxed{-9}$

iii) C.E with bypass Cap. C_E:

To gain the advantages of R_E and Reduce its disadvantages of Reducing A_V & A_I.

* C_E is connected across R_E



1) * For D.C Analysis

ALL Caps → O.C and the cct. is analyzed as C.E with R_E and hence R_E stabilize Q-pt.

$\beta = 200$, $V_{BE} = 0.6V$

$V_A = \infty$.

* From previous analysis:

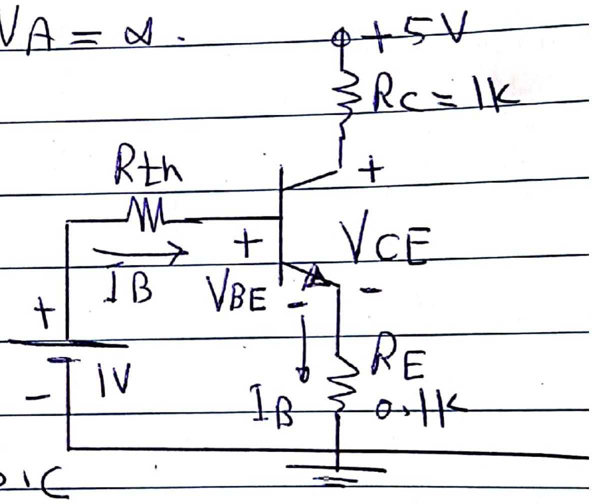
$I_{BQ} = 0.011mA$

$I_{CQ} = 2.216mA$

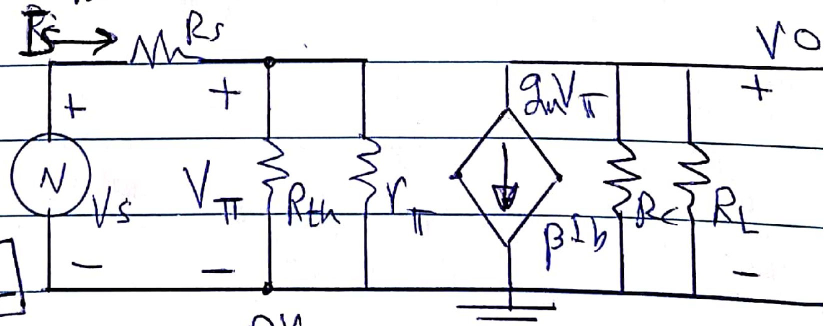
$I_{EQ} = 2.227mA$

$V_{CEQ} = 2.561V$

* BJT in F.A.M.



2) For A.C Analysis, all Caps → S.C the cct. is analyzed as Basic C.E Amp.



$A_V = -g_m (R_C // R_L) \dfrac{R_i}{R_i + R_s}$

$\boxed{R_i} = r_\pi // R_{th} = \boxed{2.046 K\Omega}$

$r_\pi = \dfrac{\beta V_T}{I_{CQ}} = 2.346 K\Omega$

$A_V = -85.23 (1//9) \dfrac{2.046}{0.1 + 2.046}$

$= \boxed{-73.13}$

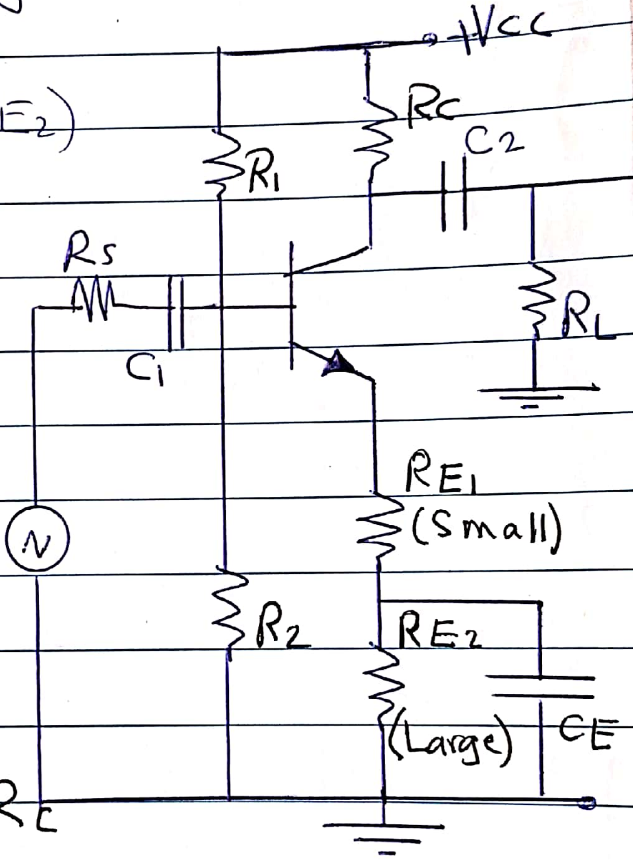
$R_i = 2.346 // 16 = \boxed{2.046 K\Omega}$

$A_I = A_V \dfrac{R_i + R_s}{R_L} = \boxed{-17.438}$

$g_m = I_{CQ}/V_T = 85.23 mA/V$

Note: when C_E is connected. D.C values unchanged but $A_V \rightarrow$ increase, $A_I \rightarrow$ Increase but $R_i \rightarrow$ decrease !!!

* In this case we ~~loose~~ have lost the advantages of high R_i and A_V & A_V stability. so Sometimes R_E is made consisting of two parts R_{E1} & R_{E2} then Connect C_E across the large R_E value, then we can gain all the advantages of R_E and minimize its disadvantages.



* For D.C analysis both $(R_{E1}+R_{E2})$ are included.
* For A.C Analysis, only R_{E1} is considered and since it is small, so it will NOT affect A_V, A_I, R_i too much.
* R_{E2} is short out for A.C Analysis and NOT affect A_V, A_I, R_i.
* For D.C.L.L, R_{E1} & R_{E2}, R_C both are present.

D.C.L.L slope $= -\dfrac{1}{R_C + (R_{E1}+R_{E2})\dfrac{\beta+1}{\beta}}$

* A.C.L.L, R_C, R_L, R_{E1}

$$\text{slope} = \frac{-1}{(R_C // R_L) + \frac{\beta+1}{\beta} R_{E1}}$$

(2) Common-Collector Amplifier.
" Emitter-follower "

$V_S \rightarrow$ base
V_o From E
$C \rightarrow$ Common Terminal

Fig.1 shows the Standered C-C Amp. where the Collector is Connected directly to V_{cc} which is grounded For a.c Signals.

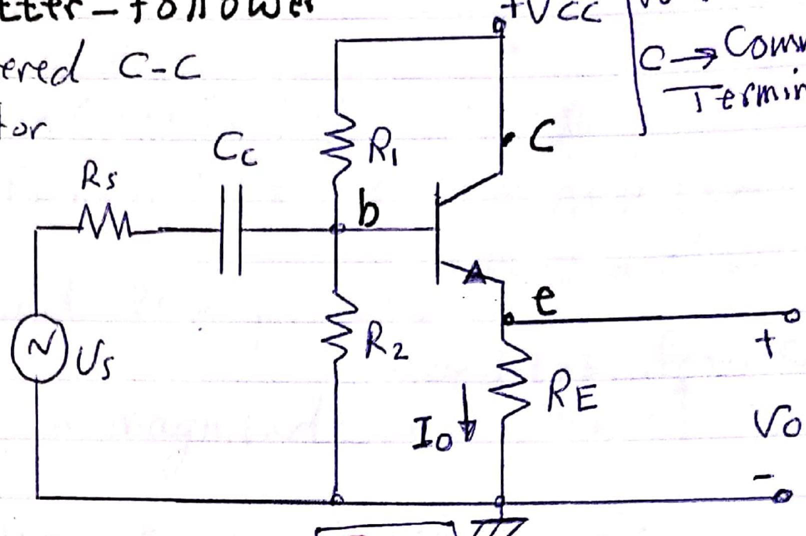


Fig.1

* This cct. can be Analysed as C-E with Emitter Resist. and taking the o/p from Emitter (Fig.2) or can be redrawn as in Fig.3 and treated as (C-C) with all signal ground at the Same point.

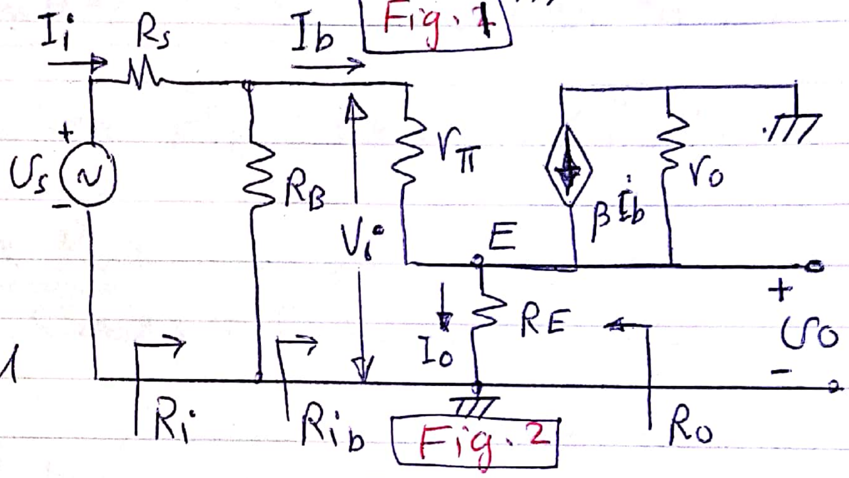


Fig.2

* However both Eqnt. ccts. will give the Same Amplifier parameters expression.

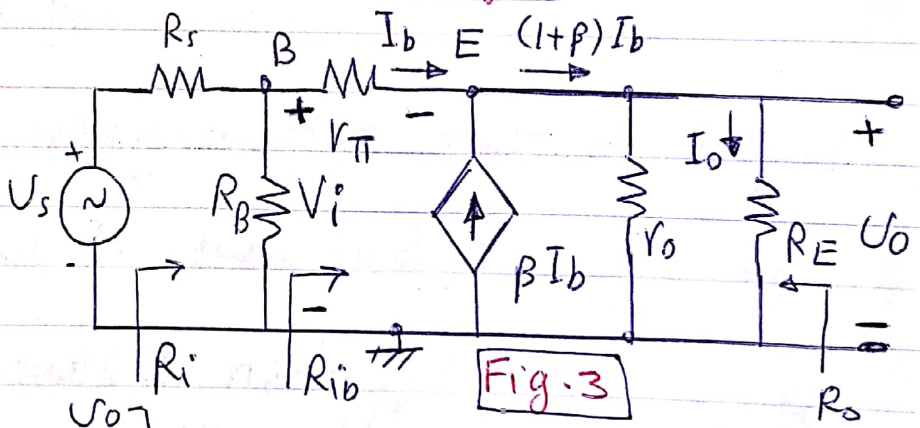


Fig.3

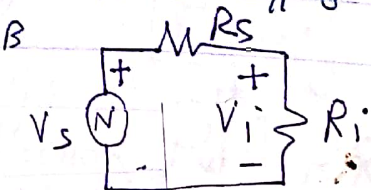
From Fig.3

Voltage-gain: $\left[A_v = \frac{V_o}{V_s}\right]$

$$V_o = (1+\beta) I_b (r_o \| R_E) \quad , \quad V_i = V_o + V_\pi = \overbrace{(1+\beta) I_b (R_E')}^{V_o} + \overbrace{I_b r_\pi}^{V_\pi}$$

$R_E' = R_E \| r_o$

$$\frac{V_i}{V_s} = \frac{R_i}{R_i + R_s} \quad \text{where} \quad R_i = R_{ib} \| R_B$$



$$\frac{V_i}{I_b} = R_{ib} = r_\pi + (1+\beta)(R_E \| r_o)$$

$$\left(\frac{V_o}{V_i}\right) = \frac{(1+\beta)(R_E \| r_o)}{r_\pi + (1+\beta)(R_E \| r_o)}$$

$$\frac{V_o}{V_s} = \frac{V_o}{V_i} \times \frac{V_i}{V_s} = \boxed{\frac{(1+\beta)(R_E \| r_o)}{r_\pi + (1+\beta)(R_E \| r_o)} \quad \frac{R_i}{R_i + R_s}}$$

For $R_i \gg R_s$, $(1+\beta)(R_E \| r_o) \gg r_\pi$, then ① $A_v \approx 1$ ✓
② $\phi = 0°$ ✓

$\boxed{A_v \simeq 1}$ (Unity and zero phase).

i.e $\underline{V_o}$ follows $\underline{V_s}$ in magnitude and ~~phase~~ phase and taken from C so

It is called (Emitter- Follower). ③ high R_i ✓

$R_i = R_B \| R_{ib}$ where $R_{ib} = r_\pi + (1+\beta)(R_E \| r_o)$

Output Resistance R_o:

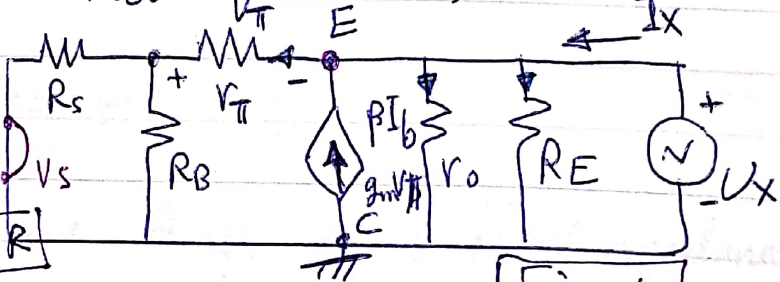
Conside the eqnt. cct. shown in Fig.4

* R_o can be found by:

setting $V_s = 0$, applying a voltage Source at output V_x which will cause I_x , then find $R_o = \dfrac{V_x}{I_x}$ by writting KCL at output node. (Node E)

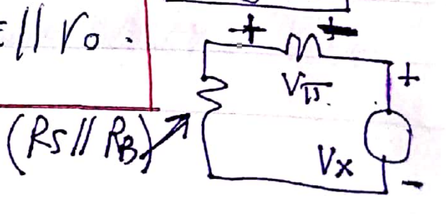
$$g_m V_\pi + I_x = \frac{V_x}{r_o} + \frac{V_x}{R_E} + \frac{V_x}{(R_s \| R_B) + r_\pi}$$

then Subt. $V_\pi = -\dfrac{V_x\, r_\pi}{r_\pi + (R_s \| R_B)}$ $\boxed{VDR}$



$\boxed{\text{Fig.4}}$

and Find $\dfrac{V_x}{I_x} = \boxed{R_o = \left(\dfrac{r_\pi + (R_s \| R_B)}{1+\beta}\right) \| R_E \| r_o.}$

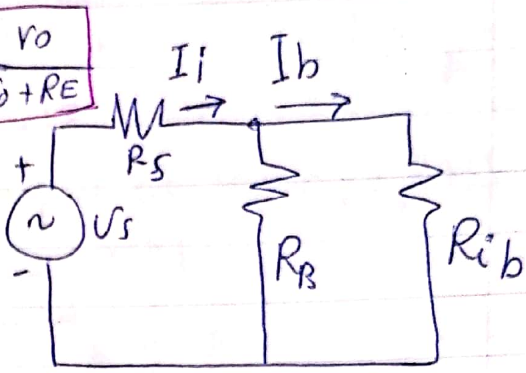


④ ~~⑧~~ Low R_o !! ✓

A.C Current-gain Ai:

$A_i = \frac{I_o}{I_i} = \frac{I_o}{I_b} \times \frac{I_b}{I_i}$, From Eqnt. cct.

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



and $I_b = I_i \frac{R_B}{R_B + R_{ib}}$

$\therefore \frac{I_b}{I_i} = \frac{R_B}{R_B + R_{ib}}$

$A_i = \frac{I_o}{I_b} \times \frac{I_b}{I_i} = (1+\beta) \frac{R_B}{R_B + R_{ib}} \frac{r_o}{r_o + R_E}$

For $r_o \gg R_E$, and $R_B \gg R_{ib}$ then

$\boxed{A_i \simeq 1+\beta}$ 5 high AI

Characteristics of C-C:

1) Approximatly unity Voltage-gain. ($A_v \simeq 1$)
2) Zero phase-shift.
3) high Current gain $A_i \simeq 1+\beta$.
4) High input impedance
5) Low output impedance

So it is used as S-S power Amp. or Buffer (impedance transformer) to provide No loading connection effect.
OR: minimize loading effect.

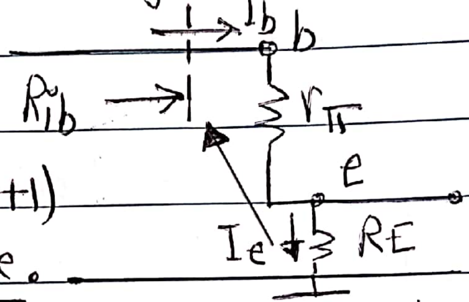
Resistance Reflection Rule "RRR" and Its Inverse "IRRR"

This rule used to calculate resistance looking from Emitter or base

R.R.R → reflection of resistance from E → B

It is based on that $I_e = (\beta+1) I_b$ and since $I \propto \frac{1}{R}$

So any resistance in the emitter, is seen from base by multiplying its value by a factor of $(\beta+1)$ as shown in Fig.



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

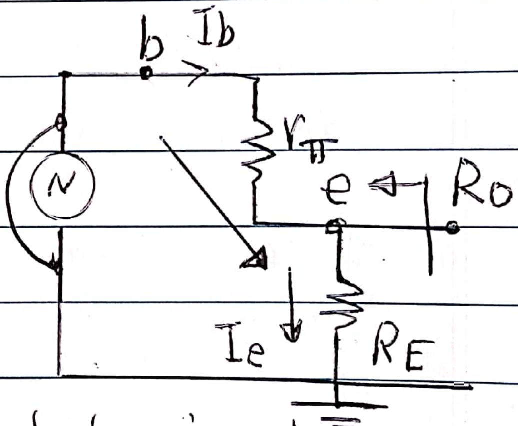
i.e R_E is multiplied by $(\beta+1)$ when it is seen from base.

∴ R.R.R → from e → to base multiply by $(\beta+1)$

*I.R.R.R: Reflection resistance from base to emitter

To reflect a resistance from base to emitter divide its value by $(\beta+1)$. i.e

r_π is seen from emitter to be $(r_\pi / \beta+1)$ So $\boxed{R_o = \left(\frac{r_\pi}{\beta+1}\right) // R_E}$



* So we can use this rule to calculate input or output resistance for C.C. Amp. directly without using voltage, current eqns. For example for R_i we can say: $R_i = R_{th} // R_{ib}$ and

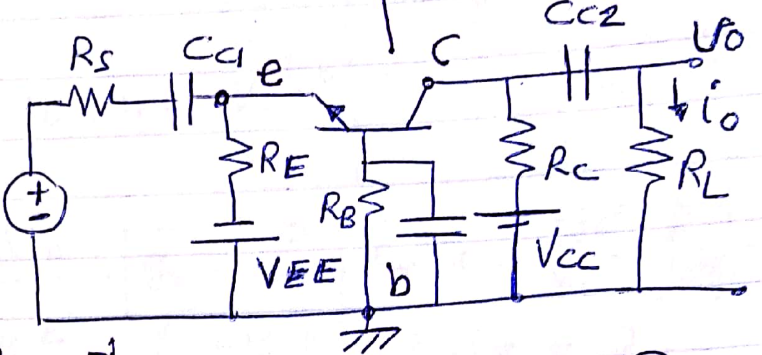
$R_{ib} = r_\pi + (\beta+1)(r_o // R_E)$ using R.R.R. $(e \to b)$

and: $R_o = \left[\frac{(R_s // R_{th}) + r_\pi}{\beta+1}\right] // r_o // R_E$ using IRRR $(b \to e)$

$V_s \rightarrow$ emitter
V_o From Collector
$B \rightarrow$ Common Ter.

③ Common-Base Amp

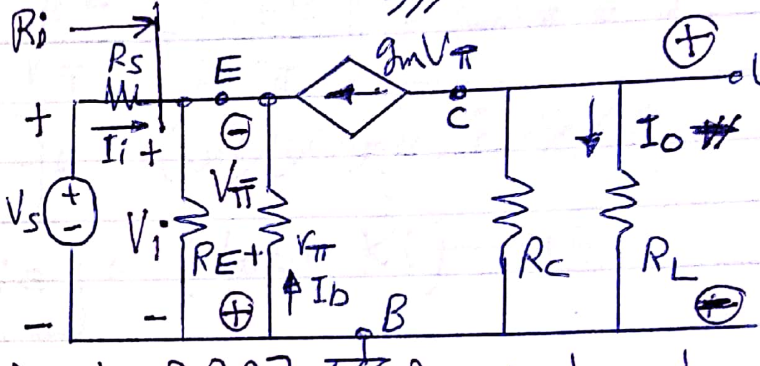
Voltage-gain:



$$A_v = \frac{v_o}{V_s} = \frac{V_o}{V_\pi} \times \frac{V_\pi}{V_s}$$

$$V_o = -g_m V_\pi (R_C // R_L)$$

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



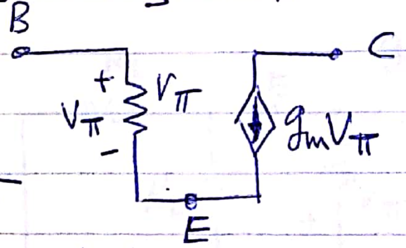
$$\frac{V_o}{V_i} = \frac{R_i}{R_i + R_s} \quad (V_i = -V_\pi)$$

where $R_i = \left(\frac{r_\pi}{1+\beta}\right) // R_E$] OR using RRR] A.C eqnt. cct.

① Low R_i

$$\therefore \frac{V_o}{V_s} = g_m (R_L // R_C) \frac{R_i}{R_i + R_s}$$

② $A_V \gg 1$



But $\frac{r_\pi}{1+\beta} \ll R_E \Rightarrow R_i \simeq \frac{r_\pi}{1+\beta}$

hybrid-π model

For $R_s = 0$, $\boxed{A_v \simeq g_m (R_L // R_C)}$

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

$$I_o = -g_m V_\pi \frac{R_C}{R_C + R_L} \quad \boxed{CDR}$$

$V_\pi = -I_i R_i$

$$V_\pi = \underbrace{\left[\left(\frac{r_\pi}{1+\beta}\right) // R_E\right]}_{R_i} I_i$$

~~KCL at Node E~~

KCL at E node

$$I_i + \frac{V_\pi}{R_E} + \frac{V_\pi}{r_\pi} + g_m V_\pi = 0$$

this will give

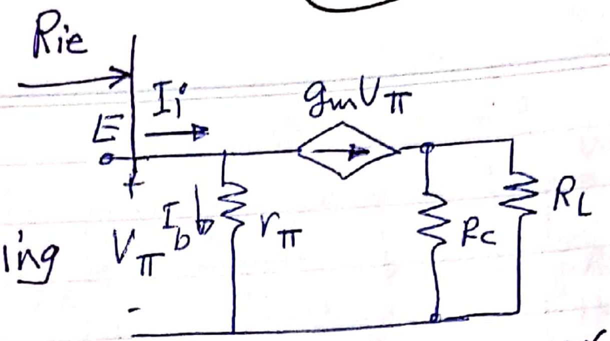
$$V_\pi = -I_i \left[\left(\frac{r_\pi}{1+\beta}\right) // R_E\right]$$

$$\therefore \frac{I_o}{I_i} = + g_m \frac{R_C}{R_C + R_L} \left[\left(\frac{r_\pi}{1+\beta}\right) // R_E\right]$$

Since $\frac{r_\pi}{1+\beta} \ll R_E$, and For $R_L = \infty$, then

③ $A_I \simeq 1$

$$A_i \simeq g_m \frac{r_\pi}{1+\beta} \simeq \frac{\beta}{1+\beta} \simeq 1$$



Input Resistance: Ri

$R_{ie} = \frac{V_\pi}{I_i}$ (Input Resistance looking to emitter.

$I_i = I_b + g_m V_\pi = \frac{V_\pi}{r_\pi} + g_m V_\pi$
$[I_b = V_\pi / r_\pi]$

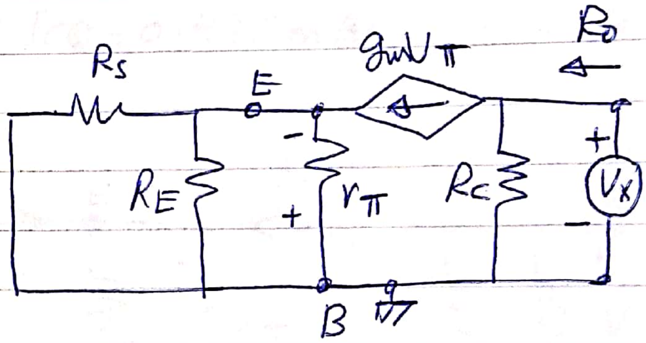
$\boxed{g_m = \frac{\beta}{r_\pi}}$ | $g_m r_\pi = \frac{I_{CQ}}{V_T} \times \frac{\beta V_T}{I_{CQ}}$ ∴ $g_m r_\pi = \beta$

$\frac{I_i}{V_\pi} = \frac{1}{r_\pi} + g_m = \frac{1}{r_\pi} + \frac{\beta}{r_\pi} = \boxed{\frac{1+\beta}{r_\pi}}$

∴ $V_\pi / I_i = \boxed{R_{ie} = \frac{r_\pi}{1+\beta}}$ ✓ (~~OR using R.R/R~~).

$\boxed{R_i = R_{ie} // R_E \simeq R_{ie}}$ ✓ (low Ri) → (4)

output Resistance: Ro



Setting $V_s = 0$ & Applying V_x at output terminal.

KCL at Node E gives

$g_m V_\pi + \frac{V_\pi}{r_\pi} + \frac{V_\pi}{R_E} + \frac{V_\pi}{R_s} = 0$ which gives $V_\pi = 0$

this means $g_m V_\pi = 0$ and Consequently

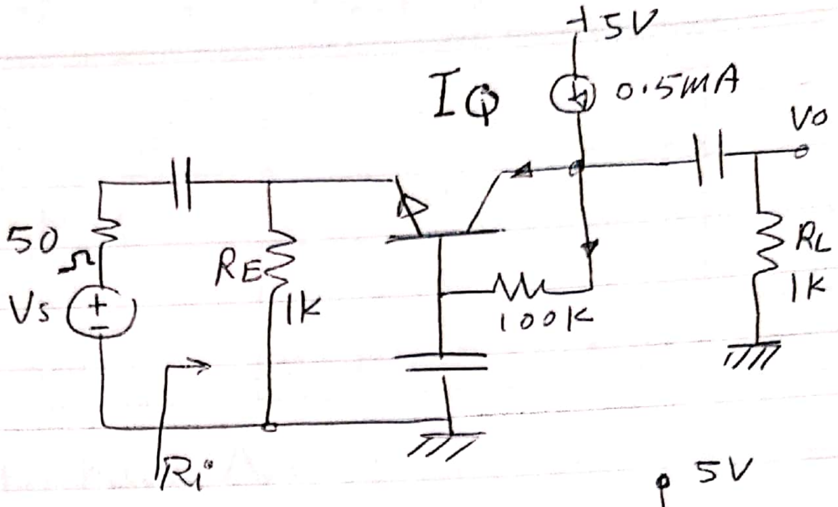
$R_o = R_C$ (high Since $r_o = \infty$)

main c/cs of C.B

1. High voltage gain ✓
2. low Current gain ($A_i \leq 1$) ✓
3. low input Resistance ✓
4. high output Resistance. ✓
5. Zero phase-shift. ✓

P 4.47 : $\beta = 100$, $V_A = \infty$

1) Find V_B, V_C, V_E
2) Find A_v, R_i



$I_E = I_Q = 0.5mA$

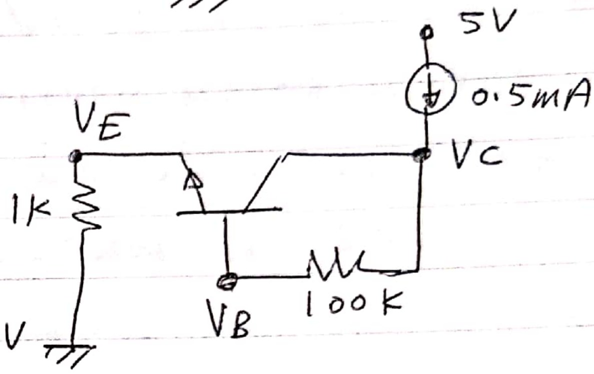
$I_B = \frac{I_E}{1+\beta} = \frac{0.5}{101} = 4.95\mu A$

$I_{CQ} = \beta I_B = 0.495mA$

$V_E = I_E R_E = 0.5 \times 1 = 0.5V$

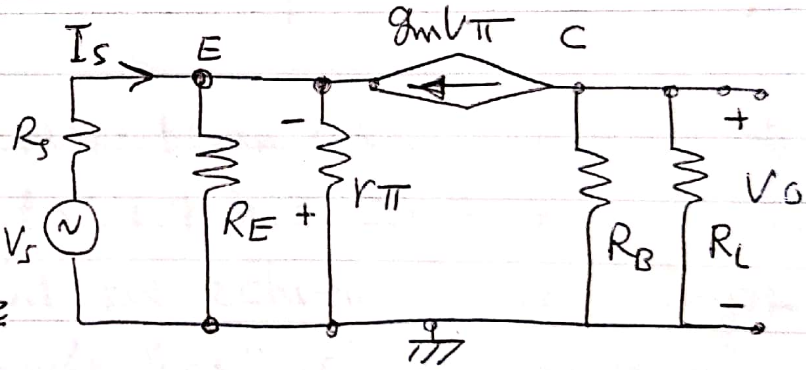
$V_B = V_E + V_{BE} = 0.5 + 0.7 = 1.2V$

$V_C = V_B + I_B R_B = 1.2 + 4.95 \times 100K = 1.7V$



(2) $r_\pi = \frac{100 \times 26}{0.495} = 5.252k\Omega$ ($I_{CQ} = 0.495mA$)

$g_m = \frac{0.495}{26} = 19mA/V$



$R_i = R_E // \frac{r_\pi}{1+\beta}$ [using RRR]

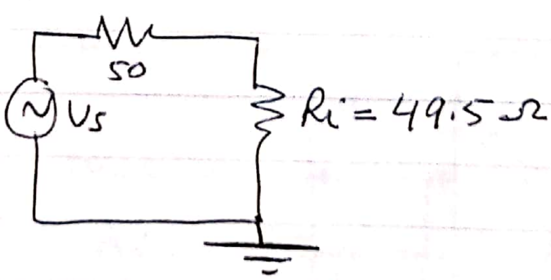
$= 1K // \frac{5.25K}{101} = \cancel{49.47}$ 49.5Ω

$\boxed{R_o = R_B = 100K\Omega}$

$R_B // R_L = 1 // 100 \simeq 1K\Omega$

$V_o = -g_m V_\pi (R_B // R_L) \Rightarrow \frac{V_o}{V_\pi} = -g_m(R_B//R_L) \simeq -19mA\,1K = \boxed{-19}$

$\frac{V_\pi}{V_s} = -\frac{R_i}{R_i + R_s} = -0.497$



$\boxed{\frac{V_o}{V_s} = 9.45 = A_v}$

Summary & Comparision of Single-Stage BJT Amps.

Amp	A_V	A_I	ϕ	Input Resistance	output Resistance
C.E	>1	>1	180°	Moderate	Moderate to high
C.C	≤ 1	>1	0	High	Low
C.B	>1	≤ 1	0	Low	Moderate to high

* In order to design or to have Amp. with Certain specification, which Can'nt achieved using a Single Stage Such as: "$A_V > 1$ & low R_o, low R_i & low R_o, Very high A_V, Very high A_I" we have to use multistage Amps.

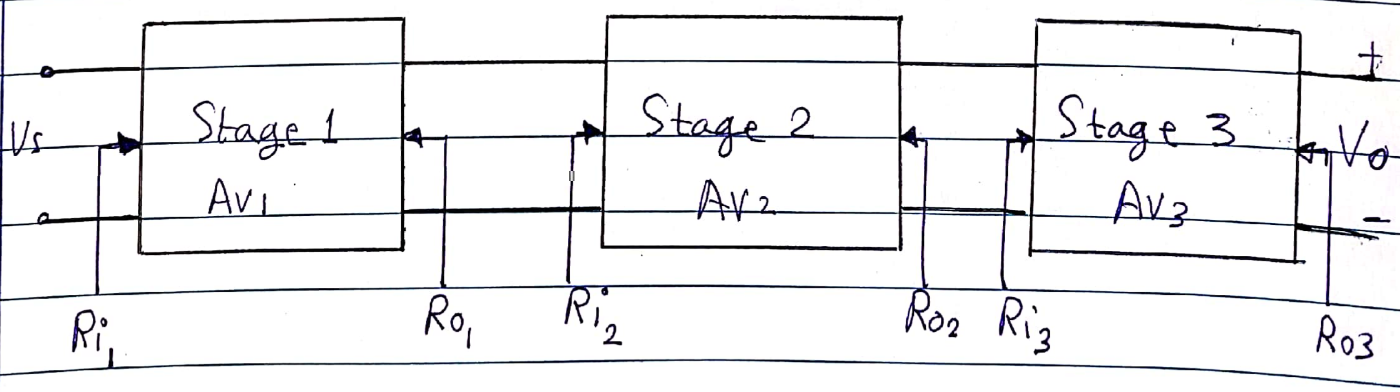
"Multistages Amplifiers"

In most applications "Combined spesifications" Single-Stage will not meet the required specifications so, multistage is used.

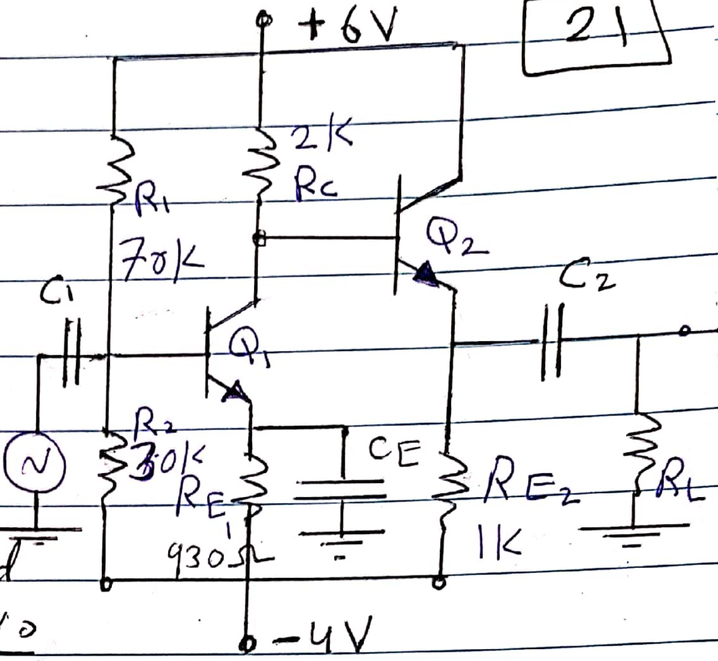
* Multistage Amp. Contains more than ONE transistor at least two and used to achieve certain specifications which Can'nt be achieved using Single stage. They can be "Cascade Amp." or "Cascode Amp."

(1) Cascade Configuration:

The stages are Connected in Series as shown in Fig.



EXA: For the cct. shown Q_1 & Q_2 are identical with $\beta = 100$, $V_{BE} = 0.7V$, $V_A = \infty$

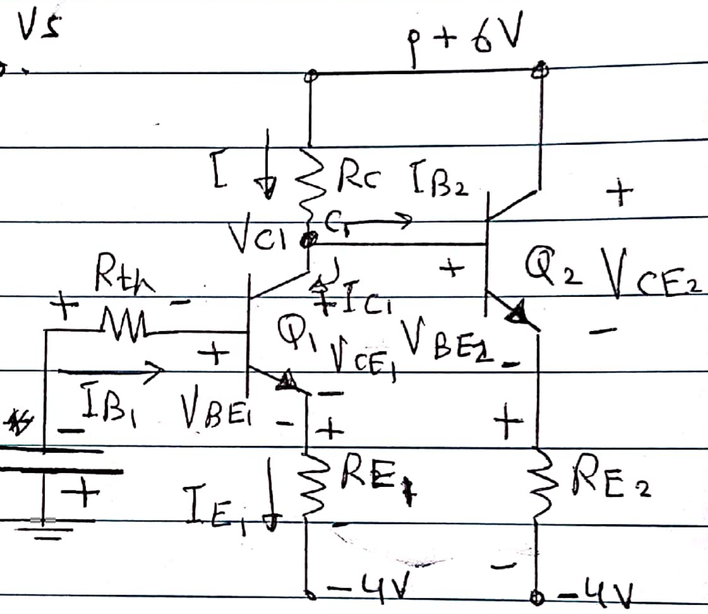


1) Determine Q-pt For each transistor (I_{CQ_1}, V_{CEQ_1}, I_{CQ_2} and V_{CEQ_2}).

2) Draw s.s. A.c eqnt. cct. and Calculate overall gain $A_V = \frac{V_o}{V_s}$ overall $A_I = \frac{I_o}{I_s}$, R_i and R_o.

1) D.C Analysis:

ALL Caps. are open-cct. and A.C Source → S.C



$$R_{th} = \frac{70 \times 30}{70+30} = 21K\Omega$$

$$V_{th} = \frac{6 \times 30}{70+30} - \frac{4 \times 70}{100}$$

$V_{th} = -1V$

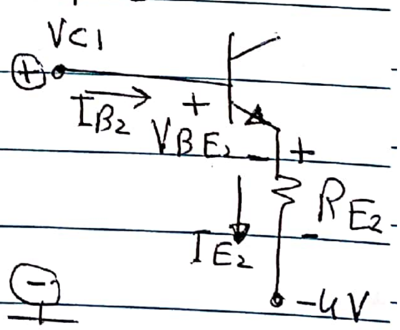
$$V_{th} + I_{B_1} R_{th} + V_{BE} + (\beta+1) I_{B_1} R_E - 4 = 0$$

$$\therefore I_{B_1} = \frac{(3-0.7)V}{21+101 \times R_{E_1}} = \frac{2.3V}{(21+93.93)K} = 0.02mA$$

$\boxed{I_{CQ_1}} = \beta I_{B_1} = \boxed{2mA}$, $I_{E_1} = (\beta+1) I_{B_1} = 2.02mA$

$$V_{CEQ_1} = 6+4 - IR_C - I_{E_1}R_{E_1} = 10 - IR_C - I_{E_1}R_{E_1}$$

to Find I? write KCL at node C_1



$$I = I_{C_1} + I_{B_2} = 2mA + I_{B_2}$$

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

$$I_{B_2} = \frac{V_{C_1} - 0.7 + 4}{(\beta+1) R_{E_2}} = \frac{V_{C_1} + 3.3}{101 R_{E_2}} = \frac{V_{C_1} + 3.3}{101} \quad ①$$

$$\frac{6-V_{C1}}{R_C} = 2 + \frac{V_{C1}+3.3}{101} \rightarrow \frac{6-V_{C1}}{2} = 2 + \frac{V_{C1}+3.3}{101}$$

$$303 - 50.5V_{C1} = 202 + V_{C1} + 3.3$$

$$V_{C1} = \frac{303-202-3.3}{51.5} = 1.897V$$

$$\therefore I = \frac{6-1.897}{2} = 2.0515mA$$

$$I_{B_2} = \frac{1.897+3.3}{101} = 0.0515\ mA$$

$$V_{CE1} = 10 - 2.0515 \times 2 - 2.02 \times 0.93 = 4.02V$$

$\therefore Q_1$ is in FAM. $(I_{B1} > 0, V_{CE1} > V_{BE1})$

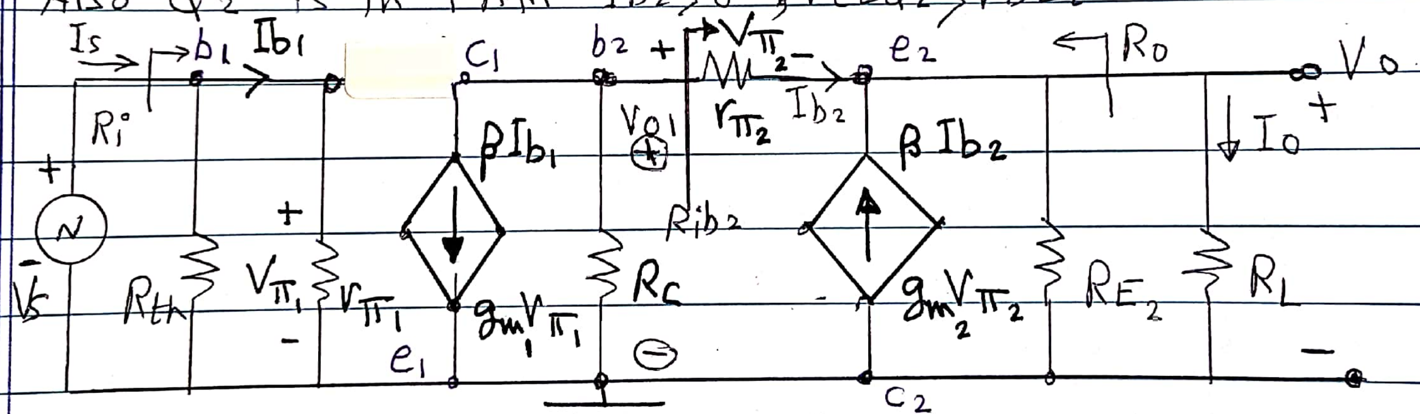
For Q_2: $I_{B2} = 0.0515mA \Longrightarrow I_{CQ_2} = 100 \times 0.0515 =$

$\therefore I_{CQ2} = 5.15\ mA$, $I_{E_2} = (\beta+1)I_{B_2} = 5.2015\ mA$

$$-V_{CC} + V_{CEQ_2} + I_{E_2}R_{E_2} - 4 = 0$$

$$\boxed{V_{CEQ_2}} = V_{CC} + 4 - I_{E_2}R_{E_2} = 10 - 5.201 \times 1 = \boxed{4.799V}$$

Also Q_2 is in FAM "$I_{B2} > 0$, $V_{CEQ_2} > V_{BE_2}$"



→ In multistage Analysis S.S. A.C eqnt. cct.
"Lable the terminals of each transistor in the cct"

$$A_V = \frac{V_o}{V_s} = \frac{V_o}{V_{o1}} \times \frac{V_{o1}}{V_s}$$

$$V_o = +(\beta+1) I_{b2} (R_{E2} // R_L)$$

$$-V_{o1} + V_{\pi 2} + V_o = 0$$

$$V_{o1} = V_{\pi 2} + V_o$$

$$V_{o1} = I_{b2}(r_{\pi 2} + (\beta+1)(R_{E2} // R_L))$$

$$\therefore \frac{V_o}{V_{o1}} = \frac{(\beta+1)(R_{E2} // R_L)}{r_{\pi 2} + (\beta+1)(R_{E2} // R_L)}$$

$$V_{o1} = -g_{m1} V_{\pi_1} (R_C // R_{ib_2})$$

and $V_{\pi_1} = V_s$

$$\therefore \frac{V_{o1}}{V_s} = -g_{m1}(R_C // R_{ib_2})$$

$$\therefore A_v = \frac{V_o}{V_s} = \overbrace{-g_{m1}(R_C//R_{ib_2})}^{A_{V1}} \overbrace{\frac{(\beta+1)(R_{E2}//R_L)}{r_{\pi 2}+(\beta+1)(R_{E2}//R_L)}}^{A_{V2}}$$

$$g_{m1} = \frac{I_{CQ1}}{V_T} = \frac{2mA}{26mV} = 76.9\,mA$$

$$r_{\pi 1} = \frac{\beta V_{T1}}{I_{CQ1}} = \frac{100 \times 26}{2} = 1.3\,K\Omega$$

$$r_{\pi 2} = \frac{\beta V_{T2}}{I_{CQ2}} = \frac{100 \times 26}{5.15\,mA} = 0.505$$

$$R_{ib_2} = (\beta+1)(R_{E2}//R_L) + r_{\pi 2} = 101(1//9) + 0.505 = 91.4K$$

$$\therefore A_v = -76.9(2//91.4)\frac{90.9}{91.4} = -149.68$$

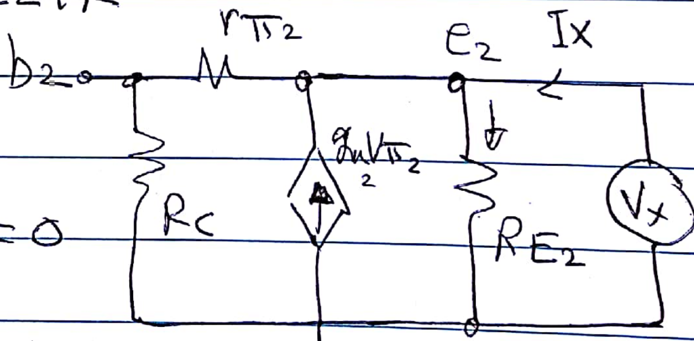
$$\underline{\underline{A_{v_1}}} = -g_{m1}(R_C//R_L) = \underline{\underline{-150.5}} \quad (C.E\ Amp).$$

$$A_{v2} = \frac{(\beta+1)(R_{E2}//R_L)}{r_{\pi_2}+(\beta+1)(R_{E2}//R_L)} = 0.994\ (C.C\ Amp).$$

$$\boxed{A_I} = A_v \frac{R_i}{R_L} = -149.68\,\frac{1.224K}{9K} = \boxed{-20.356K\Omega}$$

where $R_i = r_{\pi 1}//R_{th} = 1.3//21 = 1.224K$

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



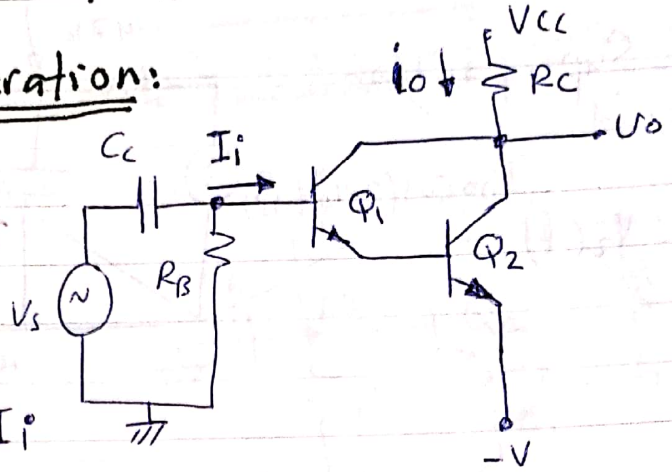
when $V_s = 0$, $V_{\pi 1} = 0$, $g_{m1}V_{\pi_1} = 0$

Using IRRR:

$$R_o = \left(\frac{R_C + r_{\pi 2}}{\beta+1}\right)//R_E = 0.0248//1 = 24.2\,\Omega$$

Cascade Amp.

(2) Darlington pair configuration:

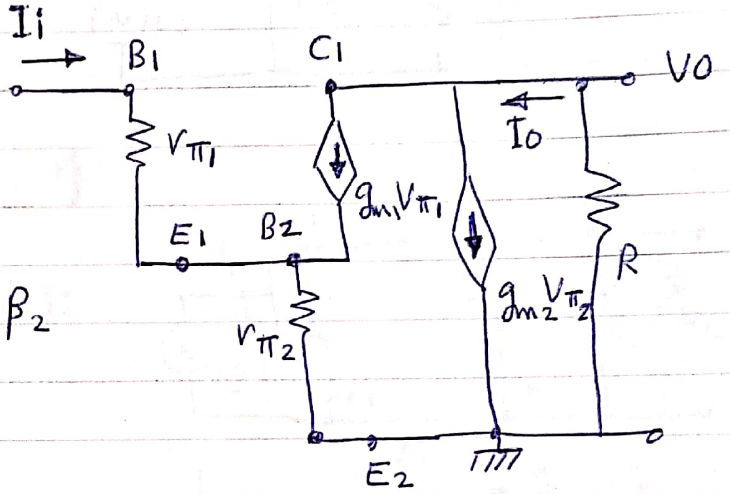


$$I_o = g_{m2} V_{\pi 2} + g_{m1} V_{\pi_1}$$

$$V_{\pi_1} = r_{\pi_1} I_i$$

$$g_{m1} V_{\pi_1} = g_{m1} r_{\pi 1} I_i = \beta_1 I_i$$

$$g_{m2} V_{\pi 2} = g_{m2} (g_{m1} V_{\pi 1} + I_i) r_{\pi 2}$$
$$= g_{m2} (\beta_1 I_i + I_i) r_{\pi_2}$$
$$= \beta_2 (1+\beta_1) I_i$$



$$\therefore I_o = I_i (\beta_2 (1+\beta_1) + \beta_1)$$

$$\therefore A_i = \beta_1 + \beta_2 (1+\beta_1) \simeq \beta_1 \beta_2$$

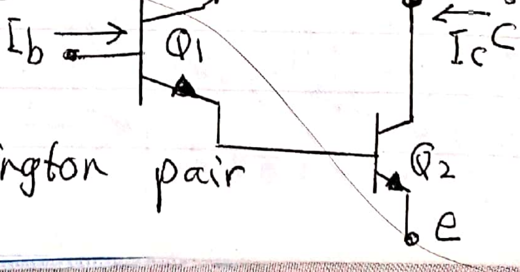
$$R_i = r_{\pi 1} + (1+\beta_1) r_{\pi_2}$$

but $r_{\pi_1} = \dfrac{\beta_1 V_T}{I_{CQ_1}}$ and $I_{CQ_1} \simeq I_{EQ_1} = \dfrac{I_{CQ2}}{\beta_2}$

$$\therefore r_{\pi_1} = \frac{\beta_1 V_T}{\frac{I_{CQ2}}{\beta_2}} = \beta_1 \boxed{\beta_2 \frac{V_T}{I_{CQ_2}}} = \beta_1 r_{\pi_2}$$

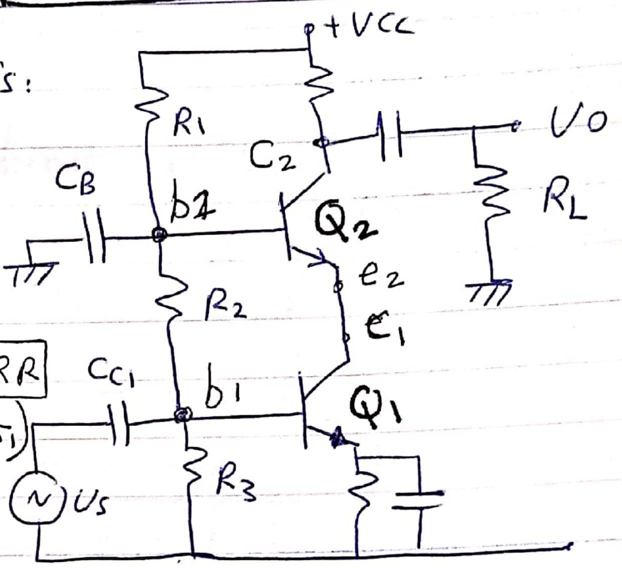
$$\therefore R_i = \beta_1 r_{\pi 2} + (1+\beta_1) r_{\pi_2} \simeq 2 \beta_1 r_{\pi_2}$$

* Darlington pair is used to provide very high current-gain $\simeq \beta_1 \beta_2$ or β^2 for identical transistors.
* The input resistance is Large due to β multiplication.
* This cct. provide very high Current gain $\simeq \beta^2$ and high R_i.



Darilington pair

3- Cascode configuration: $\boxed{(C\text{-}E \ \& \ C\text{-}B)}$ Configuration



The advantages of this Connection is:
1- high output Resistance
2- good frequency Response.
***Used as "Wideband" Amp.**

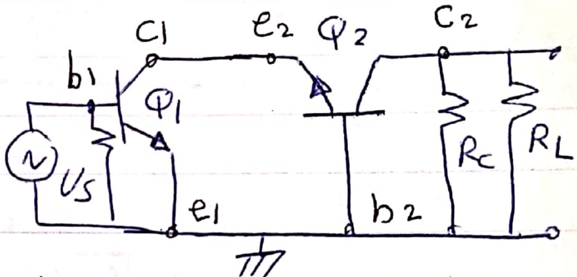
$V_o = -g_{m2}V_{\pi 2}(R_C // R_L)$

R_{ie2} using $\boxed{IRRR}$

$$V_{\pi 2} = \boxed{\left(\frac{r_{\pi 2}}{1+\beta_2}\right)} g_{m1}V_{\pi 1} = R_{ie2}(g_{m1}V_{\pi 1})$$

and $V_{\pi 1} = V_s$ So:

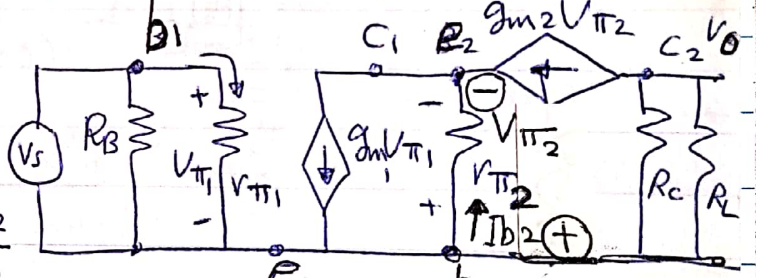
$$V_{\pi 2} = \left(\frac{r_{\pi 2}}{1+\beta_2}\right) g_{m1}V_s$$



Or at node C_1: (KCL yields):

$$g_{m2}V_{\pi 2} + \underbrace{\frac{V_{\pi 2}}{r_{\pi 2}}}_{I_{b2}} = g_{m1}V_{\pi 1}$$

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



$$\therefore (V_o/V_s) = -g_{m1}g_{m2}(R_C/R_L)\frac{r_{\pi 2}}{1+\beta_2}$$

$$= -g_{m1}(R_C//R_L)\frac{\beta_2}{1+\beta_2} \simeq -g_{m1}(R_C//R_L)$$

$R_i = R_B // r_{\pi 1}$

$R_o = R_C$

NOTE: Av of this Amp. is Av of the C.E Amp?? Why!!!

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

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

$$g_{m2}r_{\pi 2} = \beta$$

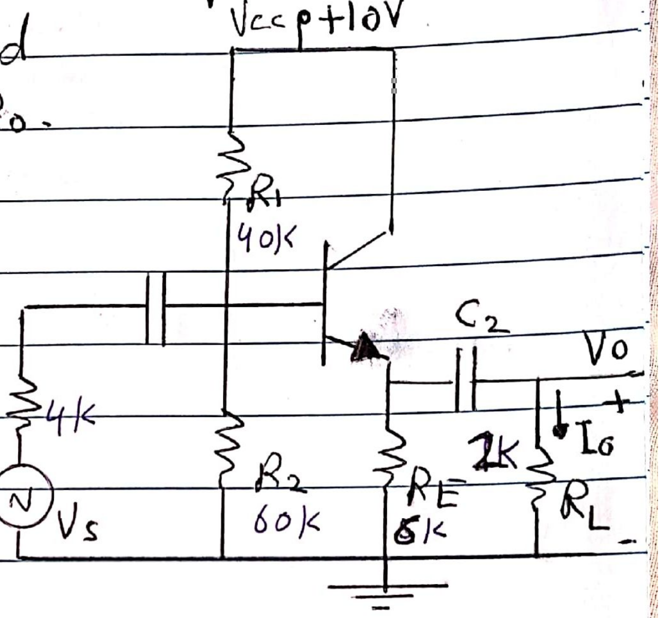
$$V_{\pi 2}\left(\frac{\beta+1}{r_{\pi 2}}\right) = g_{m1}V_{\pi 1}$$

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

EXA1: Common Collector

EXA: For the cct. shown, the BJT has: $\beta = 75$, $V_{BE} = 0.7V$, $V_A = 60V$, $V_T = 26mV$

1) Determine I_{CQ}, V_{CEQ}.
2) Write D.C.L.L eqn. and find Its slope?
3) Draw S.S.A.C eqn. cct. and Calculate A_V, A_I, R_i and R_o.



① * For D.C Analysis

ALL Caps → open cct.

A.C Source → Short cct.

* Assume the BJT in FAM

$R_{th} = R_1 // R_2 = 24K\Omega$

$V_{th} = \dfrac{V_{cc} \cdot R_2}{R_1 + R_2} = \dfrac{10 \times 60}{100} = \underline{\underline{6V}}$

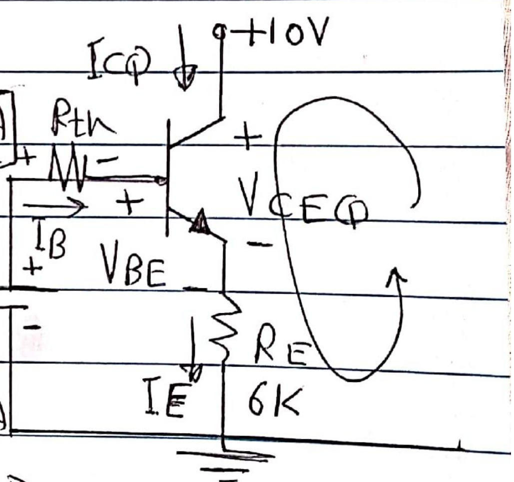
$-V_{th} + I_B R_{th} + V_{BE} + (\beta+1) I_B R_E = 0$

$\therefore \boxed{I_B} = \dfrac{V_{th} - V_{BE}}{R_{th} + (\beta+1) R_E} = \dfrac{(6-0.7)V}{(24+76\times6)K} \simeq \boxed{11\,\mu A}$

$\boxed{I_{CQ}} = \beta I_{BQ} = 75 \times 0.011 = \boxed{0.825\,mA}$

$-V_{CC} + V_{CE} + I_E R_E = 0$, $I_E = (\beta+1) I_B = 0.836mA$

$\boxed{V_{CE}} = 10 - 0.836 \times 6 = \boxed{4.984\,V}$



D.C cct.

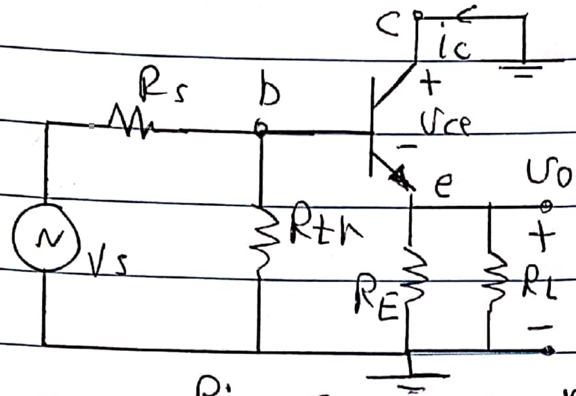
② D.C. L.L: KVL For C-E loop:

$-10 + V_{CE} + I_E R_E = 0$, but $I_E = \dfrac{\beta+1}{\beta} I_C$

$V_{CE} = 10 - I_C\left(\dfrac{\beta+1}{\beta} R_E\right)$

$\therefore$ Slope of D.C.L.L $= \dfrac{-1}{\dfrac{\beta+1}{\beta} R_E} = \dfrac{-\beta}{(\beta+1) R_E}$

(3) * For A.C Analysis, all Caps → S.C and D.C Sources → S.C



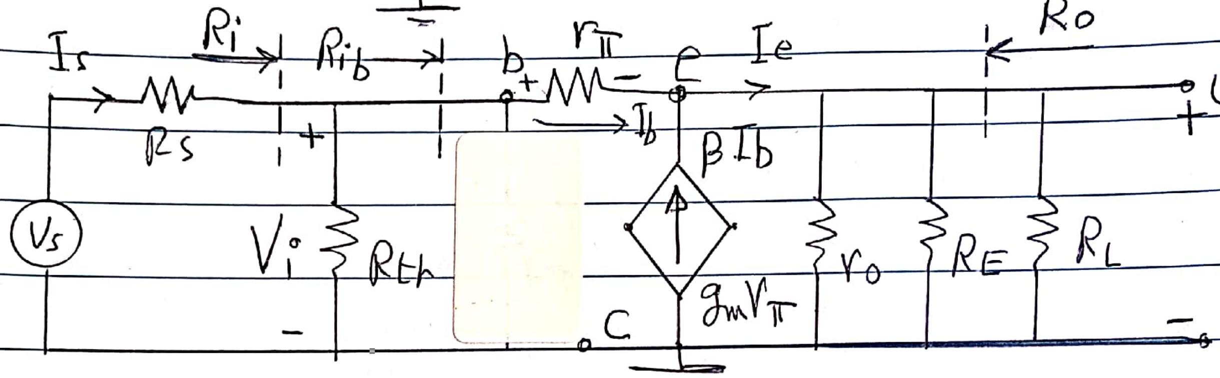
A.C.cct:

A.C.L.L eqn.

$V_{ce} + i_e(R_E \| R_L) = 0$

$V_{ce} = -\frac{\beta+1}{\beta}(R_E \| R_L)$

$\therefore Slope = \frac{-\beta}{(\beta+1)(R_E \| R_L)}$



S.S.A.C eqnt. cct.

$r_o = \frac{V_A}{I_{CQ}} = \frac{60V}{0.825mA} = 72.72K$

$r_\pi = \frac{\beta V_T}{I_{CQ}} = 2.363K$

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

$V_o = (\beta+1) I_b \bar{R_L}$, $V_i = V_\pi + V_o = I_b(r_\pi + (\beta+1)\bar{R_L})$

$\therefore \frac{V_o}{V_i} = \frac{(\beta+1)\bar{R_L}}{r_\pi + (\beta+1)\bar{R_L}}$ where $\bar{R_L} = r_o \| R_L \| R_E$

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

$R_i = R_{th} \| R_{ib}$, $R_{ib} = (\beta+1)(\bar{R_L}) + r_\pi$

$\therefore A_v = \frac{(\beta+1)\bar{R_L}}{r_\pi + (\beta+1)\bar{R_L}} \cdot \frac{R_i}{R_i + R_s}$

$A_v = \frac{76 \times 1.47}{2.363 + 76 \times 1.47} \cdot \frac{19.829}{4 + 19.829} = \boxed{0.814}$

$R_o = \frac{(R_s \| R_{th}) + r_\pi}{\beta+1} \| r_o \| R_E \simeq 76\,\Omega$

$* A_I = A_v \frac{R_i + R_s}{R_L} = 0.814 \frac{19.829 + 4}{2} = 9.7$

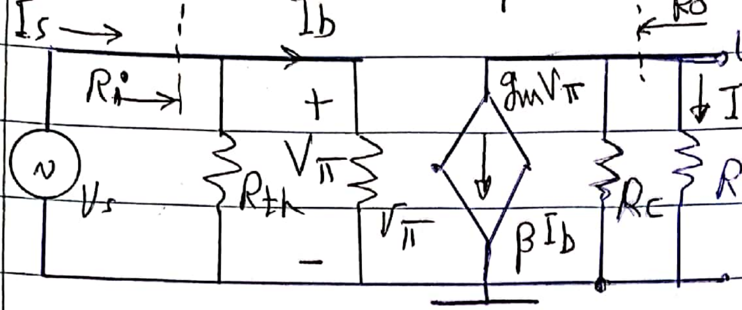
$\bar{R_L} = R_E \| r_o \| R_L$
$= 6 \| 2 \| 72.72$
$= 1.47K\Omega$

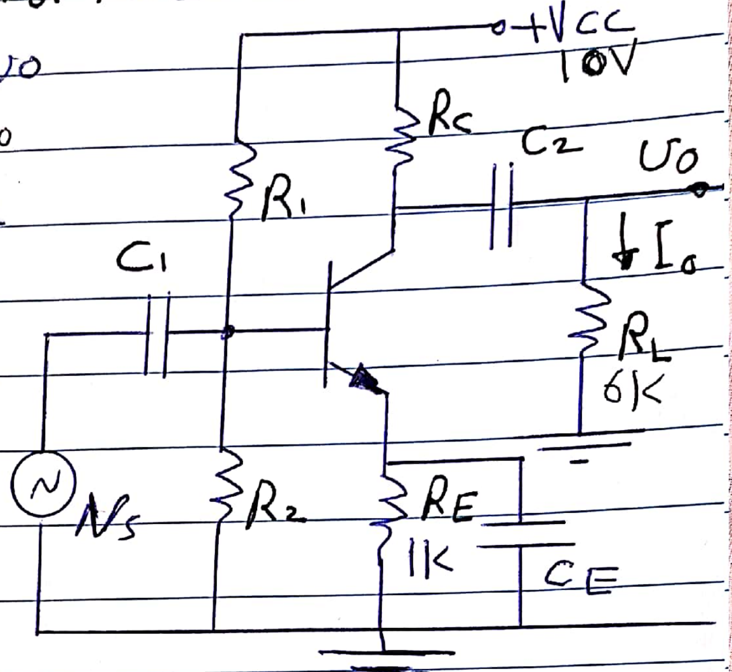
$R_{ib} = 76 \times 1.47 + r_\pi$
$= 114.1 K\Omega$

$R_i = R_{th} \| R_{ib}$
$= 24 \| 114.1$
$= 19.829 K$

① EXA.: (Design): Design the cct. shown to have $A_v = -100$ and be bias-stable (Find R_C, R_1 & R_2).

② draw s.s.A.C eqnt. cct. and Find R_{in}, R_o & A_I?





From A.C Analysis

$$A_v = \frac{v_o}{v_s} = \frac{-g_m v_\pi (R_C // R_L)}{v_\pi}$$

where $v_\pi = v_s$

$$\therefore A_v = -g_m (R_C // R_L)$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{1.3mA}{26mV} = 50 \frac{mA}{V}$$

$$-100 = -50(R_C // R_L) = -50 R_L'$$

$\overline{R_L}$ ∴ $R_L' = R_C // R_L = 2K\Omega = \frac{R_C \cdot R_L}{R_C + R_L}$

$$\therefore \boxed{R_C} = \frac{R_L \cdot R_L'}{R_L - R_L'} = \frac{6 \times 2}{6 - 2} = \boxed{3K\Omega}$$

$\beta = 100$, $V_{BE} = 0.7V$, $V_A = \infty$
$I_{CQ} = 1.3 mA$ Given!!
$V_T = 26 mV$

$$\boxed{R_o} = \frac{V_x}{I_x}\Bigg|_{V_s = 0} \rightarrow R_o = R_C = \boxed{3K\Omega}$$

$$R_i = R_{th} // r_\pi, \quad r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{100 \times 26}{1.3mA} = 2K\Omega$$

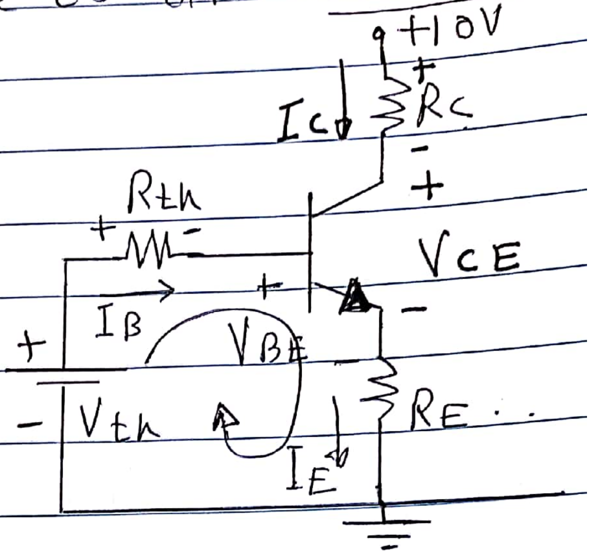
$R_{th} = 0.1(\beta + 1) R_E$ [For bias-stable design]

$$\therefore R_{th} = 0.1(101) \times 1 = 10.1 K\Omega$$

$$\therefore \boxed{R_i} = 10.1 // 2K = \boxed{1.67K\Omega}$$

$$\boxed{A_I} = A_v \frac{R_i}{R_L} = -100 \frac{1.67}{6} = \boxed{-27.83}$$

To Find R_1 & R_2 we have to draw D.C. cct



For a bias-stable design:

choose $R_{th} = 0.1(\beta+1)R_E$

$= 0.1(101)\times 1 = 10.1\ K\Omega$

but $R_{th} = \dfrac{R_1 \cdot R_2}{R_1+R_2} = 10.1\ K\Omega$

and $V_{th} = \dfrac{V_{cc} \cdot R_2}{R_1+R_2}$

$R_1 \cdot V_{th} = \dfrac{V_{cc} \cdot R_1 \cdot R_2}{R_1+R_2} = \boxed{V_{cc} \cdot R_{th}}$

$\therefore R_1 = \dfrac{V_{cc}}{V_{th}} R_{th}$

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

$\therefore V_{th} = V_{BE} + I_B(R_{th} + (\beta+1)R_E)$

$I_B = \dfrac{I_C}{\beta} = \dfrac{1.3}{100} = 0.013\ mA$

$\therefore V_{th} = 0.7 + 0.013(10.1 + 101\times 1) = 2.1443\ V$

$\therefore \boxed{R_1} = \dfrac{10}{2.1443}(10.1) = \boxed{47.1\ K\Omega}$

$\boxed{R_2} = \dfrac{R_1 \cdot R_{th}}{R_1 - R_{th}} = \dfrac{47.1\times 10.1}{47.1-10.1} = \boxed{12.857\ K\Omega}$

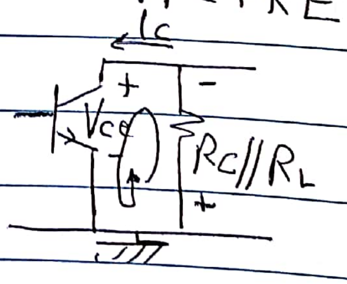
D.C.L.L eqn: (IF it is required)

$-V_{cc} + I_C R_C + V_{CE} + I_E R_E = 0$, but $I_E = \dfrac{\beta+1}{\beta} I_C$

$\therefore V_{CE} = V_{cc} - I_C\left(R_C + \dfrac{\beta+1}{\beta} R_E\right)$

$\therefore$ Slope $= -\dfrac{1}{R_C + \dfrac{\beta+1}{\beta} R_E}$ * For $\beta \gg 1$, Slope $= -\dfrac{1}{R_C + R_E}$

A.C.L.L eqn: From A.C cct.



$V_{ce} + i_c(R_C // R_L) = 0 \Rightarrow V_{ce} = -i_c(R_C // R_L)$

slope $= -\dfrac{1}{(R_C // R_L)}$

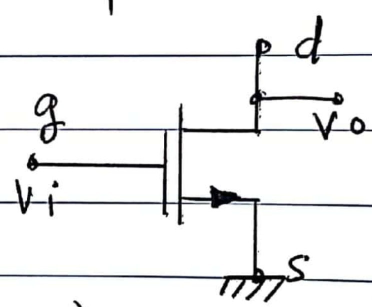
MOSFET Amplifiers CH. 4

For a MOSFET to be used as an Amplifier, it must be biased in Saturation Region.
To be sure that MOSFET in Sat. Regn., D.C analysis must be performed and cheak that $V_{DS} > V_{DS(sat)}$ where $V_{DS(sat)} = V_{GS} - V_{TN}$ and V_{TN} is given, V_{GS} is obtained from the circuit.

Single-Stage MOSFETs Amps.

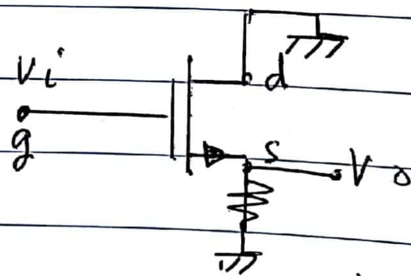
There are three configurations according to the common terminal.

i) Common-Source Amplifier (C.S. Amp).



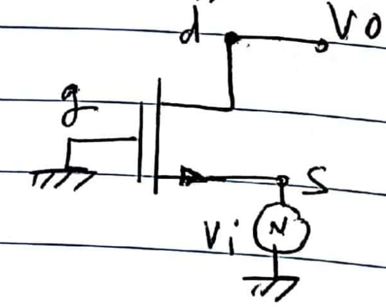
V_i is given to gate
V_o is taken from drain
Source is Common terminal.

ii) Common-drain Amp. (Source-follower).



$V_i \rightarrow$ to gate
$V_o \rightarrow$ from Source
drain is Common-terminal.

iii) Common-gate terminal



$V_i \rightarrow$ to Source
$V_o \rightarrow$ from drain
gate is Common terminal.

① Common-Source Amp.

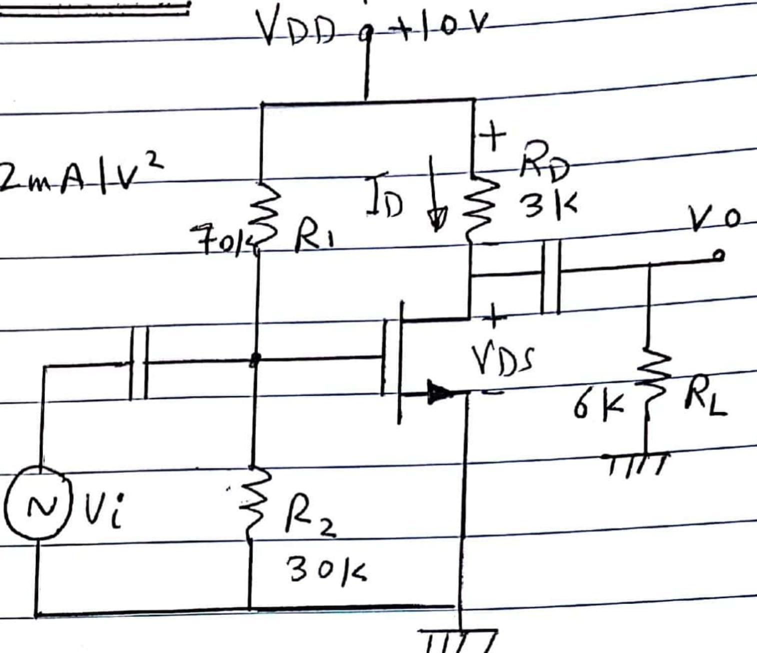
i) Basic C.S. Amp.

Given $V_{TN} = 2V$, $K_n = 2mA/V^2$

$\lambda = 0.01 V^{-1}$

a) Calculate I_D, V_{DS}

b) Draw S.S. A.C eqn. cct. & find A_V, A_I, R_i, R_o



A) For D.c Analysis:

assume MOSFET in Sat.

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

from the cct. $V_{GS} = V_G - V_S = \dfrac{10 \times 30}{100} - 0 = 3V$

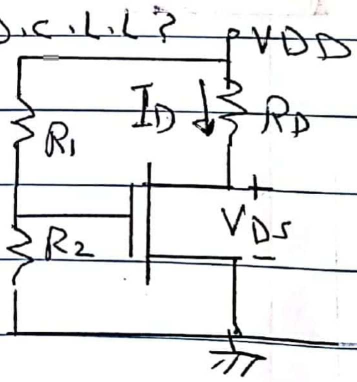
$I_D = 2(3-2)^2 = 2mA$

$V_{DS} = 10 - I_D R_D = 10 - 3 \times 2 = 4V.$

$V_{DS(sat)} = V_{GS} - V_{TN} = 3 - 2 = 1V$

Since $V_{DS} > V_{DS(sat)} \Rightarrow$ MOSFET is in Sat.

* Write D.c Load-line eqn. Find slope. Draw D.c.L.L?



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

$\therefore V_{DS} = 10 - I_D R_D$ (D.c.L.L eqn.)

$\text{slope} = -\dfrac{1}{R_D} = -\dfrac{1}{3K}$

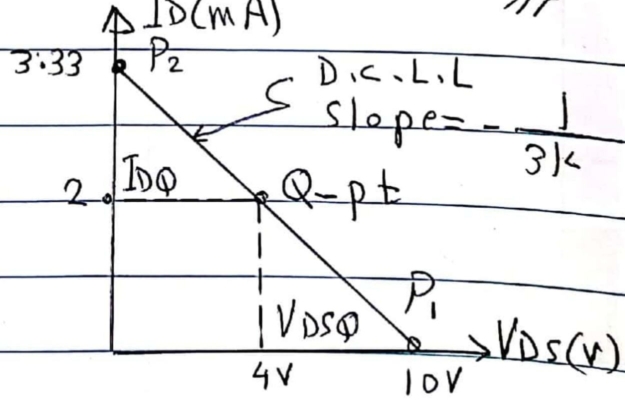
* For $I_D = 0$, $V_{DS} = 10V \rightarrow P_1(10V, 0)$

* For $V_{DS} = 0$, $I_D = 10/3K = 3.33mA$

$P_2(0V, 3.33mA)$.

power dissipation: $P_D = I_D . V_{DS}$

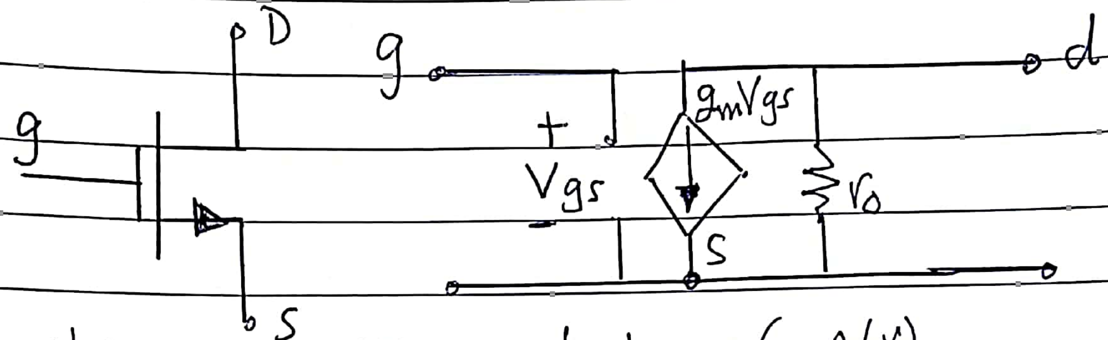
$\therefore P_D = 2 \times 4 = 8 mW.$



2) A.C Analysis:

To perform A.C Analysis, we have to draw A.C. cct. and replace MOSFET by its model.

MOSFET Model



where: g_m : Transconductance (mA/V)

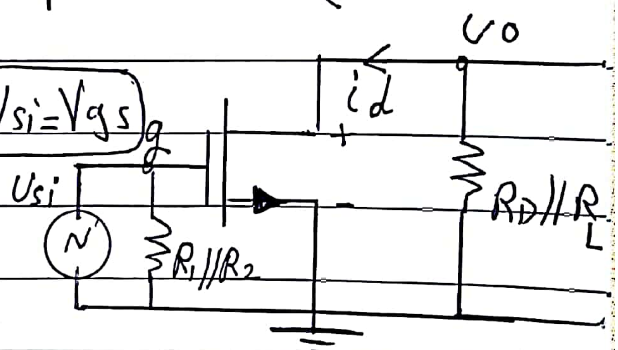
$$g_m = \frac{\partial I_D}{\partial V_{GS}} = 2K_n(V_{GS} - V_{TN})$$

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

r_o : MOSFET output resistance $\Rightarrow r_o = \frac{1}{\lambda I_D}$

where: λ : channel length modulation parameters in (V^{-1}).

* λ is given, If $\lambda = 0$, $r_o = \infty$



$A_v = \frac{v_o}{v_{si}} = \frac{-g_m V_{gs} R_L}{V_{si}}$: because $\boxed{V_{si} = V_{gs}}$

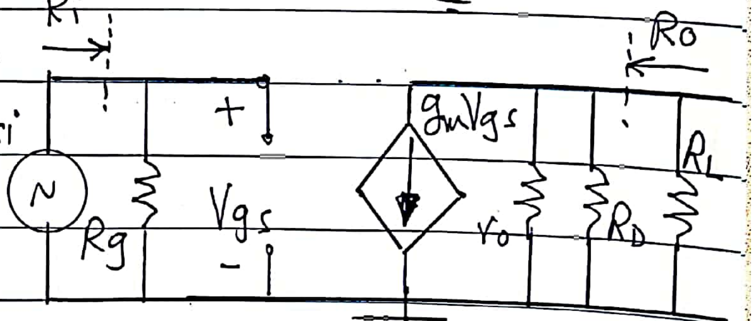
$\therefore \boxed{A_v = -g_m R_L}$, $\lambda = 0.01\,V^{-1}$

$r_o = \frac{1}{\lambda I_D}$

$\therefore r_o = 1/(0.01 \times 2 \times 10^{-3}) = 50\,K\Omega$

$g_m = 2\sqrt{K_n I_D} = 2\sqrt{2 \times 2} = 4\,mA/V$

$\therefore \boxed{A_v} = -4(3//6//50) = \boxed{-7.7}$



$R_i = R_g = R_1//R_2 = 21\,K\Omega$

$R_o = \frac{V_x}{I_x}\Big|_{V_{si}=0}$

when $V_{si} = 0$, $V_{gs} = 0$, $g_m V_{gs} = 0 \Rightarrow$ O.C $\therefore R_o = r_o // R_D$

$\therefore R_o = 50//3 = 2.83\,K\Omega$

ii) C.S with R_s:

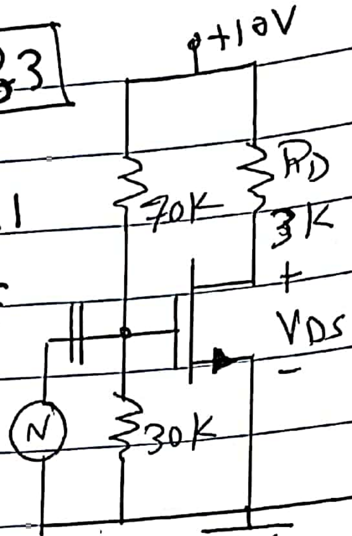
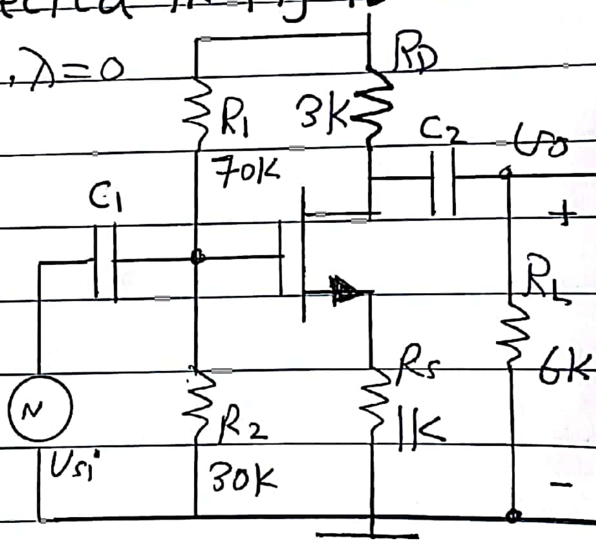


Fig.1
Basic

R_s is used to stabilize Q-pt against K_n parameter variation which is an Advantages.

* Consider the basic cct. discussed in (i)
When $K_n = 2mA/V^2$, $V_G = 3V$, $V_s = 0$, $I_D = 2mA$, $V_{DS} = 3V$
and $V_{DS(sat)} = V_{GS} - V_{TN} = 1V$ and MOSFET in Sat. Regn.
But $\boxed{\text{If } K_n = 4mA/V^2}$, $I_D = 4(3-2)^2 = 4mA$
$V_{DS} = 10 - I_D R_D = 10 - 4\times3 = -2V$
∴ The MOSFET will be in Linear Regn and Can't be used as Amplifier.

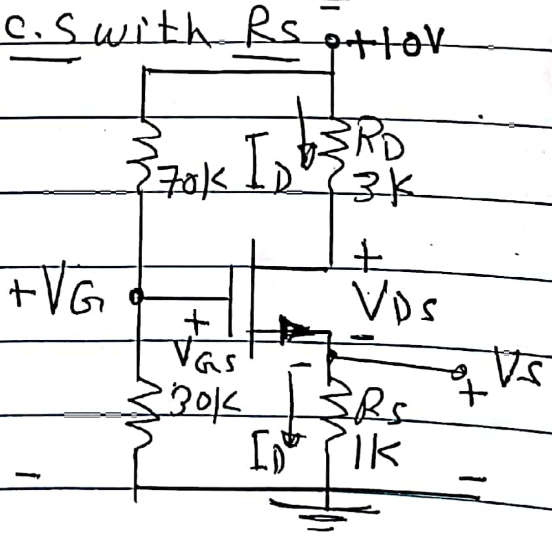
Now: If $R_s = 1K\Omega$ is connected in Fig. (2)



* Given: $V_{TN} = 2V$, $K_n = 4mA/V^2$, $\lambda = 0$
1) Find V_{GS}, I_D, V_{DS}.
2) Draw S.S. A.C eqnt. cct. and determine A_v, R_i, R_o

D.C. Analysis:
all Caps. → open-cct.
A.C Source → S.C
Assume the MOSFET in Sat. Regn.

C.S with R_s



$I_D = K_n(V_{GS} - V_{TN})^2$
$V_{GS} = V_G - V_s$, $V_G = \dfrac{10\times30}{100} = 3V$
$V_s = I_D R_s = 1\times I_D = I_D$
∴ $V_{GS} = 3 - I_D$ from this eqn.
$\boxed{I_D = 3 - V_{GS}}$

$\therefore 3 - V_{GS} = 4(V_{GS}^2 - 4V_{GS} + 4)$

$4V_{GS}^2 - 15V_{GS} + 13 = 0$

$\therefore V_{GS} = \dfrac{15 \mp \sqrt{(-15)^2 - 4\times4\times13}}{2\times4} = \dfrac{15 \mp 4.123}{8} = \boxed{2.39V} \text{ or } \boxed{1.36V}$

$\therefore I_D = 4 - 2.39 = 0.61 \text{ mA}$

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

$V_{DS} = 10 - 0.61(3+1) = 7.56 V$

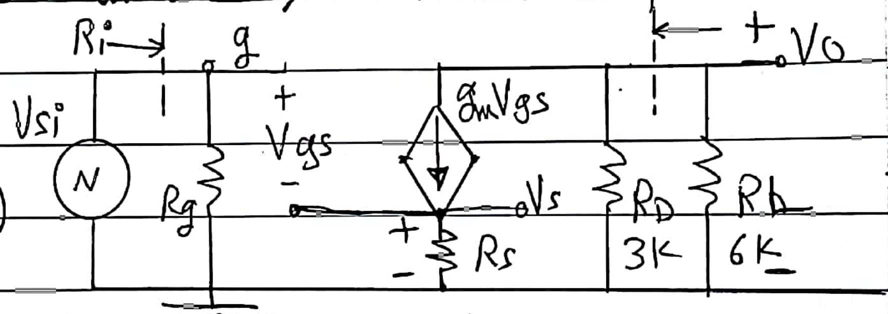
$V_{DS(sat)} = V_{GS} - V_{TN} = 2.39 - 2 = 0.39V$

Since $V_{DS} > V_{DS(sat)}$ $\therefore$ MOSFET is in Sat. Regn.

$\therefore$ R_s stabilize Q-pt againt K_n parameter Variation!!

* A.C Analysis:

ALL Caps. and D.C Sources $\rightarrow$ short.cct.



$A_v = \dfrac{V_o}{V_{si}} = \dfrac{V_o}{V_{gs}} \times \dfrac{V_{gs}}{V_{si}}$

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

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

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

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

$\therefore (V_{gs}/V_{si}) = \dfrac{1}{1 + g_m R_s}$

$\therefore A_v = \dfrac{-g_m(R_D // R_L)}{1 + g_m R_s}$ $\boxed{\text{i.e } R_s \text{ reduces } A_v}$

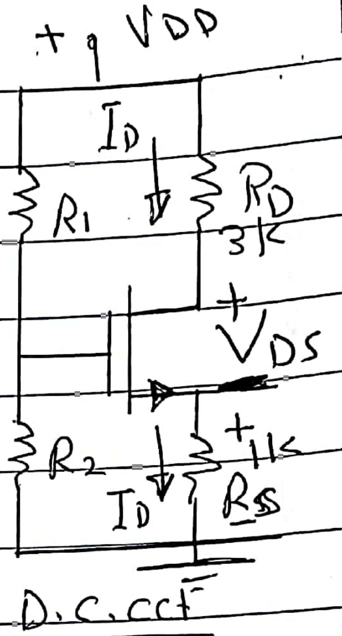
For this cct. $g_m = 2\sqrt{K_n I_D} = 2\sqrt{4\times0.61} = 3.124 \text{ mA/V}$

$\therefore A_v = \dfrac{-3.124\times(3//6)}{1 + 3.124\times1} = -1.515$

$R_i = R_g = 70 // 30 = 21 K\Omega$

$R_o = \dfrac{V_x}{I_x}\Big|_{V_{si}=0} \Rightarrow R_o = R_D = 3 K\Omega$

A.C & D.C. Load-line



1) D.C.L.L → KVL from D.C.cct.

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

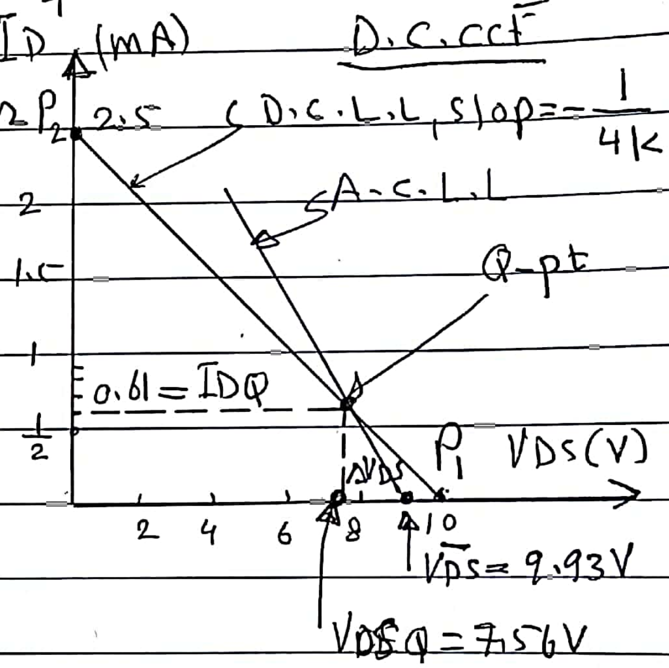
$\therefore \boxed{V_{DS} = V_{DD} - I_D(R_D + R_S)}$ D.C.L.L eqn.

i) For $I_D = 0$, $V_{DS} = V_{DD} = 10V \rightarrow P_1(10V, 0\,mA)$

ii) For $V_{DS} = 0$, $I_D = V_{DD}/(R_D + R_S) = \frac{10}{4} = 2.5\,mA$

$P_2(0V, 2.5\,mA)$.

$\text{slope} = -1/(R_D + R_S) = -1/4K\Omega$



② A.C.L.L: Consider A.c.cct.

KVL For ($d \rightarrow s$) loop:

$v_{ds} + i_d R_S + i_d (R_D // R_L) = 0$

$\therefore v_{ds} = -i_d \left[R_S + (R_D // R_L)\right]$

$\therefore \text{slope} = -\frac{1}{R_S + (R_D // R_L)} = -\frac{1}{3K}$

$\cancel{\text{At}}\ V_{DS} = V_{DSQ} + \Delta V_{DS}$

$|\text{slope}| = \frac{1}{R_S + (R_D // R_L)} = \frac{\Delta I_D}{\Delta V_{DS}}$

$\therefore \Delta V_{DS} = \Delta I_D \left[R_S + (R_D // R_L)\right]$

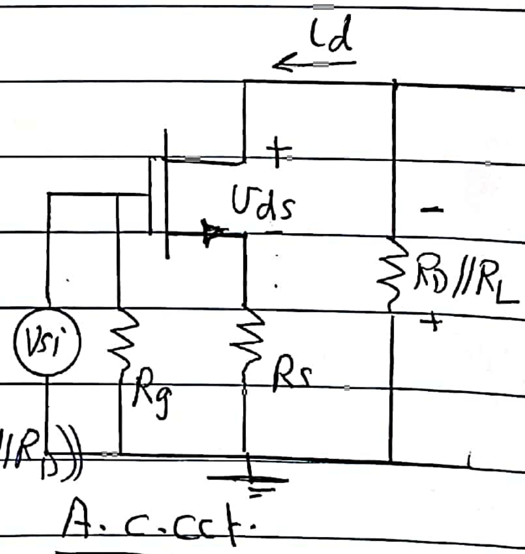
$\Delta I_D = I_{DQ} = 0.61\,mA$

$\therefore \Delta V_{DS} = 0.61(1+2) = 1.83V$

$V_{DS} = 7.56 + 1.83 = 9.39V$

Max. peak-to-peak (v_{ds}) $= 2 I_{DQ}(R_S + (R_L // R_D))$

$= 3.66V$

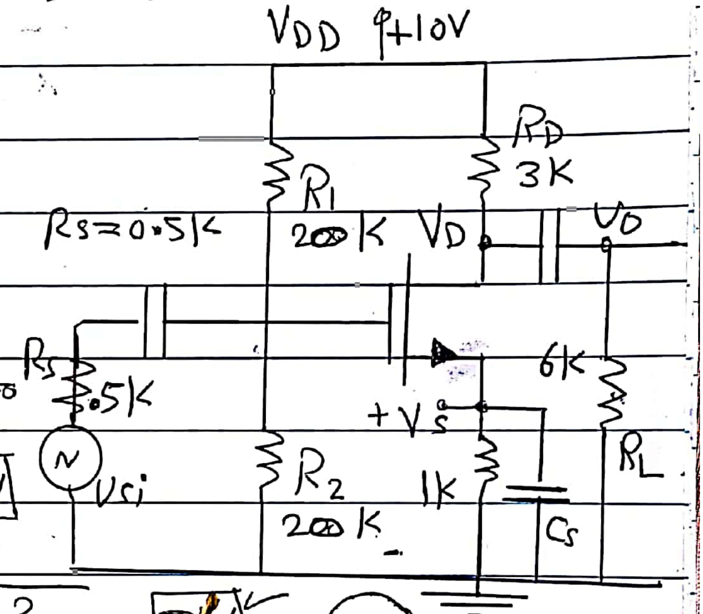


iii) C.S with bypass Capacitor "C_S"

* To Cancel the effect of R_S in reducing A_V, C_S is Connected across R_S, where in D.C Analysis C_S is open, R_S is present and stabilize Q-pt.
* For A.C Analysis C_S is short → Shorting R_S and Cancel its effect → hence increase A_V.

EXA: For the cct. shown, the MOSFET parameters are: $K_n = 2\,mA/V^2$, $V_{TN} = 2V$, $\lambda = 0.02\,V^{-1}$ and the cct. is biased at $I_D = 2\,mA$.

* Determine: V_{DS}, V_D, V_S, V_G, V_{GS}
* Draw S.S.A.C eqnt. cct. and Find A_V, R_i, R_o



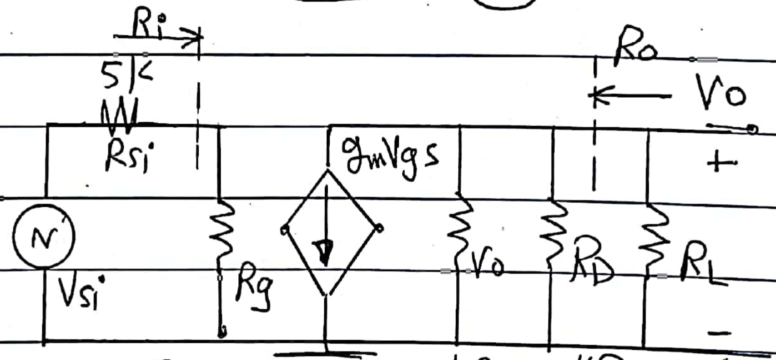
$\boxed{V_S} = I_D R_S = 2\times1 = \boxed{2V}$

$\boxed{V_D} = V_{DD} - I_D R_D = 10 - 2\times3 = \boxed{4V}$

$\boxed{V_{DS}} = V_D - V_S = 4 - 2 = \boxed{2V}$

$\boxed{V_{GS}} = V_{TN} \mp \sqrt{\frac{I_D}{K}} = 2 \mp \sqrt{\frac{2}{2}} = \boxed{3V}$ ✓ or $1V$ ✗

$\boxed{V_G} = \frac{10\times200}{200+200} = \boxed{5V}$



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

$V_o = -g_m V_{gs} \bar{R}_L$

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

$r_o = (1/\lambda I_{DQ}) = 1/(0.02\times2\times10^{-3}) = 25\,K\Omega$ $\quad R_o = r_o // R_D = 2.676\,K\Omega$

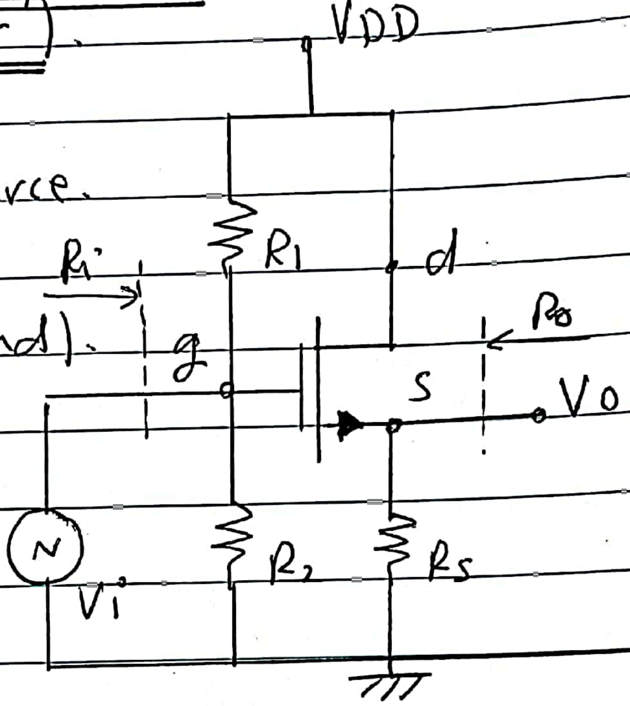
$\bar{R}_L = 25//3//6 = 1.852\,K\Omega$, $g_m = 2\sqrt{K_n I_D} = 2\sqrt{2\times2} = 4\,\frac{mA}{V}$

$\therefore (V_{gs}/V_{si}) = (R_i/R_i+R_{si})$, $R_i = R_g = 20//20 = 10\,K\Omega$

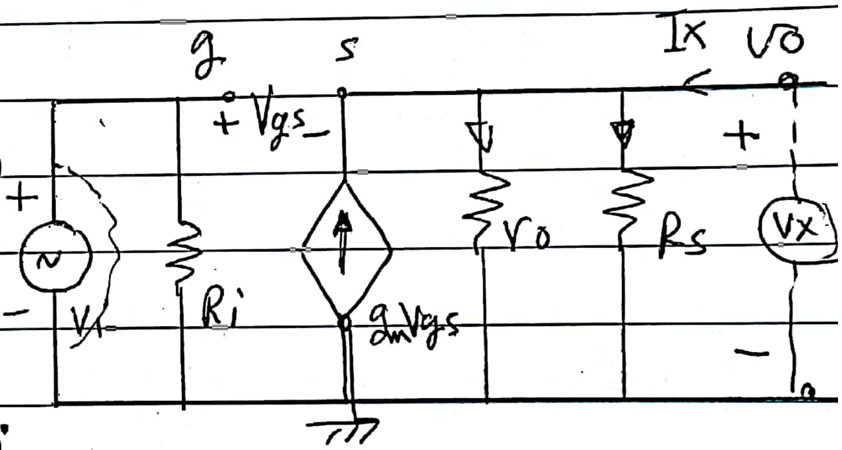
$\therefore \boxed{A_V} = -g_m \bar{R}_L \frac{R_i}{R_i+R_{si}} = -4\times1.852 \frac{10}{10+0.5} = \boxed{-7}$

$R_o = R_D // r_o = 2.676\,K\Omega$

② Common-Drain Amplifier (Source-follower)



In this Amp.
V_i to gate, V_o from Source.
drain: Common-terminal
(For A.c analysis d is at ground).
Draw S.S. A.c eqnt. cct.
and determine expressions
for A_v, R_i & R_o



$v_o = g_m V_{gs} (r_o // R_s)$

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

$V_i = V_{gs} + g_m V_{gs} (r_o // R_s)$

$V_i = V_{gs}(1 + g_m (r_o // R_s))$

$$\therefore V_{gs} = \frac{V_i}{1 + g_m (r_o // R_s)}$$

$$v_o = g_m (r_o // R_s) \frac{V_i}{1 + g_m (r_o // R_s)}$$

$$A_v = \frac{v_o}{V_i} = \frac{g_m (r_o // R_s)}{1 + g_m (r_o // R_s)} \quad \therefore A_v < 1, \ \phi = 0^\circ$$

$R_i = R_1 // R_2$

$$R_o = \left.\frac{V_x}{I_x}\right|_{V_i = 0} ; \quad I_x + g_m V_{gs} = \frac{V_x}{r_o} + \frac{V_x}{R_s}$$

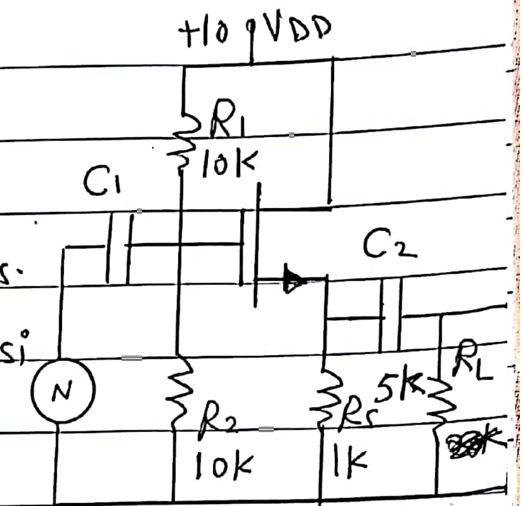
when $V_i = 0$, $V_{gs} = -V_x$

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

EXA: For the cct. shown in Fig. the MOSFET has: $K_n = 2\,mA/V^2$, $V_{TN} = 2V$, $\lambda = 0.025\,V^{-1}$. The cct. is biased at $I_D = 2mA$.

1) Draw S.S. A.C eqnt. cct. and Find: A_V, R_i, R_o

2) Write D.C. & A.C. L.L and Find slopes.



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

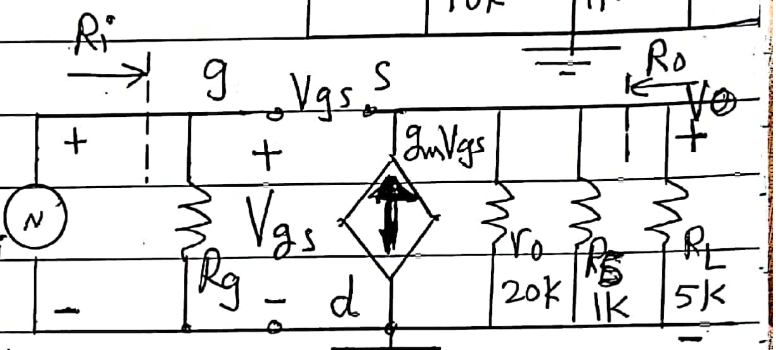
$V_o = g_m V_{gs} \overline{R_L}$

$(V_o/V_{gs}) = g_m \overline{R_L}$

where $\overline{R_L} = r_o // R_s // R_L$

$$r_o = \frac{1}{\lambda I_D} = \frac{1}{0.025 \times 2 \times 10^{-3}} = 20\,k\Omega$$

$$g_m = 2\sqrt{K_n I_D} = 2\sqrt{2 \times 2} = 4\,\frac{mA}{V}$$



S.S. A.C eqnt. cct.

$-V_{si} + V_{gs} + V_o = 0 \Rightarrow V_{si} = V_{gs} + g_m V_{gs} \overline{R_L} = V_{gs}(1 + g_m \overline{R_L})$

$$\therefore (V_{gs}/V_{si}) = \frac{1}{1 + g_m \overline{R_L}}$$

$$\therefore A_V = \frac{g_m \overline{R_L}}{1 + g_m \overline{R_L}}, \quad \overline{R_L} = 20 // 5 // 1 = 0.8\,K\Omega$$

$A_V = (4 \times 0.8)/(1 + 4 \times 0.8) = 0.762$

$R_i = R_g = 10 // 10 = 5\,K\Omega$

$$R_o = \left.\frac{V_x}{I_x}\right|_{V_{si}=0} = \frac{1}{g_m} // r_o // R_s = \underset{\Omega}{\frac{1}{4 \times 10^{-3}}} // \underset{K\Omega}{20} // \underset{K\Omega}{1} =$$

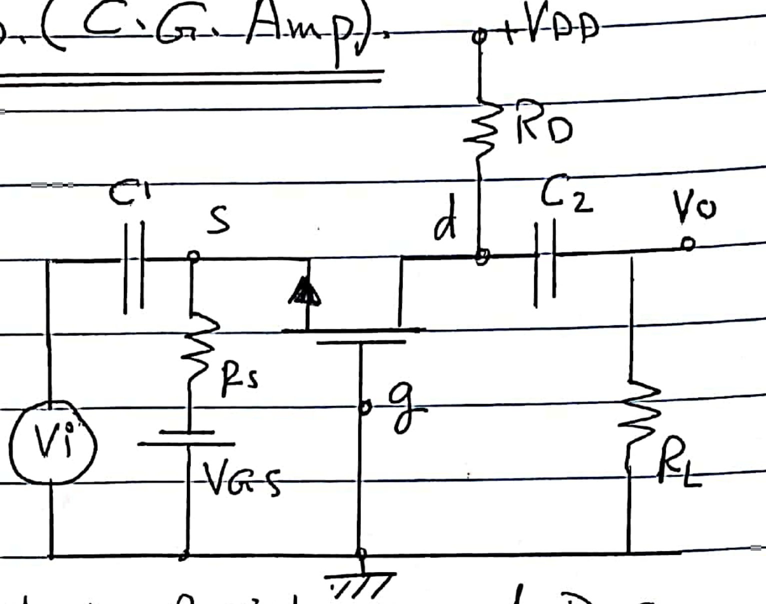
$\therefore R_o = 0.25 // 20 // 1 = 198\,\Omega$

D.C.L.L: $V_{DS} = V_{DD} - I_D R_s \Rightarrow$ slope $= -\dfrac{1}{R_s}$

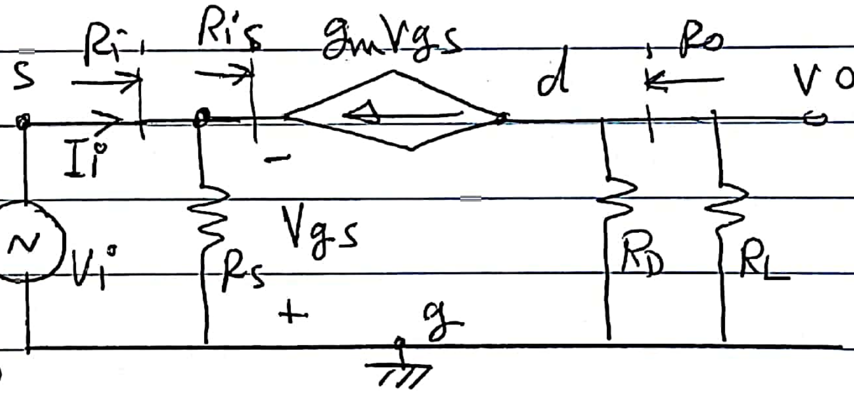
A.C.L.L: $v_{ds} = -i_d (R_s // R_L) \Rightarrow$ slope $= \dfrac{-1}{(R_s // R_L)}$

Scanned with CamScanner

(3) Common Gate Amp. (C.G. Amp).



For this Amp:
Vi to Source
Vo from drain
Gate: is Common - Terminal
For the cct. shown
assume certain Values
for K_n, V_{TN} and certain Resistance and D.C
Source such that the MOSFET is in Saturation
Regn.
Draw S.S. A.C eqnt. cct. and find A_v, R_i & R_o.



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

$V_{gs} = -V_i$

$\therefore V_o = g_m V_i (R_D // R_L)$

$\therefore A_v = \dfrac{V_o}{V_i} = g_m (R_D // R_L)$

$\therefore A_v > 1$, $\phi = 0°$

$$R_o = \left.\frac{V_x}{I_x}\right|_{v_i=0} \Rightarrow R_D$$

$$R_i = \frac{V_i}{I_i} = R_s // R'_{is}$$

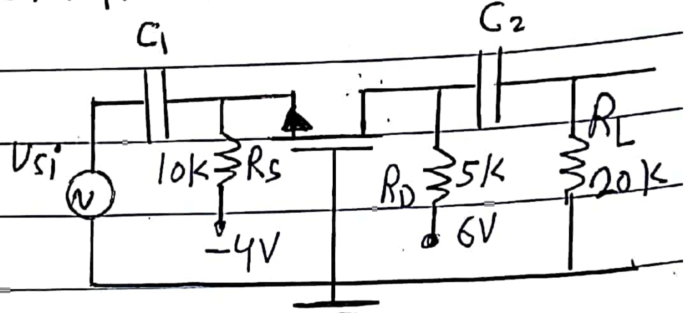
$$R'_{is} = \frac{-V_{gs}}{-g_m V_{gs}} = \frac{1}{g_m}$$

$$R_i = R_s // \frac{1}{g_m}.$$

EXA: "C.G. Amp": For the cct. shown, the MOSFET has the parameters: $V_{TN}=1V$, $K_n=3mA/V^2$, $\lambda=0$

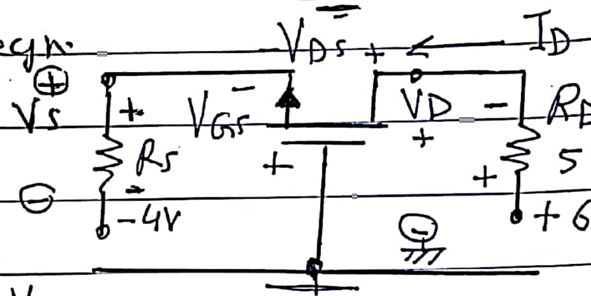
1) Determine I_{DQ}, V_{DSQ}

2) Draw S.S.A.C eqnt. cct. and Calculate A_V, R_i & R_o



D.C Analysis:

Assume the MOSFET in Sat. Regn.



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

$V_{GS}=V_G-V_S$, $V_G=0$

$V_{GS}+I_DR_S-4=0$

$V_{GS}=4-I_DR_S \Rightarrow I_D=\frac{4-V_{GS}}{10}=3(V_{GS}^2-2V_{GS}+1)$

$4-V_{GS}=30V_{GS}^2-60V_{GS}+30=0$

$30V_{GS}^2-59V_{GS}+26=0$

$V_{GS}=\frac{59\mp\sqrt{(59)^2-4\times30\times26}}{60}=\frac{59\mp19}{60}=\boxed{1.3V}$ or $\boxed{0.667}$

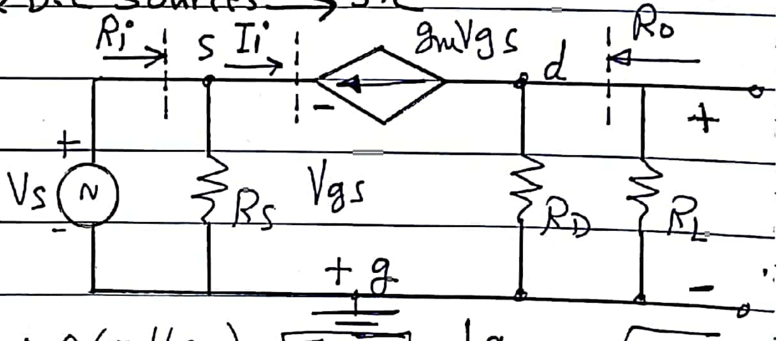
$\boxed{I_D}=\frac{4-1.3}{10}=\boxed{0.27mA}$

$-6+I_DR_S+V_{DS}+I_DR_S-4=0$

$\therefore \boxed{V_{DS}}=10-I_D(R_D+R_S)=10-0.27(5+10)=\boxed{5.95V}$

$V_D=6-I_DR_D=4.65V$, $V_S=I_DR_S-4=-1.3V$

A.C Analysis: All caps. & D.C Sources $\rightarrow$ S.C



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

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

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

$V_{gs}=-V_{si}\rightarrow\frac{V_{gs}}{V_{si}}=-1$

$\therefore A_V=+g_m(R_D//R_L)=1.8(5//20)=\boxed{7.2}$

$g_m=2\sqrt{K_nI_D}=1.8\frac{mA}{V}$

$R_i=R_S//R_{is}$, $R_{is}=\frac{-V_{gs}}{-g_mV_{gs}}=\frac{1}{g_m}=0.555K$

$R_i=10//0.555=0.526K\Omega$

$R_o=\frac{V_x}{I_x}\Big|_{V_{si}=0}\Rightarrow R_o=R_D=5K\Omega$

Multistage MOSFET Amps.

Amps. which contain more than ONE Transistor and used to achieve certain combined specification which can't be achived using single stage.

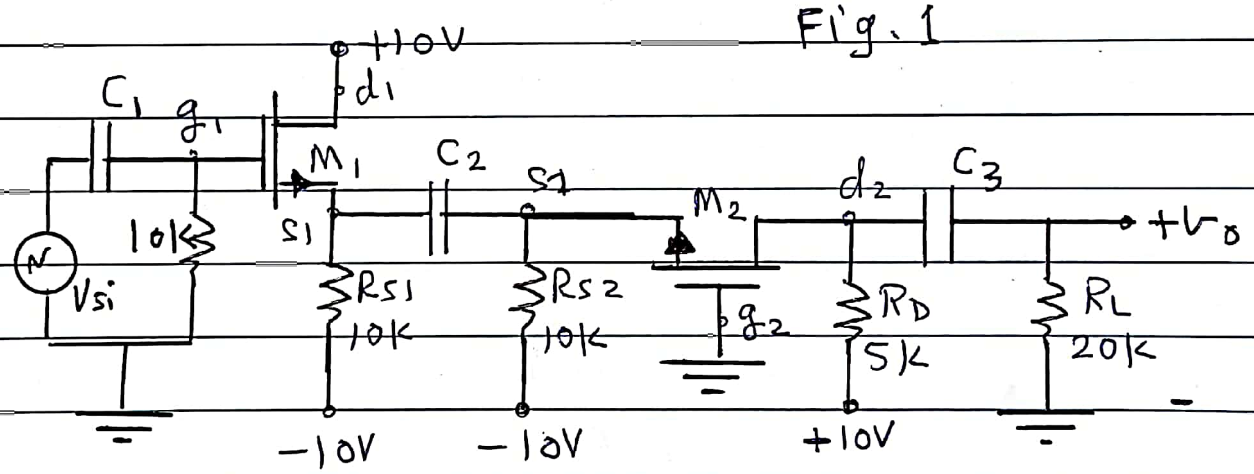
1) Cascade Multistage: These are connected in series and used to obtain high Av or other characteristics.

EX A1: Consider the circuit shown in Fig. 1 where M_1 & M_2 are identical MOSFETs with $V_{TN} = 2V$ and $K_n = 4\ mA/V^2$. $\lambda = 0$.

1) Determine I_{D1}, I_{D2}, V_{DS1} and V_{DS2}.

2) Draw S.S.A.C eqnt. cct. and calculate Av, Rin and Ro?

Fig. 1



This Amp. contain C.D Amp & C.G Amp.

D.C Analysis: For 1st stage.

$I_{D1} = K_{n1}(V_{GS1} - V_{TN1})^2$

$V_{GS1} = V_{G1} - V_{S1} = \cancel{I_G R_G} - (I_{D1}R_{S1} - 10)$

$\therefore V_{GS1} = 10 - 10 I_{D1}$

$I_{D1} = \frac{10 - V_{GS1}}{10} = 4(V_{GS1}^2 - 4V_{GS1} + 4)$

$10 - V_{GS1} = 40V_{GS1}^2 - 160V_{GS1} + 160$

$40V_{GS1}^2 - 159V_{GS1} + 150 = 0$, $V_{GS1} = 2.43V$

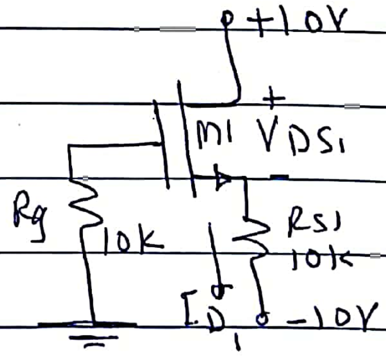


Fig. 2

$$I_{D1} = \frac{10-2.43}{10} = 0.756\ mA$$

$$V_{DS1} = 10+10-10\times 0.756 = 12.4\ V$$

For M_2:

$$I_{D2} = K_n(V_{GS2}-V_{TN2})^2$$

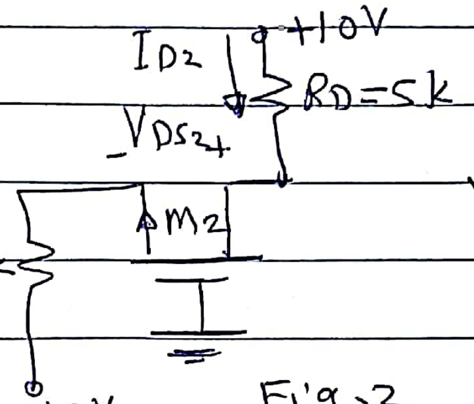


Fig.3

where $V_{GS2} = V_{G2}-V_{S2} = 0-(10I_{D2}-10)$

$V_{GS2} = 10-10I_{D2}$, $I_{D2} = \dfrac{10-V_{GS2}}{10}$

$$\frac{10-V_{GS2}}{10} = 4(V_{GS2}^2-4V_{GS2}+4)$$

So $I_{D2} = 0.756\ mA$

$$V_{DS2} = 10+10-I_{D2}(R_D+R_{S2}) = 20-0.756(5+10)\times 10^3$$

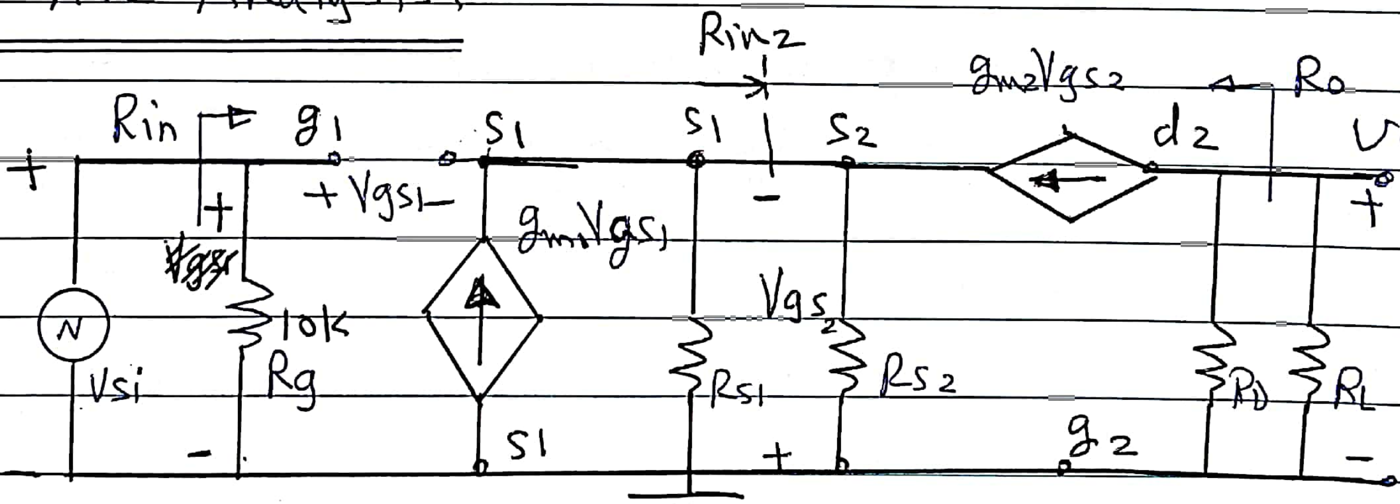
$\therefore V_{DS2} = 8.65V$

For both MOSFET $V_{DS(sat)} = V_{GS}-V_{TN} = 0.4\ V$

and $V_{DS_1}, V_{DS_2} > V_{DS(sat)}$.

So both MOSFETs in Saturation.

A.C Analysis:



S.S. A.c eqnt. cct.

Fig.4

$R_{in} = R_g = 10K\Omega$, $R_o = R_D = 5K\Omega$

$g_{m2} = 2\sqrt{K_n I_D} = 3.47\ mA/V$

~~∴ Ro ≈ 288Ω~~

$$A_V = \frac{V_o}{V_{si}} = \frac{V_o}{V_{o1}} \times \frac{V_{o1}}{V_{si}} = A_{V2} * A_{V1}$$

$$\frac{V_o}{V_{o1}} = \frac{\cancel{-} g_{m2}(R_D \| R_L)\cancel{V_{gs2}}}{\cancel{-V_{gs2}}} = g_{m2}(R_D \| R_L) \quad .(C.G\ Amp).$$

$$\frac{V_{o1}}{V_{si}} = \frac{g_{m1}\cancel{V_{gs1}}(R_{s1} \| R_{in2})}{\cancel{V_{gs1}} + g_{m1}\cancel{V_{gs1}}(R_{s1} \| R_{in2})} = \frac{g_{m1}(R_{s1} \| R_{in2})}{1 + g_{m1}(R_{s1} \| R_{in2})}$$

$$\therefore A_V = g_{m2}(R_D \| R_L) \frac{g_{m1}(R_{s1} \| R_{in2})}{1 + g_{m1}(R_{s1} \| R_{in2})}$$

$$R_{in2} = \frac{1}{g_{m2}} \| R_{s2} = 288 \| 10K = 0.28K\Omega \quad (C.G\ Amp)$$

$$R_{s1} \| R_{in2} = 0.272\,K\Omega$$

$$A_V = 3.47(5 \| 20) \frac{3.47 \times 0.272}{3.47 \times 0.272 + 1} = 6.7$$

* The overall A_V is >1
* The 〃 phase-shift is zero
* ~~The 〃 output Resistance is "Low"~~.

"Cascode Multistage

This cct. is shown in Fig. in which M_1 is Connected as C.S Amp. and M_2 is Connected as C.G Amp. This Amp. is used for high freq response Amp. "wide band Amp."

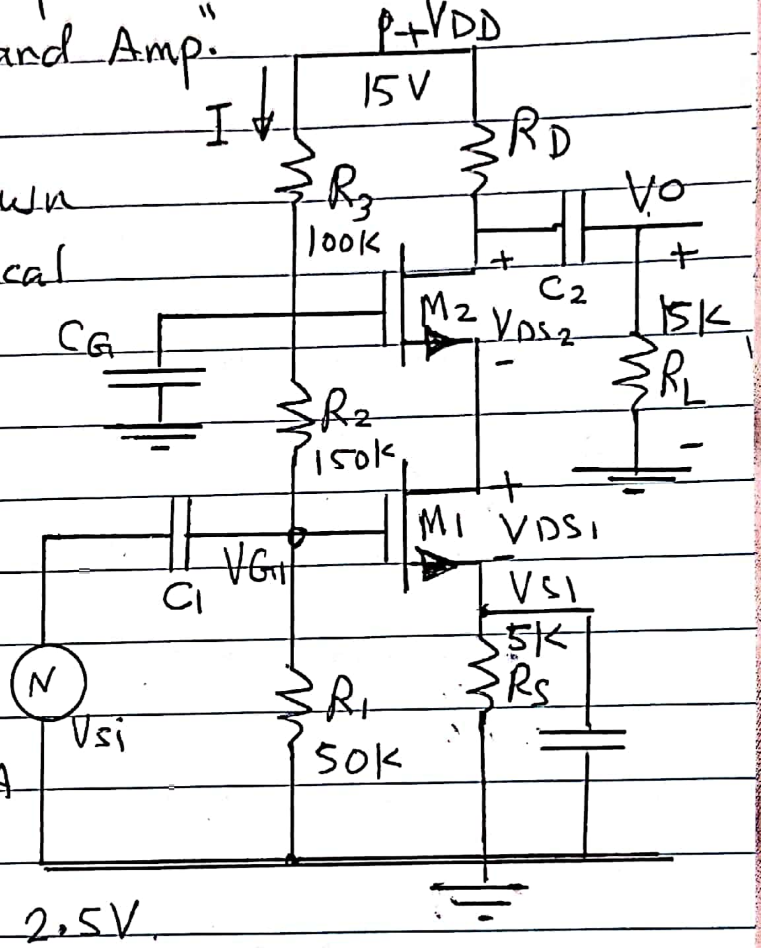


Fig. 5

EXA: For the cct. shown M_1 & M_2 are identical

With $V_{TN} = 1.0V$

$K_n = 0.8 mA/V^2$

$\lambda = 0$

* D.C Analysis:

Find V_{DS1}, V_{DS2}, I_D

all Caps. are open.

$$I = \frac{15V}{100+50+150} = 0.05mA$$

$V_{G1} = I \times R_1 = 0.05 \times 50 = 2.5V$

$V_{S1} = I_D R_s = 5 I_D$

$V_{GS1} = V_{G1} - V_{S1} = 2.5 - 5 I_D$

$$\therefore I_D = \frac{2.5 - V_{GS1}}{5} = 0.8(V_{GS1}^2 - 2V_{GS} + 1)$$

$$\therefore 4V_{GS1}^2 - 8V_{GS1} + 4 = 2.5 - V_{GS1}$$

$$4V_{GS1}^2 - 7V_{GS1} + 1.5 = 0$$

$$\therefore V_{GS1} = \frac{7 \mp \sqrt{49 - 4 \times 4 \times 1.5}}{8} = \frac{7 \mp 5}{8} = 1.5V$$

$$I_D = \frac{2.5 - 1.5}{5K} = 0.2mA$$

$V_{GS1} = V_{GS2} = 1.5V$ (Since $I_{D1} = I_{D2}$, $V_{TN1} = V_{TN2}$, $K_{n1} = K_{n2}$)

$-V_{DD}+IR_3+V_{GS2}+V_{DS1}+I_DR_s=0$

$V_{DS1}=15-0.05\times100-1.5-0.2\times5=7.5V$

$-V_{DD}+I_DR_D+V_{DS2}+V_{DS1}+I_DR_s=0$

$\therefore V_{DS2}=15-7.5-10\times0.2=5.5V$

$V_{DS(sat)}=V_{GS}-V_{TN}=1.5-1=0.5V$

$\therefore$ Both MOSFETs are in Saturation Regn.

"A.C Analysis"

all Caps. & D.C Source are S.C.

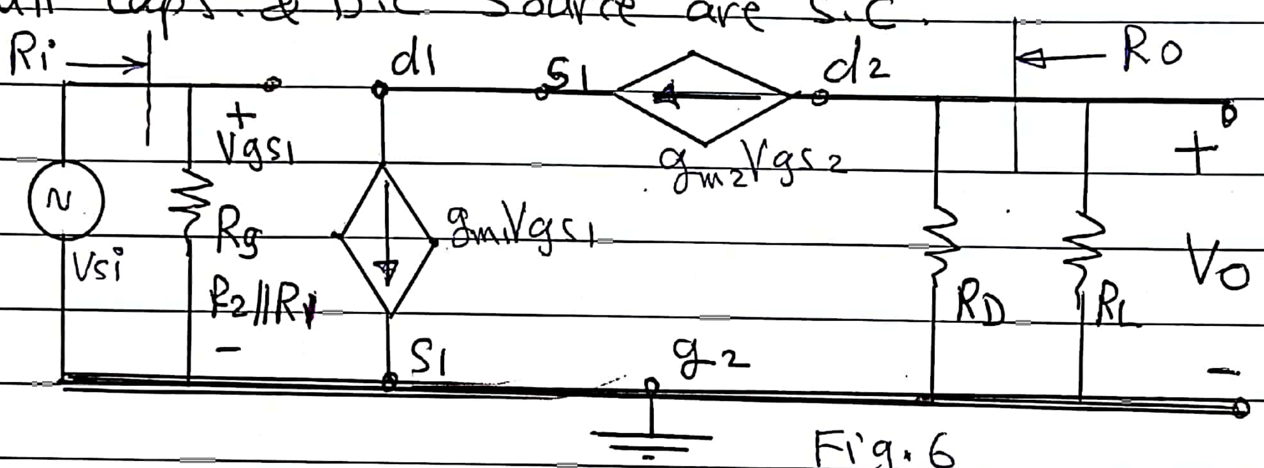


Fig.6

$$A_v=\frac{V_o}{V_{si}}=\frac{-g_{m1}\cancel{V_{gs}}(R_D//R_L)}{\cancel{V_{gs1}}}=-g_{m1}(R_D//R_L)$$

$$g_m=2\sqrt{K_nI_D}=2\sqrt{0.8\times0.2}=0.8mA/V$$

$\therefore A_v=-0.8(10//15)=-4.8$

$R_{in}=R_2//R_1=150//50=37.5K\Omega$

$$R_o=\frac{V_x}{I_x}\Big|_{V_{si}=0}$$

NOTE

The AV of this Amp. is (AV) of the C.S. Amp.??

when $V_{si}=0$, $V_{gs1}=0$, $g_{m1}V_{gs1}=0\Rightarrow O.C$

$\therefore R_o=R_D=10K\Omega$

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Operational Amplifier "Op-Amp"

Op-Amp. is an electronic device in IC form, Contain multistages direct Connected, with a Very-high Voltage gain. Compared to BJT and FET, It is Voltage Controlled - Voltage Source "VCVC".

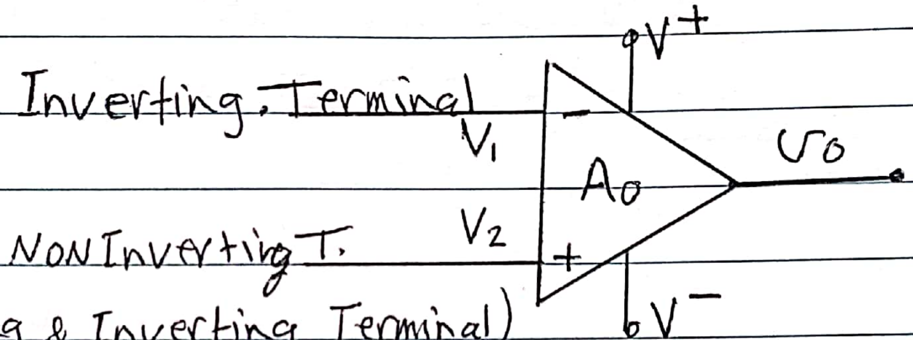
The Symbol for Op-Amp, is shown in Fig.1

Where:

$V_o = A_o(V_2 - V_1)$

A_o: open-loop gain

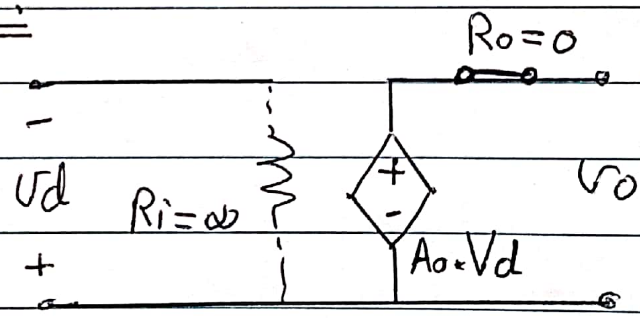
V_2, V_1 (Signal on nonInverting & Inverting Terminal)



V^+ and V^-: are positive and negative biasing Voltage.

Ideal op-Amp. parameters:

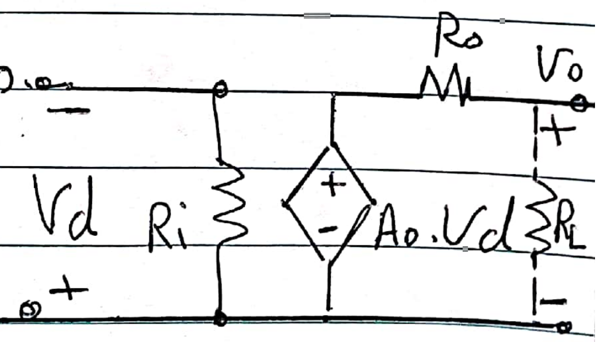
1) $R_{in} = \infty$
2) $R_o = 0$
3) open-loop gain $= \infty$
4) Bandwidth $B.W = \infty$



Ideal Op-Amp eqnt. cct.

NonIdeal op-Amp parameters

The real Op-Amps. parameters depend on the type of op-Amp. (Technology: either Bipolar, MOSFET or BiFET")



where $R_{in} \neq \infty$, $R_o \neq 0$

$B.W \neq \infty$, $A_o \neq \infty$

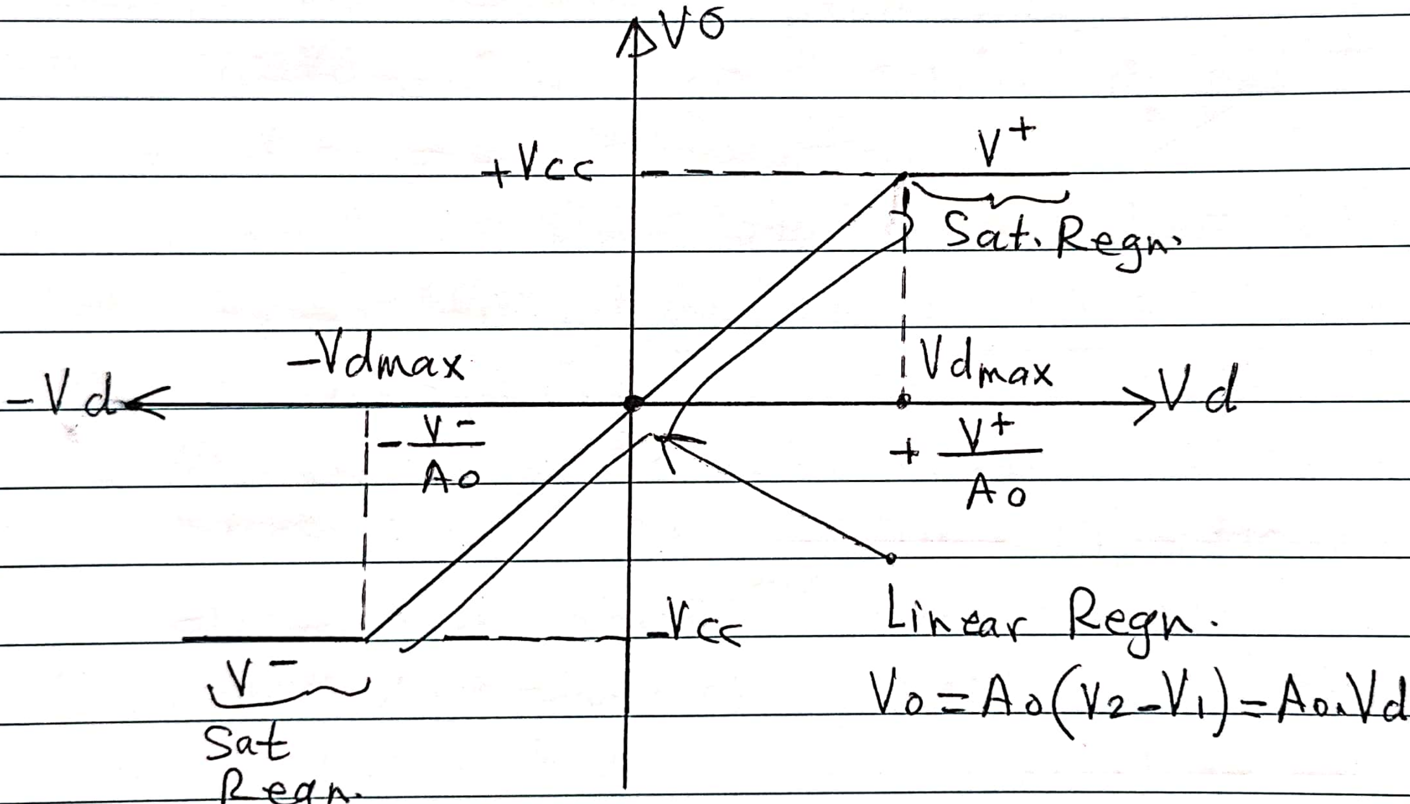
If R_L is Connected, then:

In ideal Op-Amp: $V_o = A_o . V_d$ (Independant ON R_L)

In nonideal op-Amp: $V_o = \frac{A_o . V_d . R_L}{R_L + R_o}$ (depends ON R_L).

Transfer characteristics: "a plote of V_o Versus V_i"

This c/c is obtained from this eqn: $V_o = A_o (V_2 - V_1)$ but it is not exceed $\mp V$ i.e $[V^- < V_o < V^+]$



Operating Regns:

① NON-Saturation Regn: when $[-V_{dmax} > V_d < V_{dmax}]$ in this Regn: $V_o = A_o (V_2 - V_1)$ {Linear Regn}

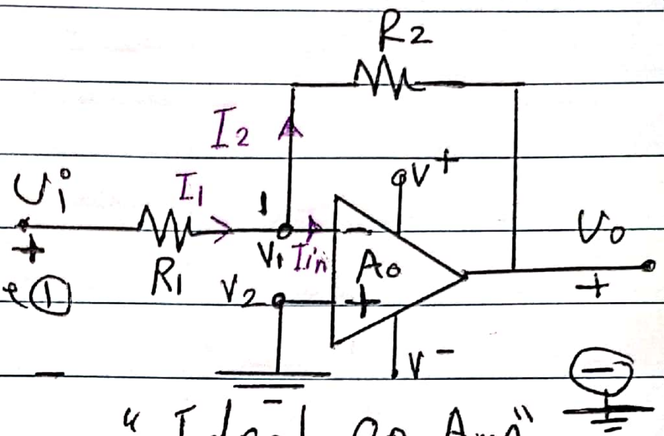
② Saturation Regn: when $[-V_{dmax} < V_d > V_{dmax}]$ In this Regn: $V_o = \mp V$ (either V^+ or V^-)

"Op-Amp. Applications"

1) Linear Applications:

a) Inverting Amplifier

To determine the voltage gain of this Amp. follow the procedure: KCL at Node 1



"Ideal Op-Amp"

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

$$\frac{V_i - V_1}{R_1} = \frac{V_1 - V_o}{R_2} + I_{in} \quad (1)$$

but $I_{in} = 0$ (Since $R_{in} = \infty$)

and $V_1 = V_2 = 0$ (Virtual ground)

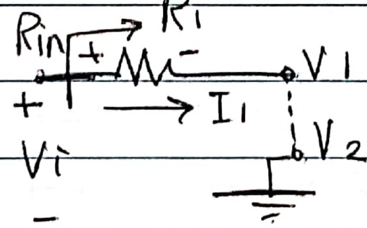
So: eqn. (1) becomes:

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

A_V is closed-loop gain.

(−) Inverting (180° phase-shift)

Input Resistance:



$$-V_i + I_1 R_1 = 0$$

$$R_i = \frac{V_i}{I_1} = R_1$$

Virtual short & Virtual ground

$V_1 = V_2$ (V. short) means $V_1 = V_2$ but Node (1) and (2) are not Connected.

* If V_1 or V_2 is Connected to ground then $V_1 = V_2 = 0$ (Virtual ground) i.e $V_1 = 0$ but Node (1) is NOT Connected to ground.

notice: $A_o \rightarrow$ open-loop gain

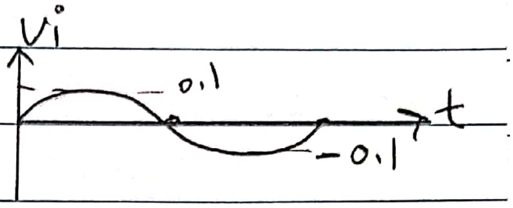
$A_V \rightarrow$ closed-loop "

EXA: design an Inverting Amp. to have $A_v = -50$ and $R_{in} = 10k\Omega$. draw $v_o(t)$ for $V_i = 0.1 \sin\omega t$

Solution:

Since $R_{in} = R_1$ (For Inv. Amp).

So R_1 must be $10k\Omega$

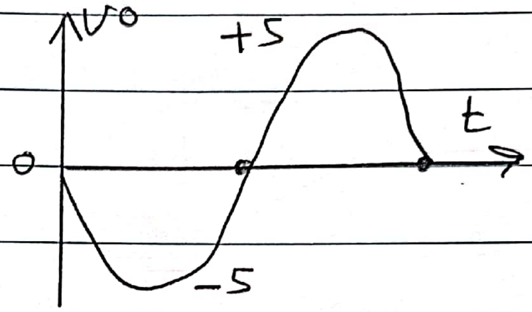


$$A_v = \frac{-R_2}{R_1} = -50$$

So $R_2 = 50R_1 = 500k\Omega$

$v_o = A_v \cdot V_i = -50 \times 0.1 \sin\omega t$

$= -5 \sin\omega t$ V

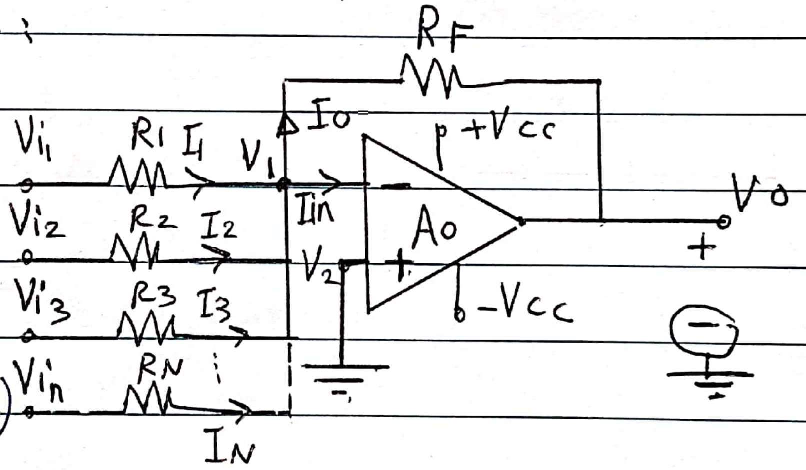


(b) Summing Amplifier:

KCL at Node ① gives;

$$I_1 + I_2 + I_3 + \dots + I_N = I_{in} + I_o$$

$$\frac{V_{i1} - V_1}{R_1} + \frac{V_{i2} - V_1}{R_2} + \frac{V_{i3} - V_1}{R_3} + \frac{V_{iN} - V_1}{R_N} = I_{in} + \frac{V_1 - V_o}{R_F} \quad \text{—— ①}$$



but $V_1 = V_2 = 0$ (V. ground)

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

So eqn. ① becomes: $\frac{V_{i1}}{R_1} + \frac{V_{i2}}{R_2} + \frac{V_{i3}}{R_3} = -\frac{V_o}{R_F}$

$$\therefore V_o = -\left(\frac{R_F}{R_1} V_{i1} + \frac{R_F}{R_2} V_{i2} + \frac{R_F V_{i3}}{R_3} + \dots + \frac{V_{iN} R_F}{R_N}\right)$$

each Vi will be multiplied (amplified) by a Certain factor, Summed, and Inverted.

If all Signals are required to be amplified by Same gain, then choose $R_1 = R_2 = R_3 = R_N = R$

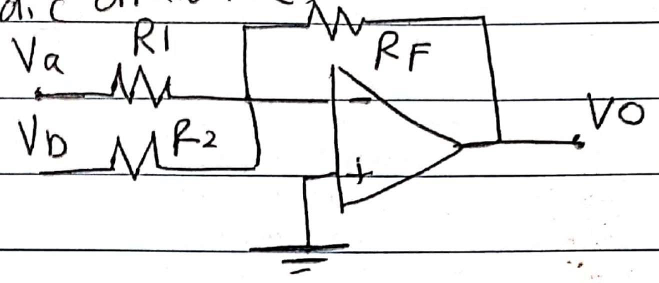
and $V_o = -\frac{R_F}{R}(V_{i_1}+V_{i_2}+V_{i_3}+\cdots+V_{i_N})$.

V_i can be "a.c or d.c signal"

EXA:

a) Design an Amp to produce $V_o = -(5V_a + 10V_b)$.

b) For $V_a = 2\sin\omega t\ V$, $V_b = -0.3\ V\ d.c$ draw $V_o(t)$



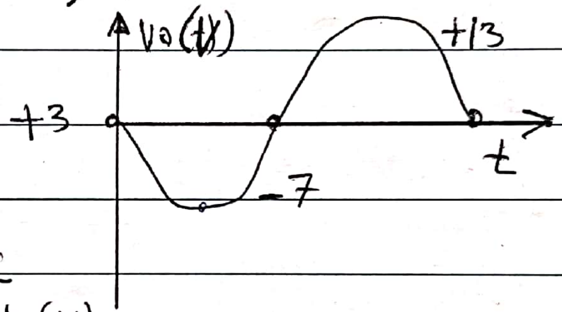
Compared to:

$V_o = -\left(\frac{R_F}{R_1}V_a + \frac{R_F}{R_N}V_b\right)$

$\frac{R_F}{R_1} = 5$, $\frac{R_F}{R_2} = 10$

let $R_F = 20K\Omega$, So $R_1 = 4K\Omega$, $R_2 = 2K\Omega$

b) $V_o = -(5\times 2\sin\omega t + (10)(-0.3)) = 3 - 10\sin\omega t\ V$



EXA: Design a cct. to produce $V_o = -10(V_a + V_b)$.

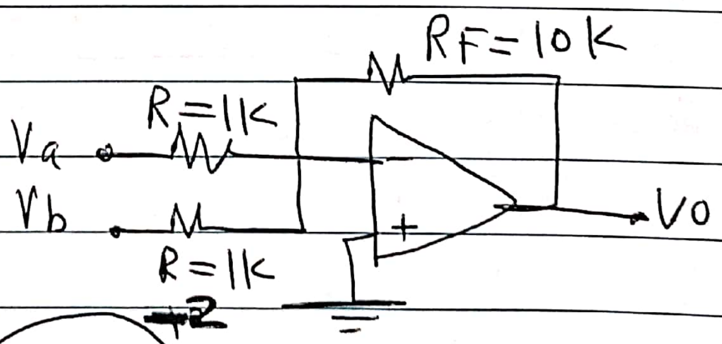
draw $V_o(t)$ when $V_a = 0.4\ V\ d.c$

$V_b = 0.2\sin\omega t\ (V)$

Solution: Compared V_o eqn. with

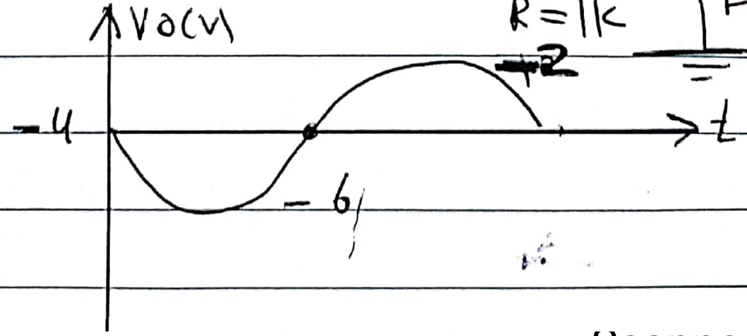
$V_o = -\frac{R_F}{R}(V_{i_1} + V_{i_2})$

$\frac{R_F}{R} = 10$, let $R_F = 10K$, $R = 1K\Omega$



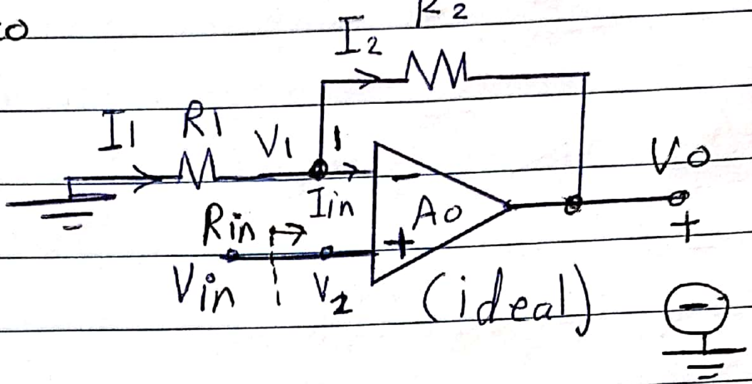
$V_o = -10(.4 + 0.2\sin\omega t)$

$= -4 - 2\sin\omega t$



3 NonInverting Amp.

The input is given to noninveting terminal



KCL at Node 1

$I_1 = I_2 + I_{in}$

$$\frac{0-V_1}{R_1} = \frac{V_1 - V_o}{R_2} + I_{in}$$

but $I_{in} = 0$, $V_1 = V_2 = V_i$ (Virtual short)

$$\frac{-V_{in}}{R_1} = \frac{V_{in} - V_o}{R_2} \Rightarrow \frac{V_o}{R_2} = \frac{V_{in}}{R_1} + \frac{V_{in}}{R_2}$$

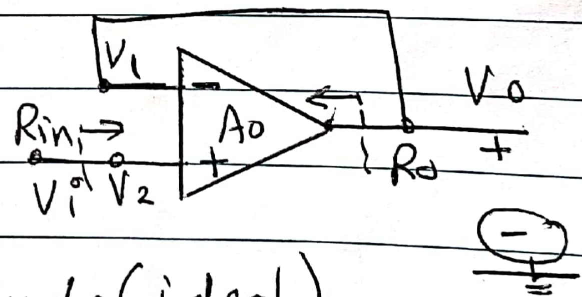
So $V_o = \left(1 + \frac{R_2}{R_1}\right) V_{in}$

$$\frac{V_o}{V_{in}} = A_v = \left(1 + \frac{R_2}{R_1}\right)$$, V_{in} will be amplified by $\left[1 + \frac{R_2}{R_1}\right]$ and NOT inverted

Input resistance $R_{in} = \infty$.

4 Voltage-Follower "Buffer"

It is a special case of noninverting in which $R_1 = \infty$ and $R_2 = 0$



$V_1 = V_2 = V_{in}$ (Virtual Short)

and Since $V_1 = V_o$

$\therefore V_o = V_{in} \Rightarrow A_v = \frac{V_o}{V_{in}} = 1$

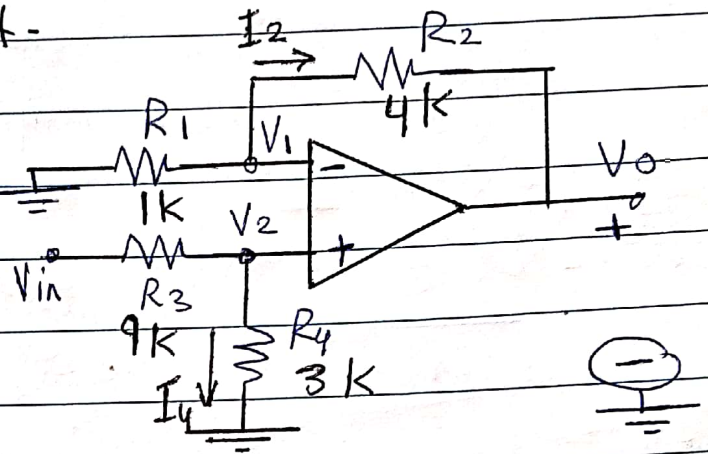
i.e V_o follows V_{in} in magnitude (ideal) and Sign, So it is called voltage-follower

[$R_{in} = \infty$, $R_o = 0$, $A_v = 1$, $\phi = 0$] characteristics of ideal Voltage-follower.

* it is used to minimize Loading effect. *

EXA: For the cct. shown in Fig. assume ideal Op-Amp. Calculate and draw $V_o(t)$ for the indicated input.

$(V_i = 8\sin\omega t\ V)$



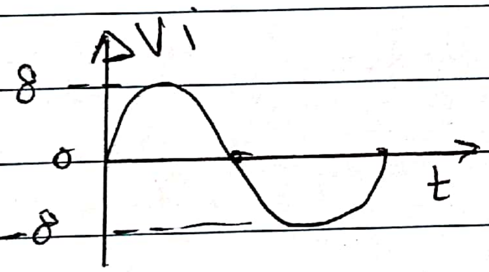
$$V_o = \left(1+\frac{R_2}{R_1}\right)V_2$$

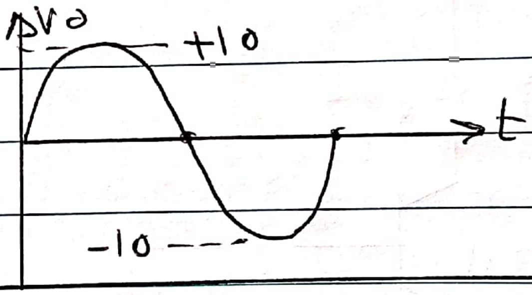
$$V_2 = \frac{V_{in}\cdot R_4}{R_3+R_4}$$

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

$$\therefore \frac{V_o}{V_{in}} = \left(1+\frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3+R_4}\right) = \left(1+\frac{4}{1}\right)\left(\frac{3}{9+3}\right) = 1.25$$

$$\therefore V_o = A_v \cdot V_{in} = 1.25\times 8\sin\omega t = 10\sin\omega t.$$





EXA: For the above cct. Calculate I_4, I_2, V_1 For the same input.

$$V_2 = \frac{R_4}{R_3+R_4}V_i = \frac{3}{9+3}(8\sin\omega t) = 2\sin\omega t\ (V)$$

$$I_4 = \frac{V_2}{R_4} = \frac{2\sin\omega t}{3K} = 0.66\sin\omega t\ mA.$$

$V_1 = V_2$ (Virtual short) $= 2\sin\omega t\ (V)$

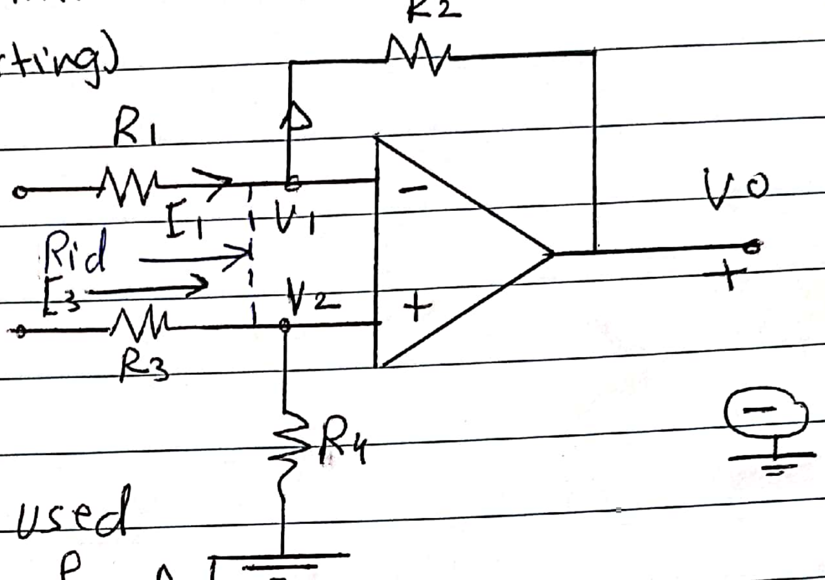
$$I_2 = \frac{V_1-V_o}{R_2} = \frac{2\sin\omega t - 10\sin\omega t}{4K} = -2\sin\omega t\ mA$$

5) Difference Amp.

In this cct. both terminals are used (Inverting & noninverting) the o/p will be in the form

$V_o = A_d(V_{i2} - V_{i1})$

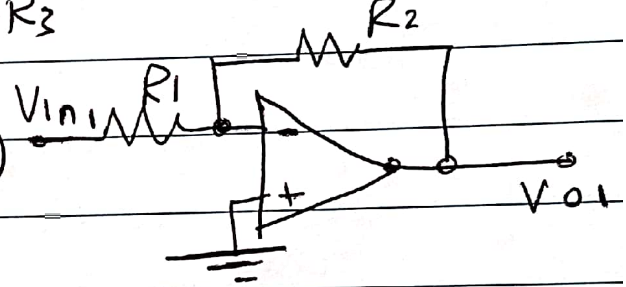
where A_d: the gain of the diff. Amp.



* Superposition will be used to find the expression for A_d

1) For V_{i1} ($V_{i2} = 0$), $V_2 = \frac{V_{i2} \times R_4}{R_4 + R_3} = 0$, so the cct. will be as shown.

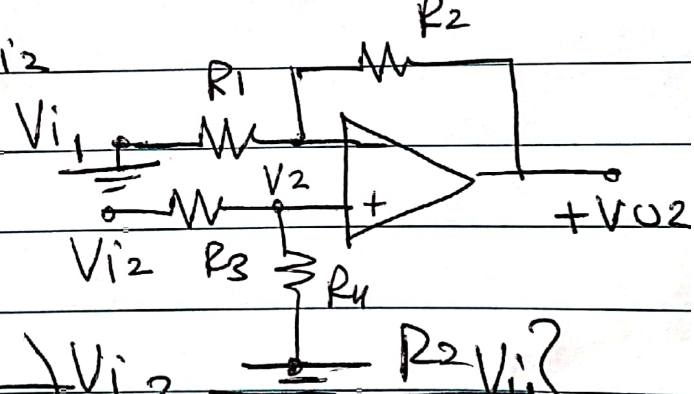
$V_{o1} = -\frac{R_2}{R_1} V_{i1}$ (Inverting Amp)



2) For V_{i2} ($V_{i1} = 0$)

$V_{o2} = \left(\frac{R_4}{R_4 + R_3}\right)\left(1 + \frac{R_2}{R_1}\right) V_{i2}$

(NonInverting)



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

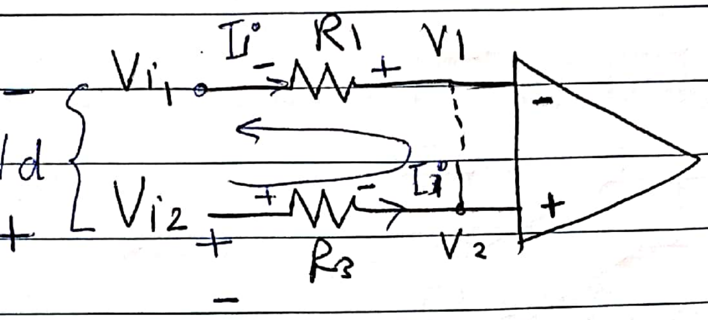
$\therefore V_o = \left\{ \left(1 + \frac{R_2}{R_1}\right)\left(\frac{(R_4/R_3)}{1 + \frac{R_4}{R_3}}\right) V_{i2} - \frac{R_2}{R_1} V_{i1} \right\}$

If $\left(\frac{R_4}{R_3} = \frac{R_2}{R_1}\right)$ then, $V_o = \frac{R_4}{R_3}(V_{i2} - V_{i1})$

$\therefore A_d = \frac{V_o}{V_{i2} - V_{i1}} = \boxed{\frac{R_4}{R_3} = \frac{R_2}{R_1}}$

Input Resistance Rid:

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



$-V_d + I_i R_3 + I_i R_1 = 0$

$V_d = I_i(R_1 + R_3)$

$\therefore R_{id} = \frac{V_d}{I_1} = R_1 + R_3$

EXA: Design a difference Amp. to have $R_{id} = 6K$ and $A_d = 50$? Calculate V_o for $V_{i1} = 2V$, $V_{i2} = 2.1V$

Solution:

For this cct. $A_d = \frac{R_2}{R_1}$ (with assumption $\frac{R_2}{R_1} = \frac{R_4}{R_3}$

also $R_{id} = R_1 + R_3$

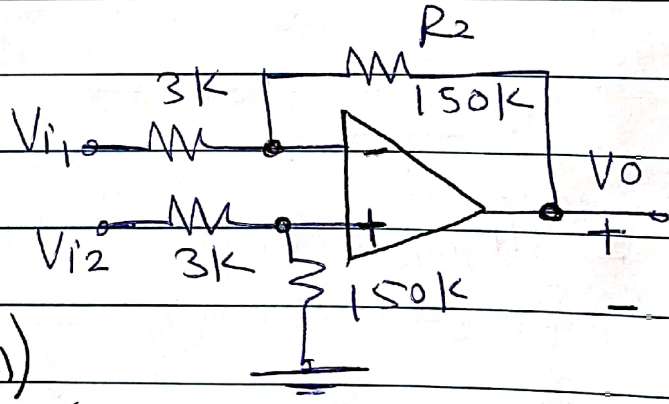
"If we choose $R_1 = R_3$ & $R_2 = R_4$, we satisfy the above Constraint. (assumption)

So $(R_1 + R_3) = 6K\Omega = R_{id}$ then $R_1 = R_3 = 3K$

$A_d = \frac{R_2}{R_1} = 50 \Rightarrow \therefore R_2 = R_4 = 50 \times 3 = 150K\Omega$

$V_o = A_d(V_{i2} - V_{i1})$

$= 50(2.1 - 2) = 5V$

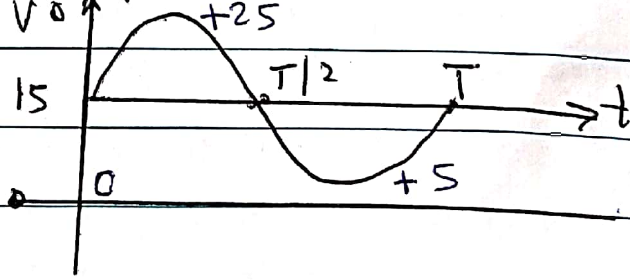


* For $V_{i1} = -0.2 \sin\omega t$

$V_{i2} = 0.3 V_{d.c}$

$V_o = 50(0.3 - (-0.2 \sin\omega t))$

$= 50(0.3 + 0.2 \sin\omega t) = (15 + 10 \sin\omega t)V$



EXA2: Design a diff. Amp. to have $A_d = 100$, $R_i = 20k$ using an ideal Op-Amp.

To satisfy $\frac{R_2}{R_1} = \frac{R_4}{R_3}$

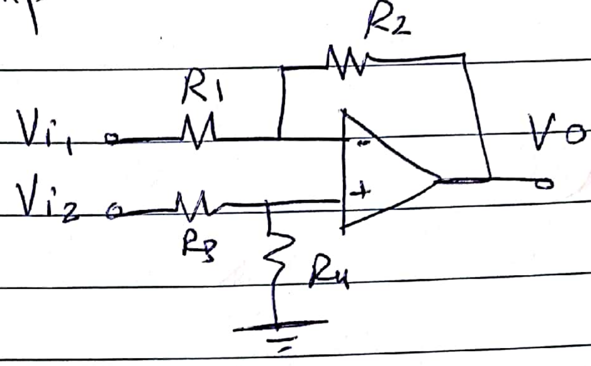
let $R_1 = R_3$, $R_2 = R_4$

then $R_{in} = 2R_1 = 2R_3 = 20k\Omega$

$\therefore R_1 = R_3 = 10k\Omega$

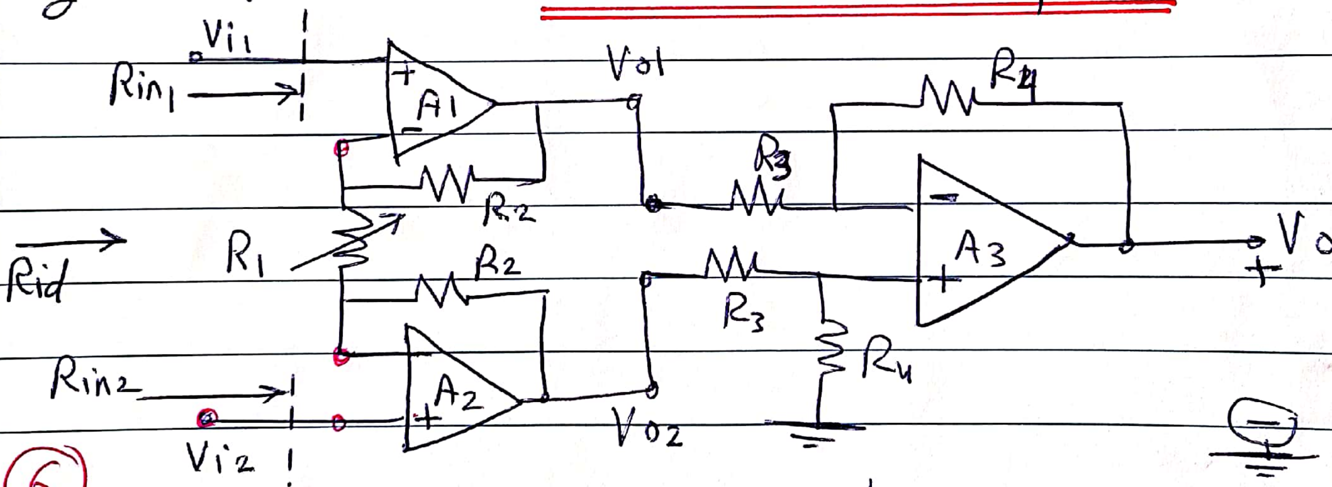
Since $A_d = \frac{R_2}{R_1} = \frac{R_4}{R_3} = 100$

$\therefore R_2 = R_4 = 1000k\Omega = 1\,M\Omega$



$\therefore$ To increase Rin or Ad we must accept high Value for R_2 & R_4 which is NOT desired in design!!!

So to solve this problem and achieve high Ad & high Rin we use an Instrumentation Amplifier.



6

Instrumention Amp.

It Contains three Op-Amps.

A_1 & A_2 $\longrightarrow$ Noninverting Amp.

A_3 $\longrightarrow$ Difference Amps.

$R_{in1} = \infty$, $R_{in2} = \infty$

$R_{id} = \infty$.

This Amp achieves: high, adjustable, single-element dependant gain. and Very high input resistance. Using proper Values for resistance.

To derive an expression for the differentional voltage gain (A_d), superposition theorm is used.

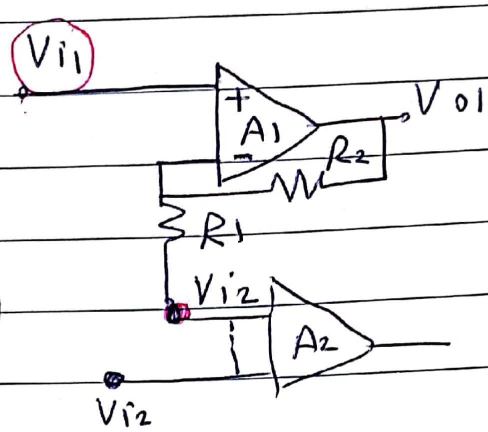
① Effect of V_{i_1} ($V_{i_2} = 0$) A_1 is NONinverting

with $V_{o_1}' = \left(1 + \frac{R_2}{R_1}\right) V_{i_1}$

② Effect of V_{i_2} ($V_{i_1} = 0$)

A_1 is inverting

$V_{o_1}'' = -\frac{R_2}{R_1} V_{i_2}$



but $V_{o1} = V_{o1}' + V_{o1}''$ (superposition)

So $V_{o1} = \left(1 + \frac{R_2}{R_1}\right) V_{i_1} - \frac{R_2}{R_1} V_{i_2}$.

The same for A_2:

NONinverting for V_{i2} & Inverting for V_{i_1}, So

$V_{o2} = \left(1 + \frac{R_2}{R_1}\right) V_{i_2} - \frac{R_2}{R_1} V_{i_1}$

But $V_o = (V_{o2} - V_{o1}) \frac{R_4}{R_3}$ (Difference Amp.)

$\therefore V_o = \frac{R_4}{R_3}\left[\left\{\left(1 + \frac{R_2}{R_1}\right) V_{i_2} - \frac{R_2}{R_1} V_{i_1}\right\} - \left\{\left(1 + \frac{R_2}{R_1}\right) V_{i_1} - \frac{R_2}{R_1} V_{i_2}\right\}\right]$

$\therefore V_o = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{R_1}\right)(V_{i_2} - V_{i_1})$

$\therefore \boxed{A_d} = \frac{V_o}{V_{i2} - V_{i_1}} = \boxed{\frac{R_4}{R_3}\left(1 + \frac{2R_2}{R_1}\right)}$

and since there are two resistances of R_2, R_3, R_4 and only single resistance named R_1, So A_d is singl-element dependante. which is $\boxed{R_1}$

i.e to change A_d, we can change R_1 only NOT all resistances, which is desirable in design.

EXA: Design an I.A to have a gain ranging from (5 → 500) Using a Max. resistance 100kΩ assuming ideal Op-Amps.

Solution: to have adjustable gain, choose R_1 to be a variable resistance consisting of Fixed resistance R_{1f} and a Variable resistance R_{1v}

R_{1f} is to limite the gain at Max. Value even when R_{1v} is Set to zero and prevent Op-Amp. Saturation.

let R_{1v} is 100kΩ potentiometer

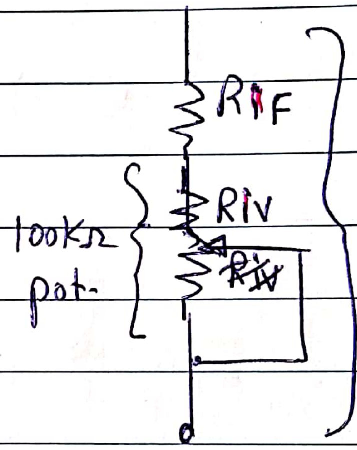
$$Ad = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{R_1}\right)$$

when R_1 is Min, $Ad \rightarrow Max$

$R_{1min} = R_{1f}$ ($R_{1v} = 0$)

when R_1 is Max, $Ad \rightarrow Min$

$R_{1max} = 100k + R_{1f}$



$$\therefore 500 = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{R_{1f}}\right)$$

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

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

$$\therefore \boxed{2R_2 = 249\, R_{1f}} \quad \text{---} \; (1)$$

$$5 = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{(100 + R_{1f})}\right)$$

$$\frac{A_{min}}{\frac{R_4}{R_3}} > 1$$

How to choose $\frac{R_4}{R_3}$

$$\therefore \boxed{2R_2 = 150 + 1.5 R_{1f}} \quad \text{---} \; (2)$$

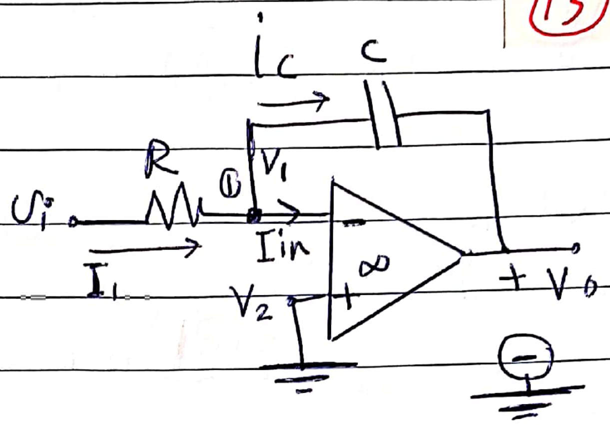
equate eqn. (1) & (2) gives: $R_{1f} = 0.606\,k\Omega$

$R_2 = 75.5\,k\Omega$, let $R_3 = 1k\Omega$ So $R_4 = 2k\Omega$

So we achive high, adjustable, Single-element dependant gain with resonable resistance values "In desired range".

7 13

Integrator:



KCL at Node ①

$I_1 = I_{in} + i_c$

$$\frac{V_i - V_1}{R} = I_{in} + C\frac{dv_c}{dt}$$

where $v_c = V_1 - V_o$

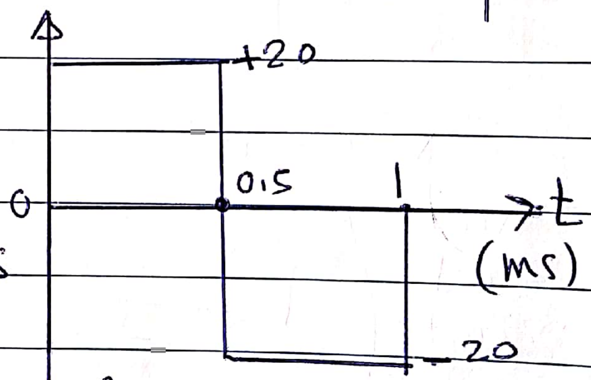
but $I_{in} = 0$, ($R_{in} = \infty$) and $V_2 = V_1 = 0$ (Virtual ~~Short~~) ground

$$\frac{V_i}{R} = 0 + \frac{-C\,dv_o}{dt}$$

$$\therefore dv_o = -\frac{V_i}{RC}dt \Rightarrow \int dv_o = -\frac{1}{RC}\int V_i\,dt$$

$$\therefore \boxed{v_o = -\frac{1}{RC}\int v_i\,dt.}$$

EXA: Calculate & Draw $v_o(t)$ for the indicated input. When $R = 1K\Omega$, $C = 1\mu F$



1) For $0 < t < 0.5$ ms

$$v_o = -\frac{1}{10^3 \times 10^{-6}}\int^{0.5} 20\,dt$$

$= -1000 \times 20t = -1000 \times 20(0.5 - 0)$ mS

$= -10V$

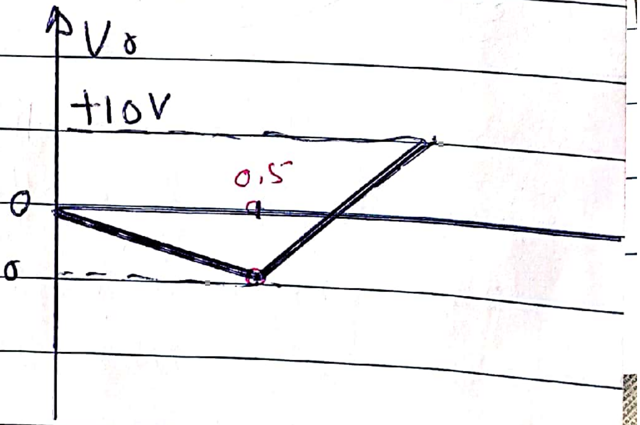
2) For $(0.5 < t < 1)$ mS

$$V_o = -\frac{1}{RC}\int -20\,dt$$

$= +1000 \times 20t = 2 \times 10^4 (1 - 0.5)$ mS

$= +10V$

f = 1KHZ

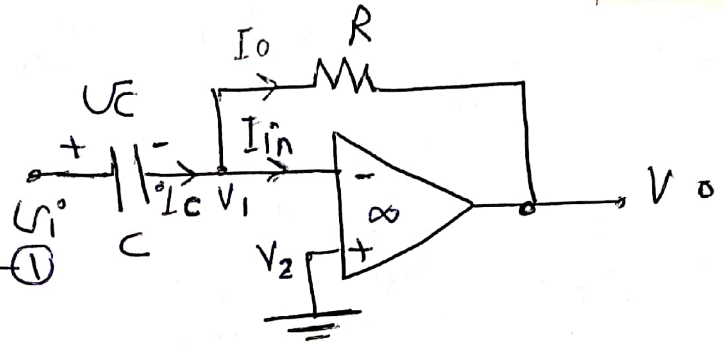


i.e when V_i is Square-Wave and V_o will be Inverted Triangular wave.

(8)

(14)

Differentiator



$$I_{in} + I_o = i_c$$

$$I_{in} + \frac{V_1 - V_o}{R} = C\frac{d\upsilon_c}{dt} \quad \text{—— (1)}$$

but $V_1 = V_2 = 0$ (Virtual ground), $I_{in} = 0$ ($R_{in} = \infty$)

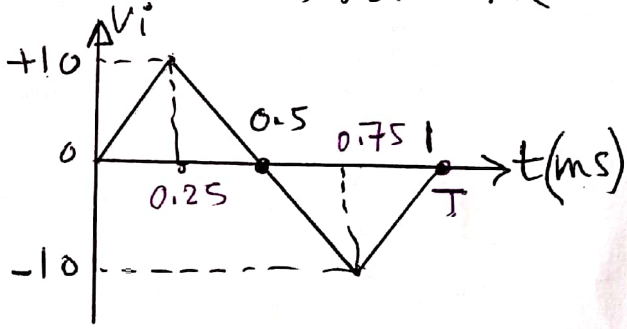
$\upsilon_c = \upsilon_i - V_1 = \upsilon_i$

∴ eqn. (1) will be: $-\frac{V_o}{R} = \frac{C\, d\upsilon_i}{dt}$

∴ $\boxed{\upsilon_o = -RC\frac{d\upsilon_i}{dt}}$ i.e $\upsilon_o \propto \frac{d\upsilon_i}{dt}$

EXAM: For the diff. shown, draw $\upsilon_o(t)$ for the indicated input.

when $R = 500\,\Omega$, $C = 1\,\mu F$.



i) For $(0 < t < 0.25)$ms

$$(\Delta v_i/\Delta t) = \frac{(10-0)}{(0.25-0)\text{ms}} = 40\times10^3 \ (V/S)$$

∴ $V_o = -RC\frac{\Delta V_i}{\Delta t} = -0.5\times10^3\times10^{-6}\times40\times10^3 = \boxed{-20V}$

ii) For $(0.25 < t < 0.75)$ms

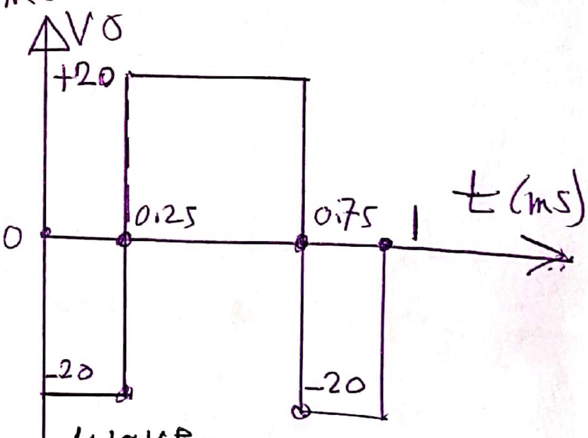
$$(\Delta V_i/\Delta t) = [-10-(+10)]/(0.75-0.25)\text{ms}$$

$= -4\times10^4$ V/S. $\boxed{V_o = +20V}$

iii) For $(0.75 < t < 1)$ms

$$(\Delta V_i/\Delta t) = \frac{0-(-10)}{(1-0.75)\text{ms}} = 4\times10^4 \text{ V/s}$$

$\boxed{V_o = -20V}$

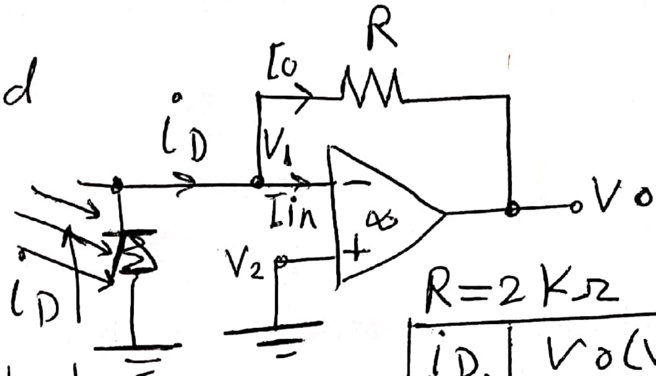


i.e the o/p is Inverted Square wave.

(9)

Current-to-Voltage Converter (I-to-V)

Some time, it is required to convert the o/p current (such as photodiode) into an output voltage. The cct. shown can do that:



$i_D = I_{in} + I_o \Rightarrow i_D = I_{in} + \dfrac{V_1 - V_o}{R}$

but $I_{in} = 0$, $V_1 = V_2 = 0$ (ideal op-Amp)

$\therefore \boxed{V_o = -i_D \cdot R} \Rightarrow V_o \propto I_D$.

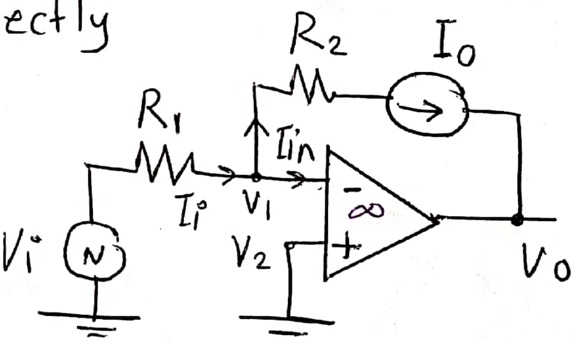
$R = 2\,K\Omega$

i_D (mA)	V_o(V)
1	-2V
3	-6V
5	-10V
7	-14V
10	-20V

EXA: Calculate Vo corespounding to i_D For R=2K

(10) Voltage-to-Current Converter: (V-to-I)

In this cct. the o/p current is directly proportional to input voltage.



$I_i = I_o + I_{in}$

$\dfrac{V_i - V_1}{R_1} = I_o + I_{in}$

but $V_1 = V_2 = 0$ (V.G) and $I_{in} = 0$ ($R_{in} = \infty$).

$\therefore \boxed{I_o = \dfrac{-V_i}{R_1}}$ i.e $I_o \propto V_i$

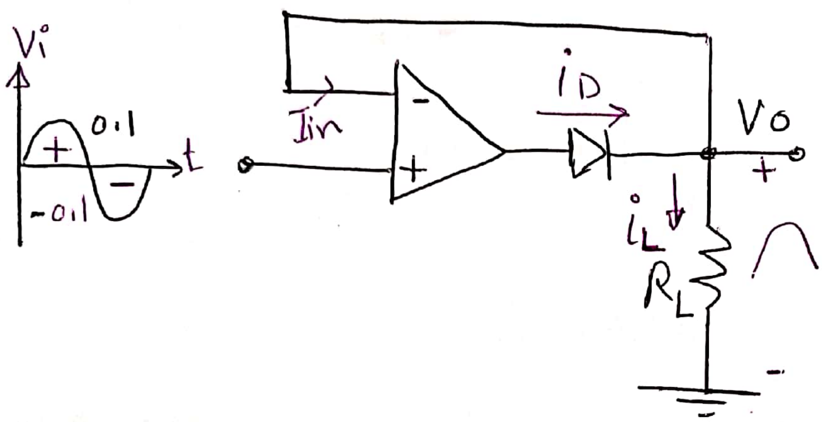
a more complex cct. can be used, but this is a simple cct. Remember that the op-Amp. works in Linear Regn.

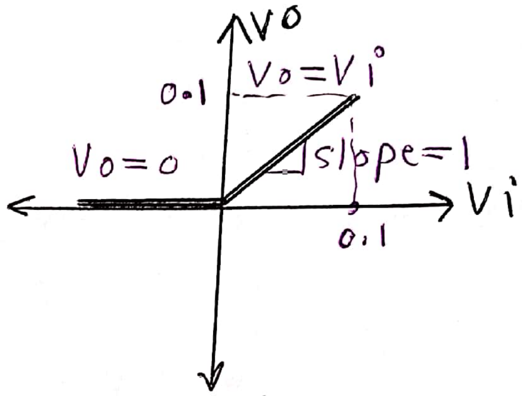
Scanned with CamScanner

NONLinear Applications

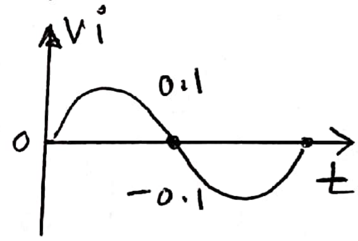
① Precision Half-Wave Rectifier

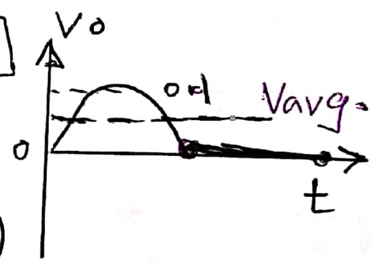
To rectify signals with peak values $< V_\gamma$ of diode, we use precision rectifier, which is an op-Amp with Diode, such as shown in Fig.





1) During +ve H.C of Vi (Vi > 0)
 $V_o = V_i$ (The cct. is voltage-follower)
 So i_L & i_D are positive. This means the loop is closed and $\boxed{V_o = V_i}$

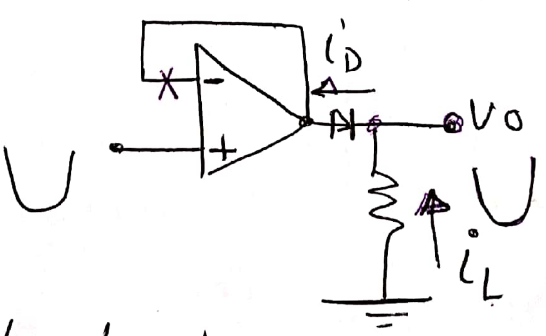




2) During -ve H.C of Vi (Vi < 0)
 the Load and diode Current (i_D & $i_L < 0$)
 which mean the diode is OFF
 and the loop is broken, So $i_D = 0$
 and Vo is Zero

$V_{o\,avg} = \frac{0.1}{\pi}$ (V)

∴ Vo is half-wave
with average value
$V_{o\,avg} = \frac{V_{ip}}{\pi}$.



* If we change the diode direction, Vo will be -ve HWR

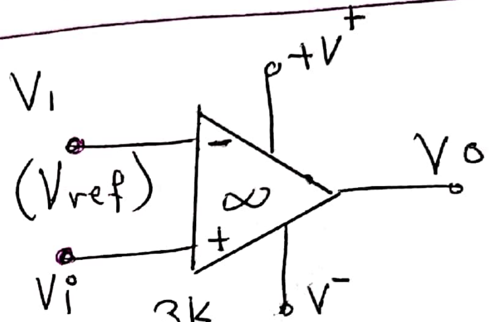
② Voltage-Comparator

In this cct. the op-Amp. is used in open-loop mode (i.e No Connection between V_o and ⊖ terminal, the op-Amp. works in Saturation mode with $V_o = A_o(V_2 - V_1) = V^+$ or V^- $(V_{cc}, -V_{cc})$
$= A_o \cdot V_d$

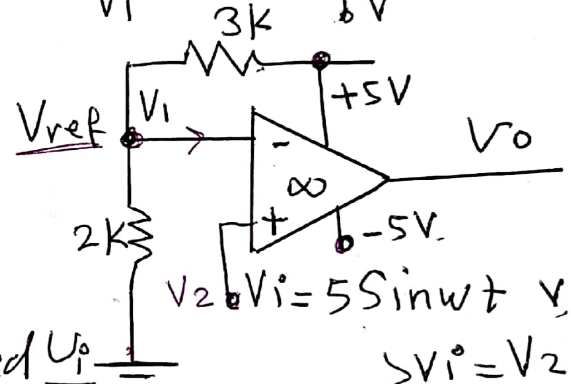
$\boxed{\text{Since } A_o = \infty, V_2 - V_1 = V_d}$

1) If $V_2 > V_1$ then $V_o = V^+$
$(V_o = A_o \cdot V_d = \infty \rightarrow (V_o = V^+)$

2) If $V_2 < V_1$, then $V_o = V^-$
$V_o = -A_o \cdot V_d = -\infty \rightarrow V_o = V^-$



ONE oF V_2 or V_1 will be a referance Voltage the other will be the input Voltage.



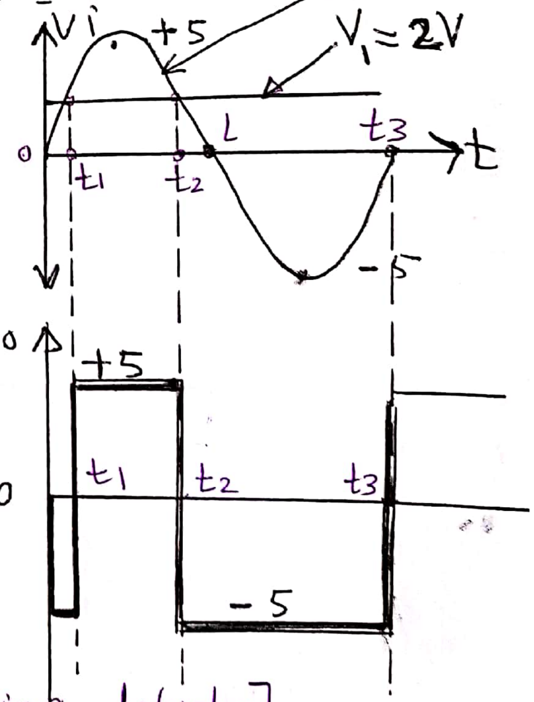
EXA: For the cct. shown Draw $V_o(t)$ for the indicated V_i

$$V_{ref} = V_1 = \frac{V^+ \cdot 2k}{(2+3)k} = 2V$$

① For $[0 < t < t_1]$, $V_1 > V_2 \Rightarrow V_o = V^- = -5V$

② For $[t_1 < t < t_2]$, $V_2 > V_1 \Rightarrow V_o = V^+ = +5V$

③ For $[t_2 < t < t_3]$, $V_2 < V_1 \Rightarrow V_o = V^- = -5V$

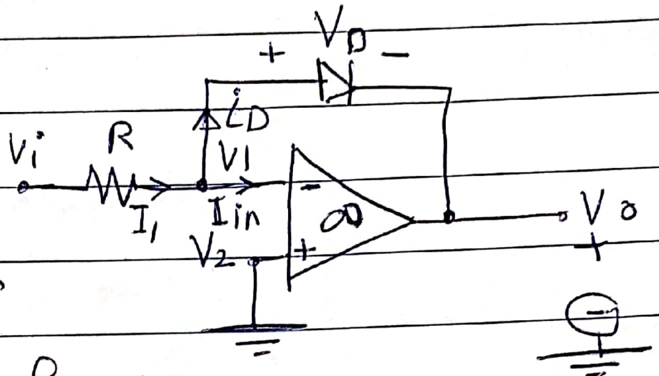


So $V_o(t)$ is shown, Square-wave between V^+ and V^-

* IF $V_{ref} = 0$, then the o/p is Symmetrical Square-wave and the cct. is Called [Zero-Crossing detector]

3

Log Amplifier:



In this cct. the output is proportional to the "Log of input Voltage"

to derive an expression for V_o:

$I_1 = I_{in} + i_D$ (KCL at Node 1)

$$\frac{V_i - V_1}{R} = I_{in} + I_s e^{\frac{V_D}{nV_T}} \quad (1)$$

but $I_{in} = 0$, $V_1 = V_2 = 0$ (ideal op-Amp)

also $V_D = V_1 - V_o = -V_o$

So eqn. (1) will be

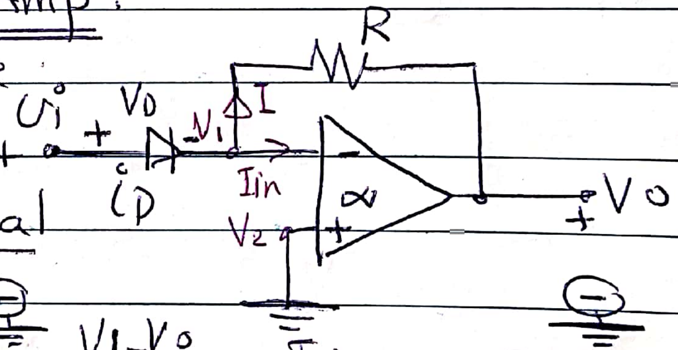
$$\frac{V_i}{R} = I_s e^{-\frac{V_o}{nV_T}} \Rightarrow \frac{V_i}{R I_s} = e^{-\frac{V_o}{nV_T}}$$

$$\therefore \boxed{V_o} = -nV_T \ln \frac{V_i}{R \cdot I_s} = -V_T \ln \frac{\boxed{V_i}}{R \cdot I_s} \quad (\text{For } n = 1)$$

i.e $V_o \propto \ln V_i$

4 Antilog or Exponential Amp.

The Complement or Inverse function of Log. Amp. is Antilog or exponential Amp.



$$i_D = I + I_{in} \Rightarrow I_s e^{\frac{V_D}{nV_T}} = \frac{V_1 - V_o}{R} + I_{in} \quad (1)$$

but $I_{in} = 0$, $V_1 = V_2 = 0$, $V_D = V_i - V_1 = V_i$ (ideal opAmp)

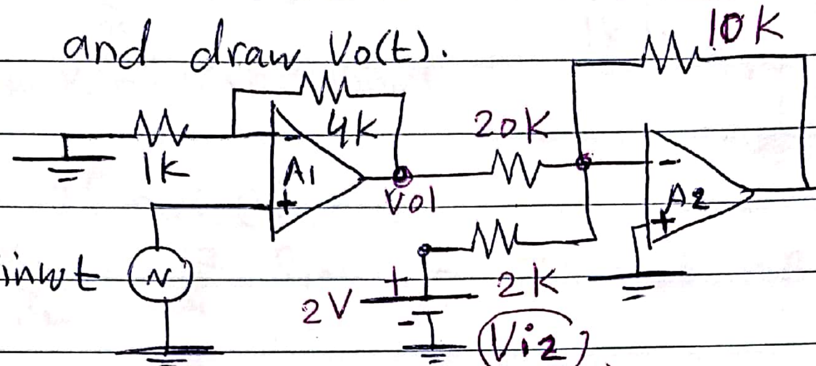
eqn (1) will be: $I_s e^{\frac{V_i}{nV_T}} = \frac{-V_o}{R}$

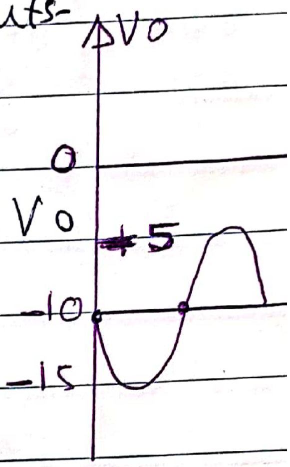
$$\therefore \boxed{V_o = -I_s R e^{\frac{V_i}{nV_T}}}$$

i.e $\boxed{V_o \propto e^{\frac{V_i}{nV_T}}}$

EXAMPLES:

EXA 1: For the cct. shown, Assume ideal Op-Amp. Calculate Vo for the indicated inputs and draw Vo(t).





$$V_o = -\left(\frac{10}{20}V_{o1} + \frac{10}{2}V_{i2}\right)$$

$$V_{o1} = \left(1+\frac{4}{1}\right)V_{i_1} = 5\times 2\sin\omega t = 10\sin\omega t \ (V)$$

$$\therefore V_o = -\left(0.5(10\sin\omega t) + 5(2)\right) = -10 - 5\sin\omega t \ (V)$$

EXA 2: For the cct. Shown, Assume ideal Op. Amp. Calculate Vo, Iz, I1 & I2

Assume Z-D is "ON"

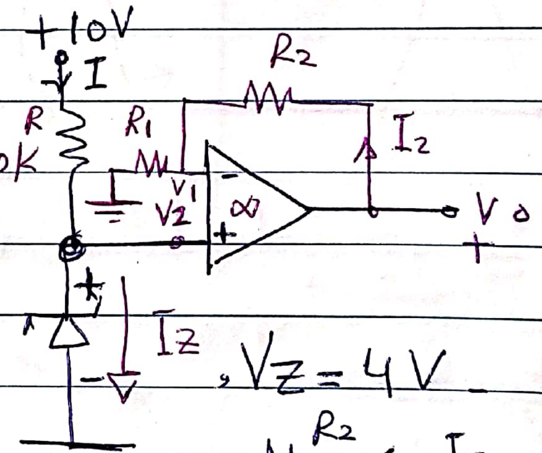
$-10 + IR + V_Z = 0$

$$I_R = I_Z = \frac{10-4}{10k} = 0.6\,mA$$

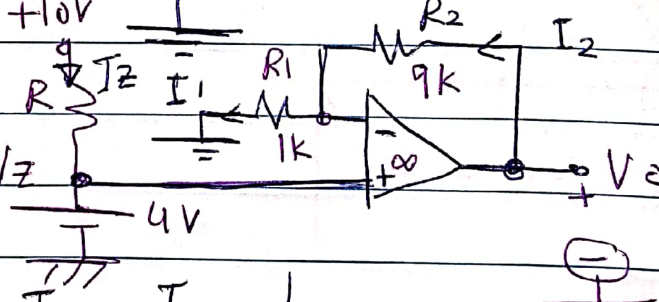
Since $I_Z > 0 \ \therefore$ Z-D is $\boxed{ON}$

$$V_o = \left(1+\frac{9}{1}\right)V_Z = 40\,V$$

$$I_1 = I_2 = \frac{V_o - 0}{9+1} = \frac{40}{10} = 4\,mA.$$



, Vz = 4V

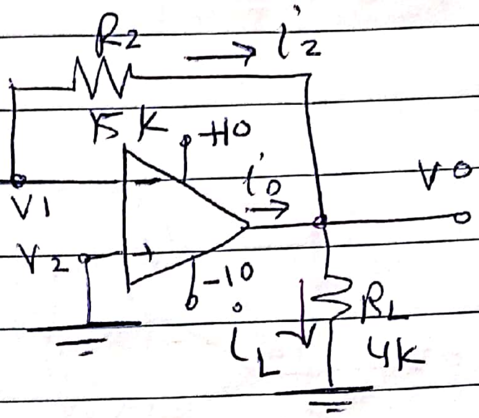


* This cct. is Called Voltage Referance cct.

* Recalculate Vo, Iz, I2 & I1 when Vz = 12V ???

iii) $V_i = 0.8 \sin\omega t$ (V)

$A_v = -\frac{R_2}{R_1} = -15$



$V_o = A_v \cdot V_i = -15 \times 0.8 \sin\omega t$

$V_o = -12 \sin\omega t$ (V)

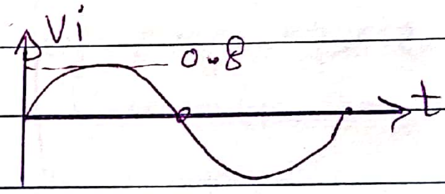
$i_L = \frac{V_o}{R_L} = \frac{-12}{4} \sin\omega t = -3 \sin\omega t$ mA

$i_2 = \frac{V_1 - V_o}{R_2} = \frac{0-(-12\sin\omega t)}{15} = 0.8 \sin\omega t$ mA $= i_1$

$i_o = i_L - i_2 = -3\sin\omega t - 0.8\sin\omega t = -3.8 \sin\omega t$ mA

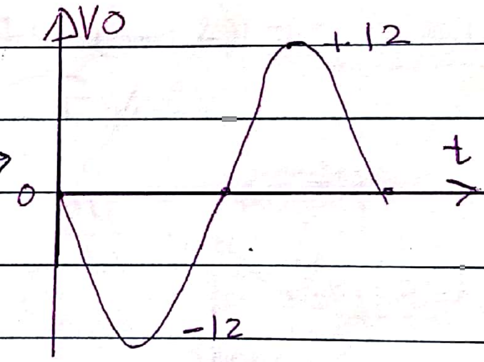
$R_{in} = R_1 = 1K\Omega$

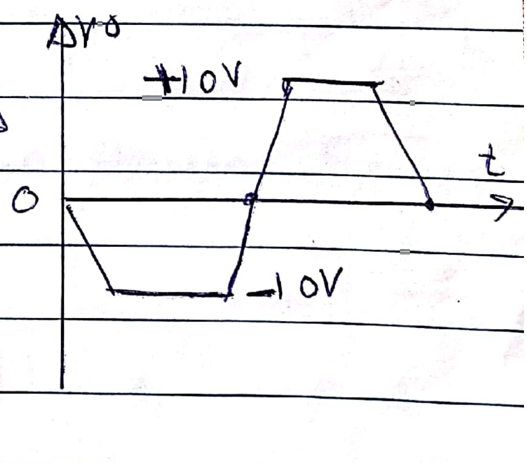
Draw* $V_i(t)$ and $V_o(t)$



* Draw $V_o(t)$ If V^+ and V^- are (+10V) and (-10V)

- If $V^+ = +10V$ & $V^- = -10V$ then V_o will be Saturated at +10V & -10V as shown





ExA 3:

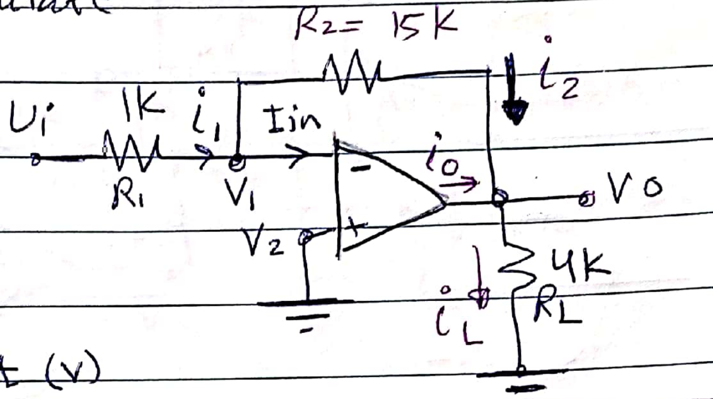
Assume ideal Op-Amp. Calculate $A_v, R_i, V_o, i_1, i_2, i_L, i_o$

For $V_i =$

i) $-0.20V$ (d.c)

ii) $0.08V$ (D.C)

iii) $0.8\sin\omega t\ (V) \Rightarrow 0.8\sin\omega t\ (V)$



i) $A_v = -\frac{R_2}{R_1} = -15$, $V_o = A_v \cdot V_i = -15(-0.2) = 3V$

$i_L = \frac{V_o}{R_L} = \frac{3V}{4K} = 0.75\ mA$

$i_2 = \frac{V_1 - V_o}{R_2} = \frac{0-3}{15} = -0.2\ mA = i_1$ (because $I_{in}=0$)

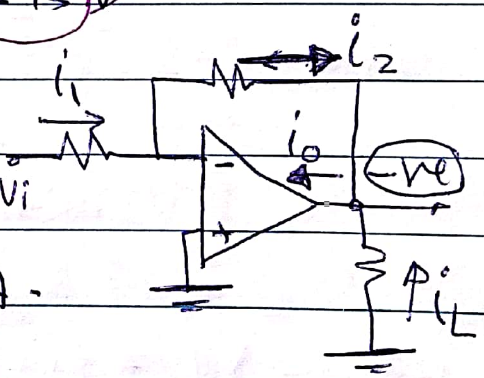
$R_{in} = R_1 = 1K\Omega$

Op-Amp: Source Current. $I_o \rightarrow$

$i_o + i_2 = i_L \Rightarrow \boxed{i_o} = i_L - i_2 = 0.75-(-0.2) = \boxed{0.95\ mA}$

ii) For $V_i = 0.08V$, $A_v = -\frac{R_2}{R_1} = -15$

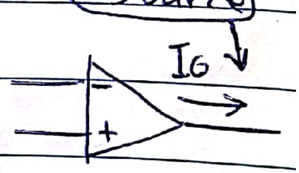
$V_o = A_v \cdot V_i = -15 \times 0.08 = -1.2V$



$i_L = \frac{V_o}{R_L} = \frac{-1.2}{4} = -0.3mA.$

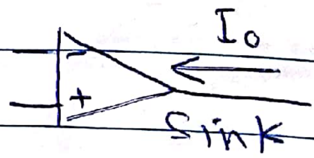
$i_2 = \frac{V_1 - V_o}{R_2} = \frac{0-(-1.2)}{15K} = 0.08mA.$

$i_o = i_L - i_2 = -0.3 - 0.08 = -0.38mA.$ Source

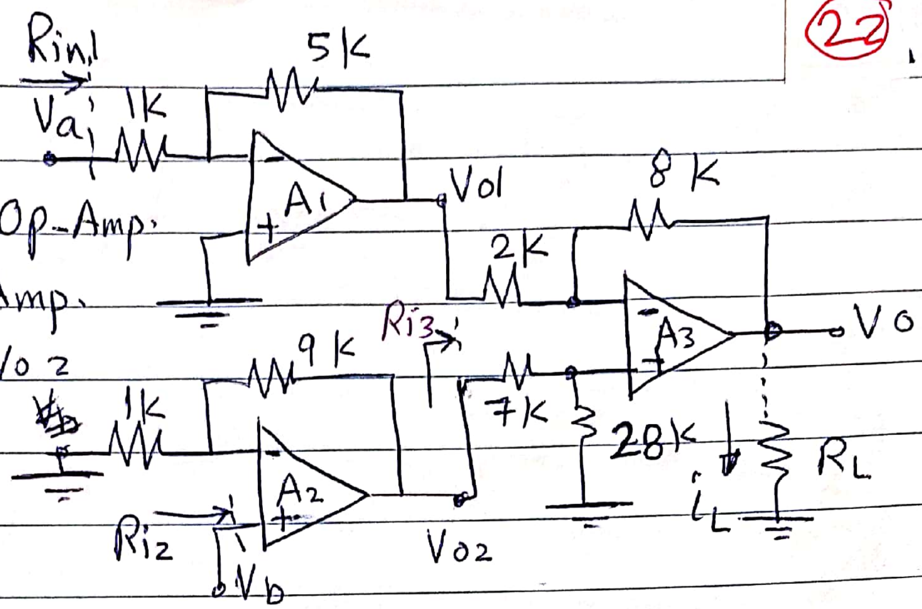


$i_1 = \frac{V_i - V_1}{R_1} = \frac{0.08V}{1K} = 0.08mA.$

"The Op-Amp Sink Current" !!! $\xleftarrow{I_o}$



EXA4: (A)



Assume ideal Op-Amp.

i) Name each Amp.

ii) Calculate V_{o1}, V_{o2} & V_o interms of V_a, V_b

iii) Calculate R_{in1}, R_{in2}, R_{i3}?

A_1: Inverting Amp., A_2: Noninverting Amp.

A_3: Difference Amp.

$V_{o1} = -\frac{5}{1} V_a = -5V_a$, $V_{o2} = \left(1 + \frac{9}{1}\right) V_b = 10 V_b$

$V_o = \frac{8}{2} = \frac{28}{7} (V_{o2} - V_{o1}) = 4\left(10V_b - (-5V_a)\right)$

$V_o = 40 V_b + 20 V_a$

iii) $R_{in1} = R_1 = 1K\Omega$, $R_{in2} = \infty$, $R_{i3} = 2 + 7 = 9K\Omega$

EXA4: (B)

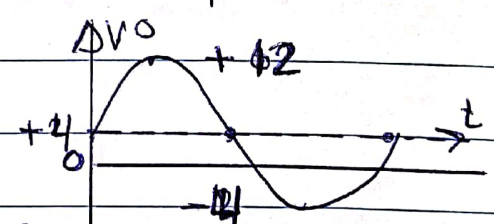
If $R_L = 2K\Omega$ is Connected, $V_a = 0.2V$ d.c

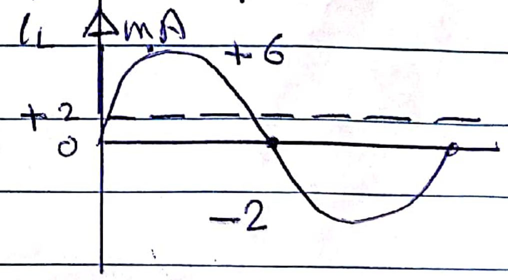
$V_b = 0.2 \sin \omega t$ (V), Calculate V_o, i_L & Draw $v_o(t)$, $i_L(t)$

* Since $V_o = 20V_a + 40V_b = 20 \times 0.2 + 40 \times 0.2 \sin \omega t$

$\therefore V_o = 4 + 8 \sin \omega t$ (V)

$i_L = \frac{V_o}{R_L} = 2 + 4 \sin \omega t$ mA





Frequency Response

It is a plote of Amp. gain versus frequency

- The gain can be A_V or A_I and can be in:
  dB: $A_V(dB) = 20\log\frac{V_o}{V_s}$ and $A_I(dB) = 20\log\frac{I_o}{I_s}$
  or (unitless) $A_V = \frac{V_o}{V_s}$, $A_I = \frac{I_o}{I_s}$.
- The freq. can be in (HZ) or ω (rad/sec).
- Consider the Amp. shown in Fig. 1 which is C.E BJT Amp. (C_μ & $C_\pi \Rightarrow$ high-freq. caps).

C_1 & $C_2 \rightarrow$ Coupling Capacitor

$C_E \rightarrow$ bypass Cap.

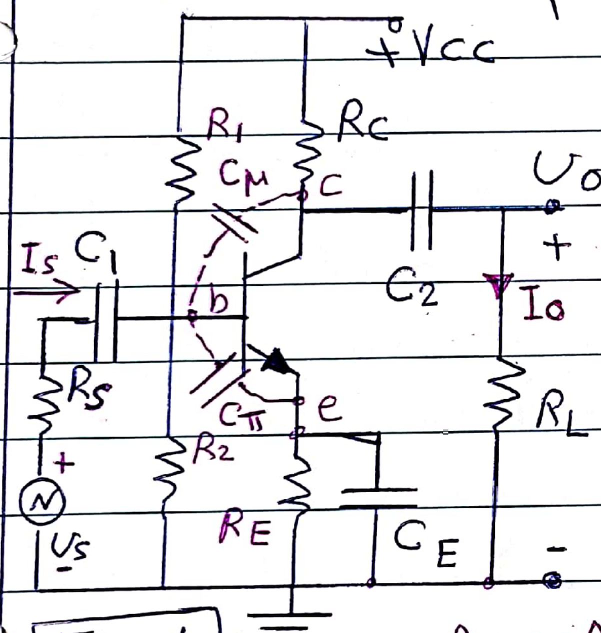


Fig. 1

Any Amp. has ONE (at least) Coupling Cap (C_1, C_2) or bypass Cap C_E OR two or three has the F.R shown.

(Typical F.R)

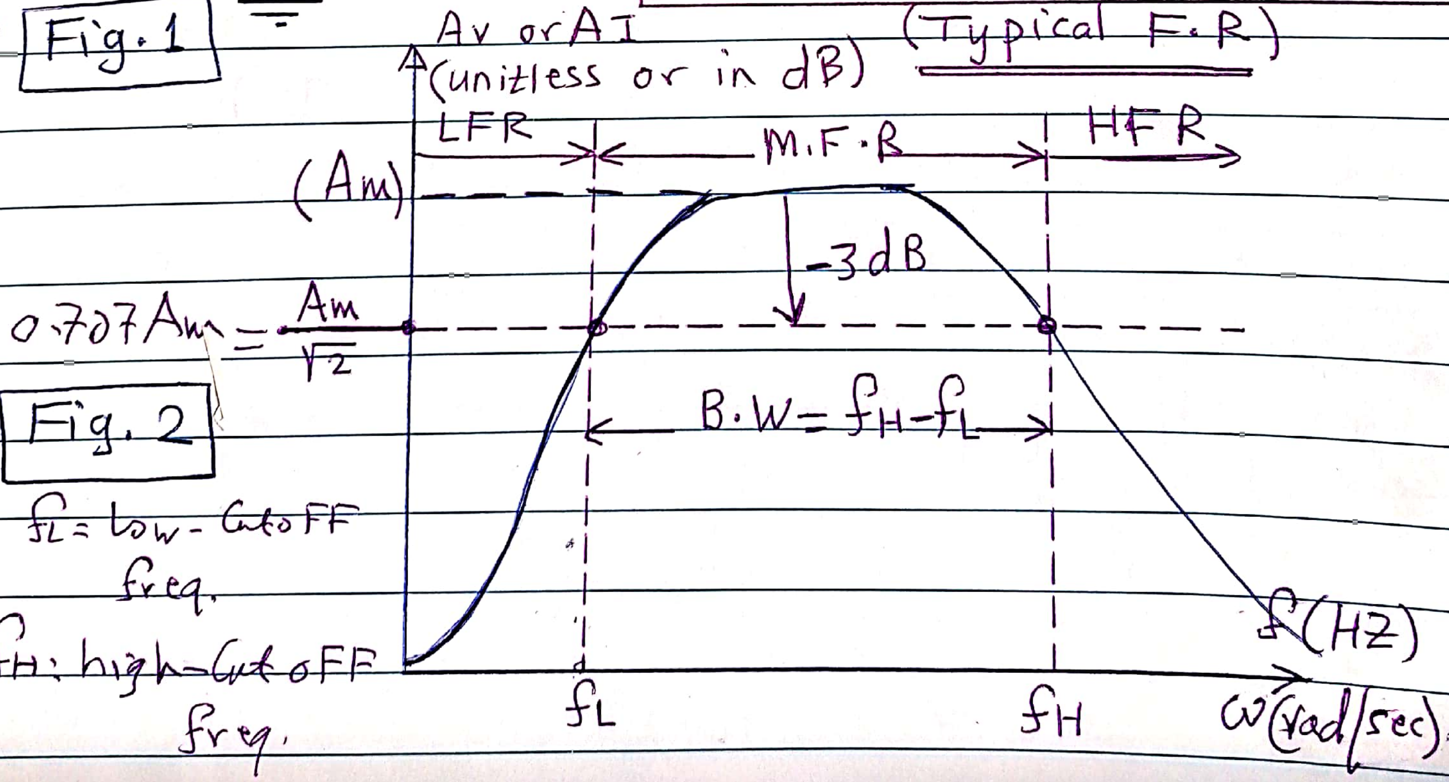


Fig. 2

f_L = low-Cutoff freq.

f_H: high-Cutoff freq.

- The typical freq. Resp. shown in Fig. 2 has three main regions:

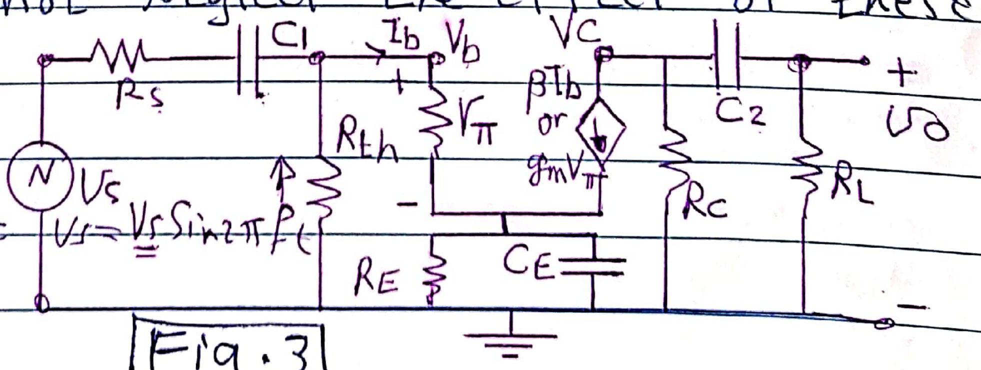
① Low Freq. Regn. (LFR)

This Regn. extends from ($0 \to f_L$), in which the gain is frequency dependant such that as freq. increases the gain increases. due to the effect of Coupling Cap. (C_1, C_2) and bypass Cap C_E. These capacitors has high reactances ($X_C = \frac{1}{2\pi f C}$) at low freq. So they effective at Low freq. Regn. This is "Why the gain at LFR is frequency depandent".

* But "why as freq. ↑, the gain ↑":
because these Caps. are in the series path of the input signal, so as $f\uparrow$, $X_C\downarrow$, more signal reaches base, more signal reaches Collector and more Signal reaches R_L So: as $f\uparrow$, $X_C\downarrow$, $V_b\uparrow$, $V_c\uparrow$, $V_o\uparrow$, $A_v\uparrow$. because since ($V_s = V_s \sin 2\pi f t$) in freq. response we Can Increase $f\uparrow$ NOT V_s.

The Value of "f_L → low freq depends on C_1, C_2, C_E. $\boxed{\text{In LFR: } C_\pi \,\&\, C_\mu \Rightarrow \text{O.C}}$ $X_{C_\pi} = X_{C_\mu} = \infty$

So we Can not Neglect the effect of these Capacitors.



LF. A.C eqnt cct.

Fig. 3

(2) Medium freq. Regn "MFR"

This Regn. extends from ($f_L \rightarrow f_H$) over a bandwidth ($B.W = f_H - f_L$). This is a usful Regn oF Amp. operation. $X_C = \frac{1}{2\pi f C}$

- In this Regn. all Coupling and bypass Caps. are considered short ~~short~~ ccts so the Amp. will behave as an pure resistive Amp. with a Certain gain Am. $\boxed{C_\pi \,\&\, C_\mu \Rightarrow \text{are open cct}, X_{C_\pi} = X_{C_\mu} = \infty}$
- In this regn, the gain is freq. independant.

"actualy all A.C analysis we did it in this ~~term~~ (BJT Amp. & MOSFET Amp) were in MFR.

- The equivalent cct. in M.F.R is shown below by assuming C_1, C_2 and C_E are short cct.

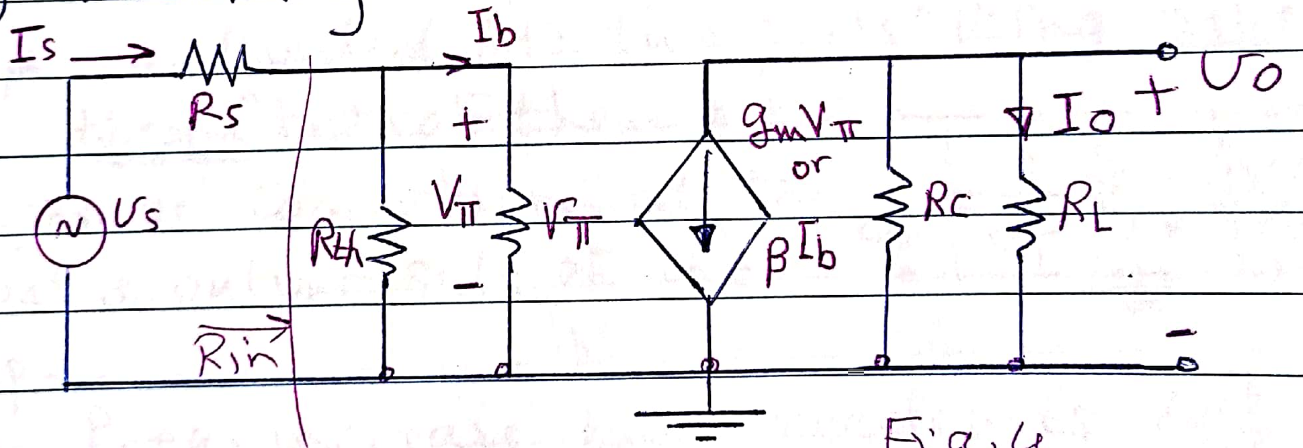


Fig.4

MF A.C eqnt cct.

$$A_{vm} = \frac{-g_m (R_C // R_L)\; R_{in}}{R_{in} + R_S}$$

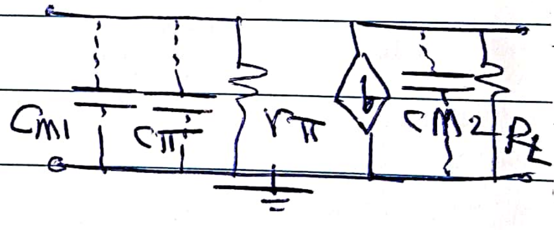
$R_{in} = r_\pi // R_{th}$

3 High-freq. Regn.

- This Regn. extends from $f_H \rightarrow \infty$.
- The gain is frequency dependant such that as $f\uparrow$ the gain decrease.
- In this Regn: $C_1, C_2 \& C_E$ are considered short circuit but new stray capacitances ($C_\pi \& C_\mu$) appear effectivily (No physical existance) due to physical structure of BJT where:

  C_π: B-E Jn diffusion capacitance (F.W biased Jnj. capacitance

  C_μ: Reversed-biased Jn capacitance.
- These capacitances appear in high-freq. Regn. So the gain is freq. dependant.
- C_μ is divided into two parts "Using Miller theorm" both of them are in parallel connection at the input & output side of the Amp.



- As freq. increase their reactances $X_C\downarrow$ So $(R_L // X_{C_{M2}})$ decrease and $|A_v| = g_m(R_L // X_{C_{M2}})\downarrow$ that is "why as $f\uparrow$, $A_v\downarrow$ in HFR".

However in this Regn. "$C_1, C_2 \& C_E \rightarrow S.C$" but $C_\pi \& C_\mu \rightarrow$ effective.

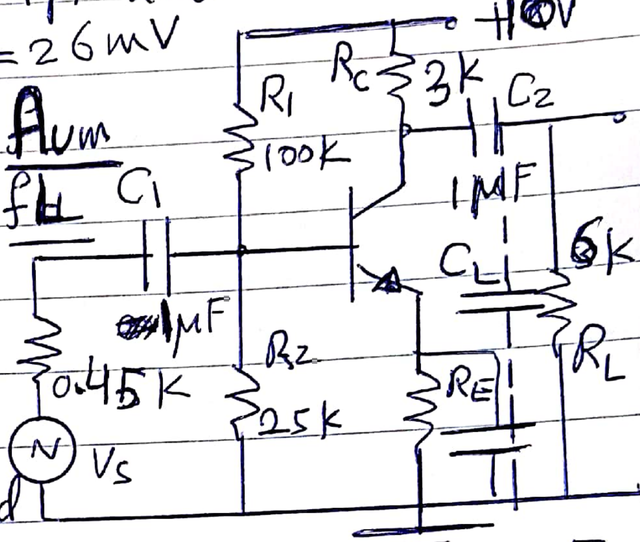
$C_\pi \& C_\mu$ are given in data sheet of BJT

* Somtime C_L is connected in parallel with R_L to control f_H and make it NOT depend on $C_\mu \& C_\pi$.

Frequency Response Analysis:

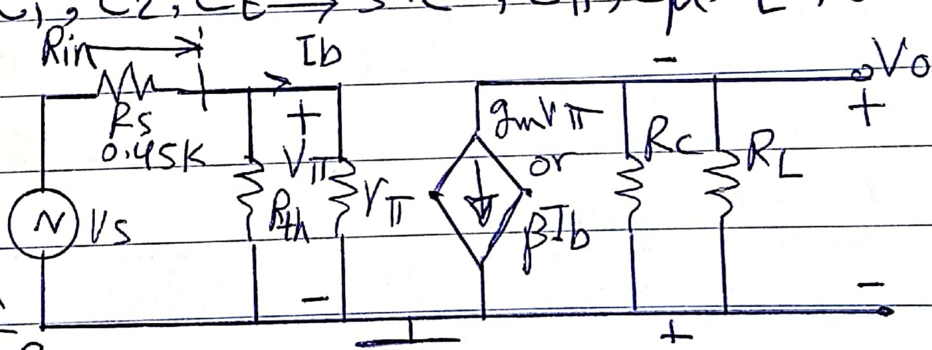
ExA: For the cct. shown in Fig. 1, the BJT has:
$\beta = 100$, $C_\pi = 30pF$, $C_\mu = 4pF$ and the cct is biased at $I_{CQ} = 2.6mA$, $V_T = 26mV$

1) Draw MF eqnt. cct. & Find A_{vm}
2) " LF " " " " f_L
3) " HF " " " f_H.
4) Sketch Freq. Response of the Amp. (A_v versus f)
5) If $C_L = 0.2nF$ is connected in parallel with R_L recalculate f_H and Comment??



$R_E = 0.2K$, $C_E = 20\mu F$

① MF eqnt. cct: $C_1, C_2, C_E \rightarrow$ S.C, $C_\pi, C_\mu, C_L \rightarrow$ O.C



$$A_v = \frac{V_o}{V_s} = \frac{V_o}{V_\pi} \times \frac{V_\pi}{V_s} = -g_m(R_C // R_L)\frac{R_{in}}{R_{in}+R_s}$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{2.6mA}{26mV} = 100\ mA/V, \quad r_\pi = \frac{\beta V_T}{I_{CQ}} = 1K\Omega$$

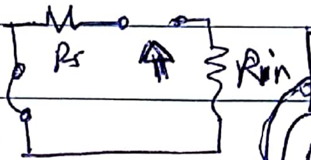
$$R_{in} = r_\pi // R_{th} = 1 // (100 // 25) = 0.952\ K\Omega$$

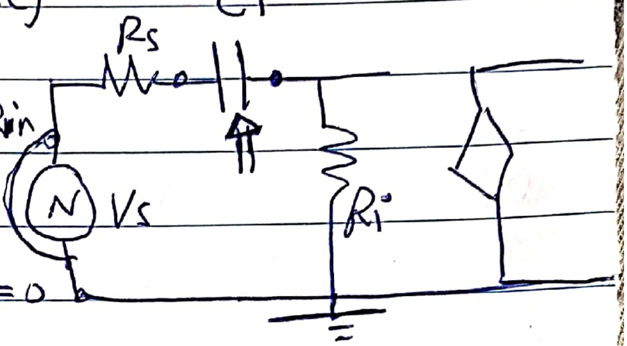
$$\boxed{A_v} = -100(3 // 6)\frac{0.952K}{(0.45 + 0.952)K} = \boxed{-136}$$

② L.F.R (C_π, C_μ, $C_L \to$ O.C), C_1, C_2 & $C_E \to$ exist

(i) Effect of C_1 (C_2 & $C_E \to$ S.C)

$$f_{L_1} = \frac{1}{2\pi C_1 R_{eq_1}}$$





R_{eq_1} : Rth seen by C_1 when $V_s = 0$

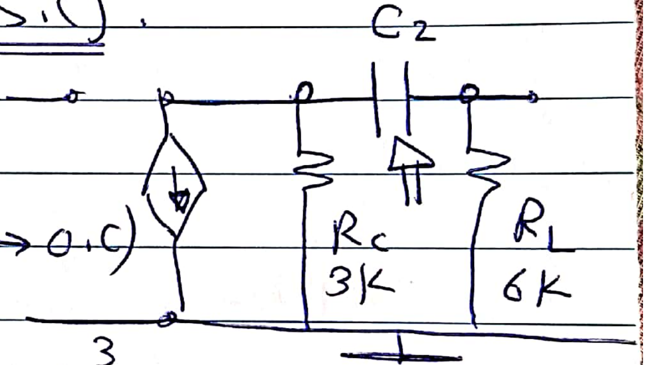
$R_{eq} = R_{in} + R_s$

$$\therefore = \frac{1}{2\pi C_1 (R_{in} + R_s)} = \frac{1}{2\pi \times 1 \times 10^{-6} \times (0.45 + 0.952)K} =$$

$$\boxed{f_{L_1}} = \frac{10^3}{2\pi \times 1.402} = \boxed{113.5\ HZ}$$

(ii) Effect of C_2 (C_1 & $C_E \to$ S.C).

$$f_{L_2} = \frac{1}{2\pi C_2 R_{eq_2}}$$



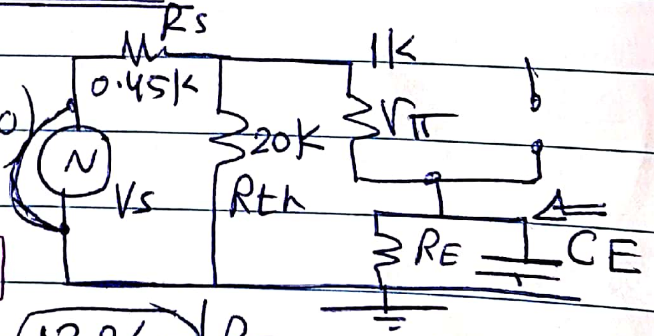
R_{eq_2} = Rth seen by C_2 (C.S $\to$ O.C)

$R_{eq_2} = R_C + R_L = 9K\Omega$

$$\therefore \boxed{f_{L_2}} = \frac{1}{2\pi \times 10^{-6}(9) \times 10^3} = \frac{10^3}{18\pi} = \boxed{17.68\,HZ}$$

(iii) Effect of CE (C_1 & $C_2 \to$ S.C)

$$f_{L3} = \frac{1}{2\pi C_E R_{eq_3}}$$



R_{eq_3} = Rth seen by C_3 (when $V_s = 0$)

$$R_{eq_3} = \left(\frac{(R_s \| R_{th}) + r_\pi}{\beta + 1}\right) \| R_E \quad \boxed{\text{(IRRR)}}$$

$$= \left(\frac{(0.45 \| 20) + 1}{101}\right) \| 0.2 = \boxed{13.26\,\Omega} \quad R_E = 0.2K$$

$$\therefore \boxed{f_{L_3}} = \frac{1}{2\pi \times 2 \times 10^{-5} \times 13.26} = \boxed{600\,HZ}$$

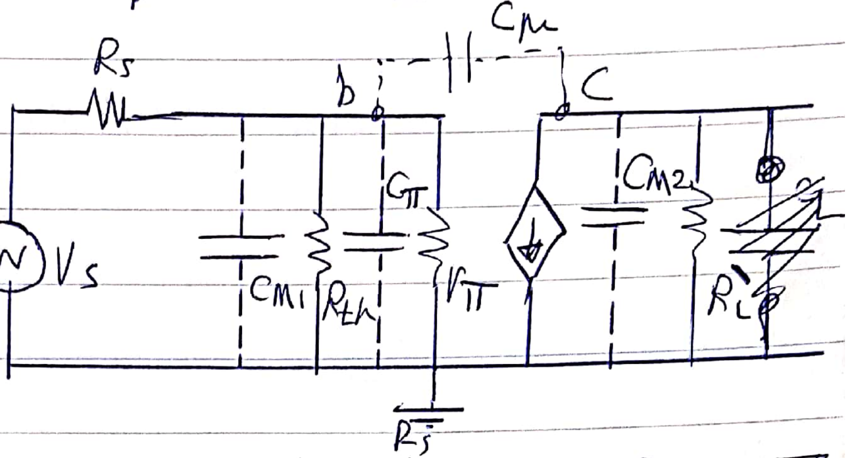
The effective f_L is the highest one (600 Hz)

(3) High-Freq. Analysis (HFR).

$C_1, C_2, C_E \rightarrow$ S.C, C_μ, C_π & C_L are effected.

* Using Miller Theorm "

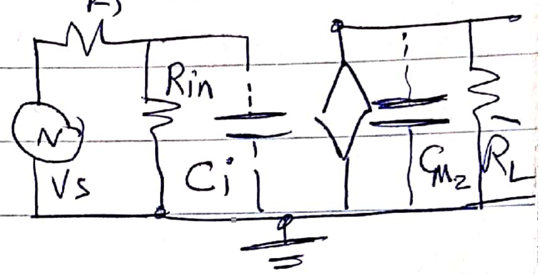
C_μ is divided into two parts.



C_{M1}: between base and ground.

$$C_{M1} = C_\mu(1-K)$$

C_{M2}: between Collector & ground



$$C_{M2} = C_\mu\left(1-\frac{1}{K}\right)$$

where $K = \dfrac{v_c}{v_b} = \dfrac{v_o}{v_\pi} = -g_m \bar{R_L}$

$$K = -100(3//6) = -200$$

$\therefore C_{M1} = 4(1-(-200)) = 804\,pF$

$C_{M2} = 4\left(1-\dfrac{1}{(-200)}\right) \simeq C_\mu = 4\,PF$

$f_{Hi} = \dfrac{1}{2\pi C_i R_{eqi}}$, $C_i = C_\pi + C_{M1} = 834\,pF$

R_{eqi}: Rth seen by C_i (when $V_s = 0$)

$R_{eqi} = R_s // R_{th} // r_\pi = 0.45 // 20 // 1 = 0.305\,K\Omega$

$\therefore \boxed{f_{Hi}} = \dfrac{1}{2\pi \times 834 \times 10^{-12} \times 0.305 \times 10^3} = \dfrac{10^9}{2\pi \times 834 \times 0.305} = \boxed{625.7\,K}$

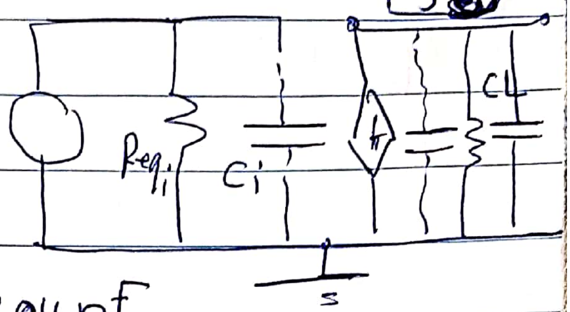
$f_{Ho} = \dfrac{1}{2\pi C_o R_{eqo}}$, $R_{eqo} = \bar{R_L} = 2\,K\Omega$, $C_o = C_{M2}$

$\therefore \boxed{f_{Ho}} = \dfrac{1}{2\pi \times 2 \times 10^3 \times 4 \times 10^{-12}} = \dfrac{10^9}{16\pi} = \boxed{19.9\,MHZ}$

$\therefore$ The effective f_H is the lowest Value

$\therefore \boxed{f_H} = \boxed{625.7\,KHZ}$

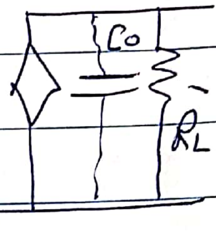
(5) If $C_L = 0.2nF$ is Connected in parallel with R_L, then $C_o = C_{M2} + C_L$



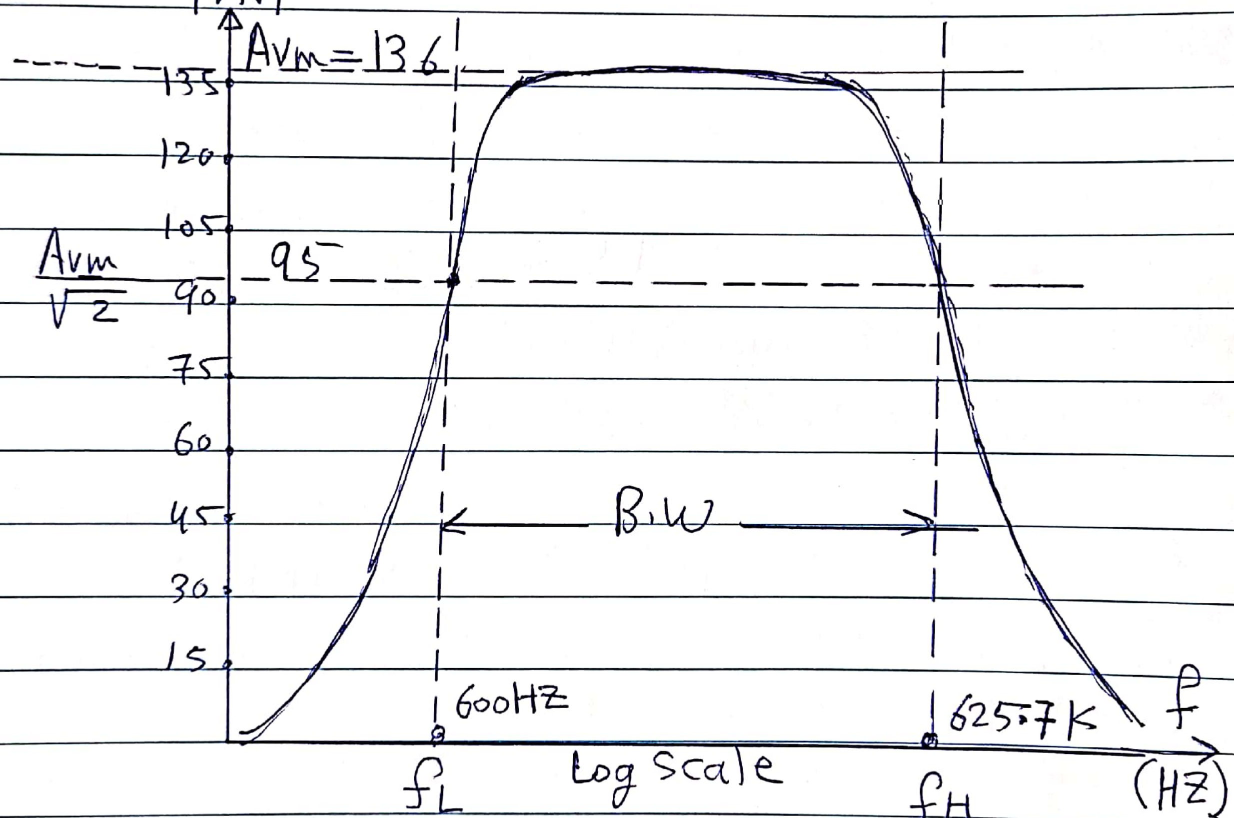
$$= (4 + 200)\,pF = 204\,pf$$

$$\therefore f_{Ho} = \frac{1}{2\pi R_L C_o} = \frac{1}{2\pi \times 10^3 \times 2 \times 204 \times 10^{-12}}$$

$$\boxed{f_{Ho}} = \frac{10^9}{4\pi \times 204} = \frac{10^9}{816\pi} = \boxed{396\,KHZ}$$

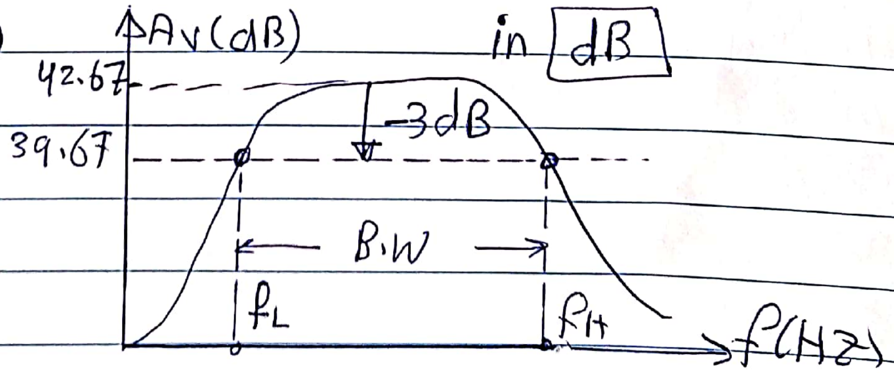


i.e the Value of C_L will Control the Value of f_H.



$B.W = f_H - f_L = 625.7 - 0.6 = 625.1\,KHz.$

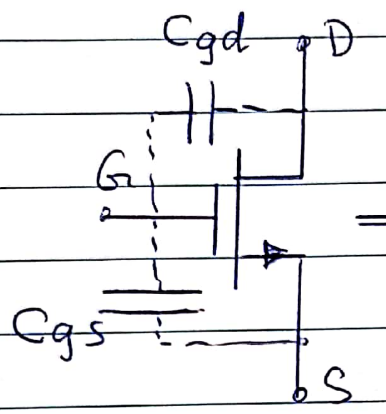
$A_v(dB) = 20\log(136)$
$= 42.67\,dB$

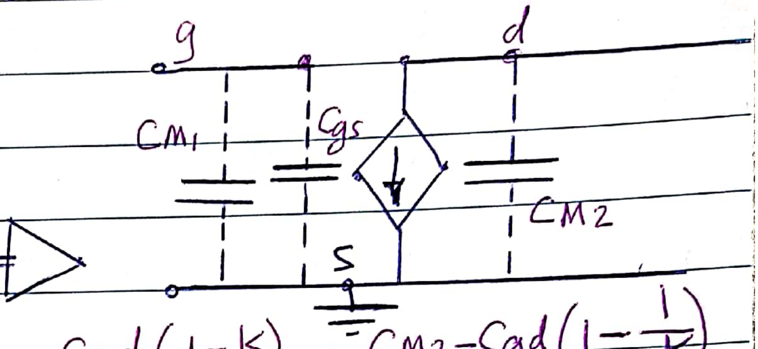


Frequency Response of FET Amp.

The low-Cutoff frequencies are determined by Coupling (C_1, C_2) and bypass Cap (C_s). While the high-freq. (Cut-off) freq. is determined by FET high-freq. cap. and load capacitor (if any).

FET high-freq. Model:





$C_{M1} = C_{gd}(1-K)$, $C_{M2} = C_{gd}(1-\frac{1}{K})$

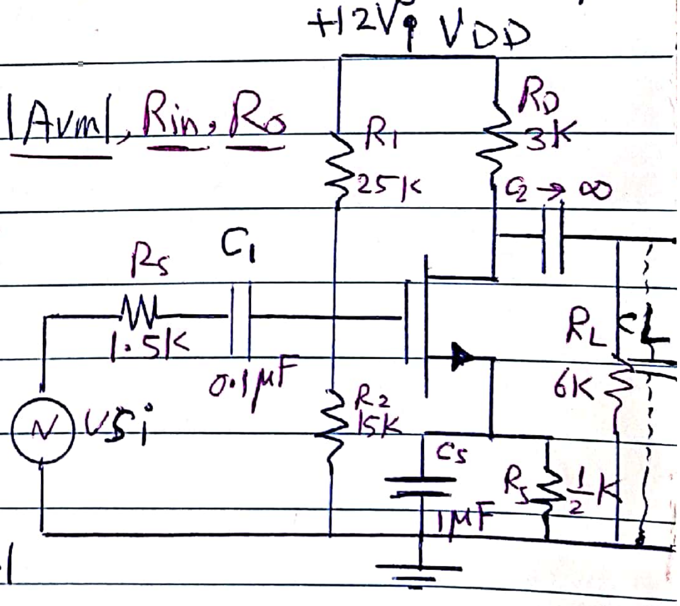
where $K = \frac{V_d}{V_{gs}} = \frac{v_o}{V_{gs}}$.

C_{M1} & C_{M2} are Miller Caps.

EXAMPLES:

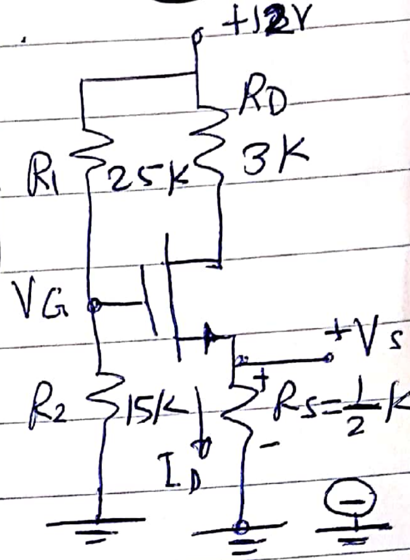
For the cct. shown: (C.S) Amplifier, the MOSFET parameters: $K_n = 1\,mA/V^2$, $V_{TN} = 2V$, $\lambda = 0$, $C_{gd} = 0.2\,pF$ and $C_{gs} = 1\,pF$.

1) Draw MF eqnt. cct. and Find $|A_{vm}|$, R_{in}, R_o
2) Draw LF " " " f_L
3) " HF " " " f_H
4) Sketch freq. Response of Amp (A_v(dB) Versus f).
5) what must be the Value of C_L Connected in parallel with R_L required to make $f_H = 500\,KHZ$.



1) We have to find I_D, to find g_m.

Assume the trans. in Sat. Regn.



$I_D = K_n(V_{GS}-V_{TN})^2$ $\boxed{\text{all cap are o.c}}$

$V_{GS} = V_G - V_S = \frac{12\times R_2}{R_1+R_2} - I_D R_S$ $\boxed{V_S = I_D R_S}$

$V_{GS} = \frac{12\times 15}{40} - 0.5 I_D = 4.5 - 0.5 I_D$

∴ $\boxed{I_D = (4.5 - V_{GS})/0.5}$

$\frac{4.5 - V_{GS}}{0.5} = 1(V_{GS}-2)^2 = V_{GS}^2 - 4V_{GS} + 4$

$0.5V_{GS}^2 - 2V_{GS} + 2 - 4.5 + V_{GS} = 0$

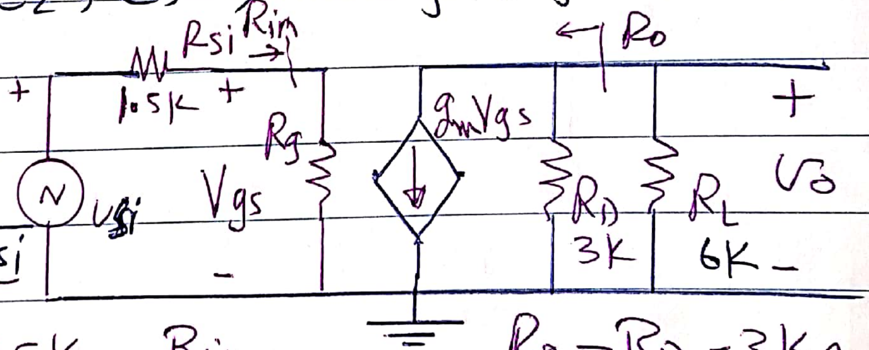
$0.5V_{GS}^2 - V_{GS} - 2.5 = 0$

$V_{GS} = \frac{1 \mp \sqrt{1+5}}{2\times 0.5} = \frac{1\mp\sqrt{6}}{1} = \boxed{3.45V}$ or $\boxed{-1.45}$

∴ $I_D = (4.5 - 3.45)/0.5 = 2.1\ mA$

$g_m = 2\sqrt{K_n I_D} = 2\sqrt{1\times 2.1} = 2.9\ mA/V$

*In MF Regn: $C_1, C_2, C_S \to$ S.C, C_{gs} & $C_{gd} \to$ O.C



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

$= \frac{-g_m V_{gs}(R_D\|R_L)}{V_{gs}} \cdot \frac{R_g}{R_g+R_{si}}$

$R_g = R_1\|R_2 = 9.375K = R_{in}$, $R_o = R_D = 3K\Omega$

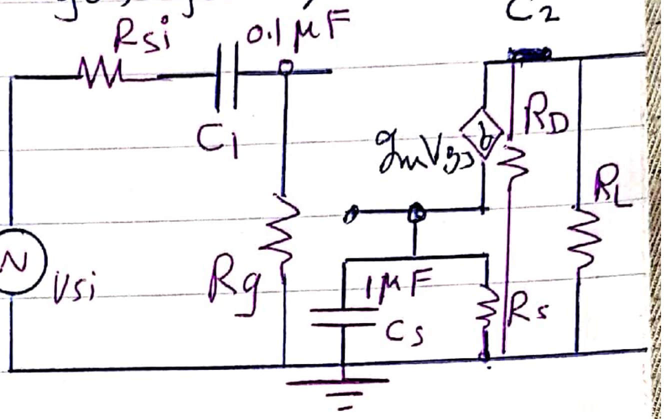
∴ $A_v = -g_m(R_D\|R_L)\frac{R_g}{R_g+R_{si}} = -2.9(2)\frac{9.375\ K}{(1.5+9.375)K}$

∴ $A_{vm} = -5 \Rightarrow \boxed{|A_{vm}| = 5}$

$|A_{vm}|(dB) = 20\log 5 = 13.98\ dB$

② Low-freq. Regn.: $C_1, C_S \rightarrow$ exist, $C_2 \rightarrow$ S.C because C_2 is ∞ in this example. $C_{gd}, C_{gs} \longrightarrow$ O.C

ⓘ Effect of C_1 ($C_S \rightarrow$ S.C)



$$f_{L1} = \frac{1}{2\pi C_1 (R_{si} + R_g)}$$

$$= \frac{1}{2\pi \times 1 \times 10^{-7} \times 10.875 \times 10^{3}}$$

$$f_{L1} = \boxed{146\ HZ}$$

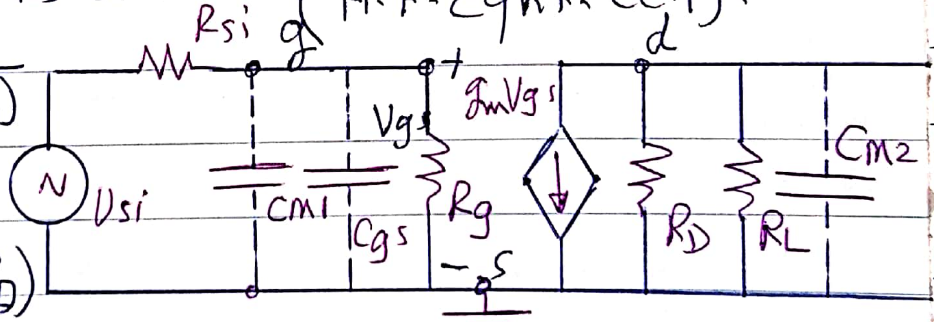
$$f_{L2} = \frac{1}{2\pi R_S C_S} = \frac{1}{2\pi \times 1 \times 10^{-6} \times 0.5 \times 10^{3}} = \boxed{318 HZ}$$

$$f_{L3} = \frac{1}{2\pi C_2 (R_L + R_D)} = \frac{1}{2\pi \times \infty \times 9 \times 10^{3}} = \boxed{0\ HZ.}$$

$\therefore$ f_L(effective) is the highest Value = 318 HZ.

③ High-freq. Regn: ($C_1, C_2, C_S \longrightarrow$ S.C) and C_{gd} & C_{gs} are effective. and C_L (if any)

The HF eqn. cct. is shown (H.F. eqnt. cct).



$$f_{Ho} = \frac{1}{2\pi C_{M2} (R_L // R_D)}$$

$$C_{M1} = C_{gd}(1 - K)$$

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

$$= -2.9\,(2) = -5.8$$

$$C_{M2} = C_{gd}\left(1 - \frac{1}{(-5.8)}\right) = \boxed{0.2345\,pF}$$

$$\therefore \boxed{f_{Ho}} = \frac{1}{2\pi \times 0.2345 \times 10^{-12} \times 2 \times 10^{3}} = \boxed{339.349\ MHZ}$$

$$f_{Hi} = \frac{1}{2\pi C_i R_{eq}}, \quad R_{eq} = R_{si} // R_g = 1.355\,K\Omega$$

$$C_i = C_{M1} + C_{gs}, \quad C_{M1} = C_{gd}(1 - K) = 0.2(1 + 5.8) = 1.36\,pF$$

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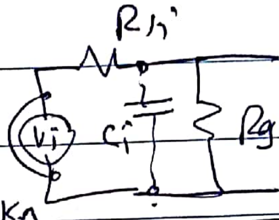
$C_i = 1 + 1.36 = 2.36\,pF$



$(R_{si} \parallel R_g) = 1.355\,K\Omega$ (R_{eqi})

$\therefore f_{Hi} = \dfrac{1}{2\pi \times 2.36\times10^{-12} \times 1.355\times10^{3}} = \boxed{49.770\,MHz}$

$\therefore f_H$ (effective) is the lowest Value $= 49.77\,MHz$

(4) Freq. Resp.

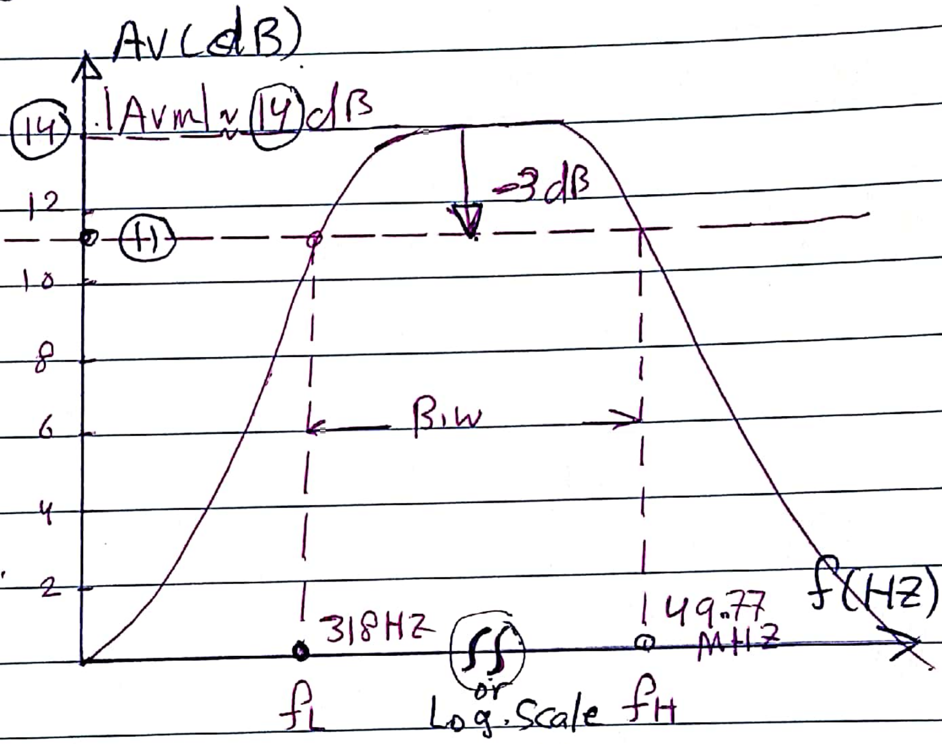
$11 = [|A_{vm}| - 3]\,dB$

$B.W = f_H - f_L$

For $f_H \gg f_L$

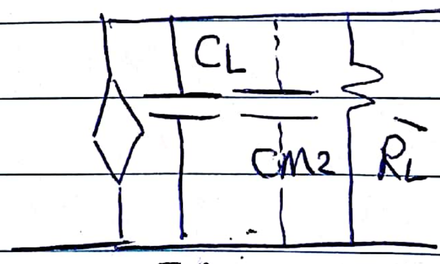
$B.W \approx f_H$

$\approx 49.77\,MHz.$



5) If $C_L = ?$ required to make $f_H = 500\,KHz$

$f_H = \dfrac{1}{2\pi R_L' (C_L + C_{M2})}$



$\therefore (C_{M2} + C_L) = \dfrac{1}{2\pi f_H R_L'}$

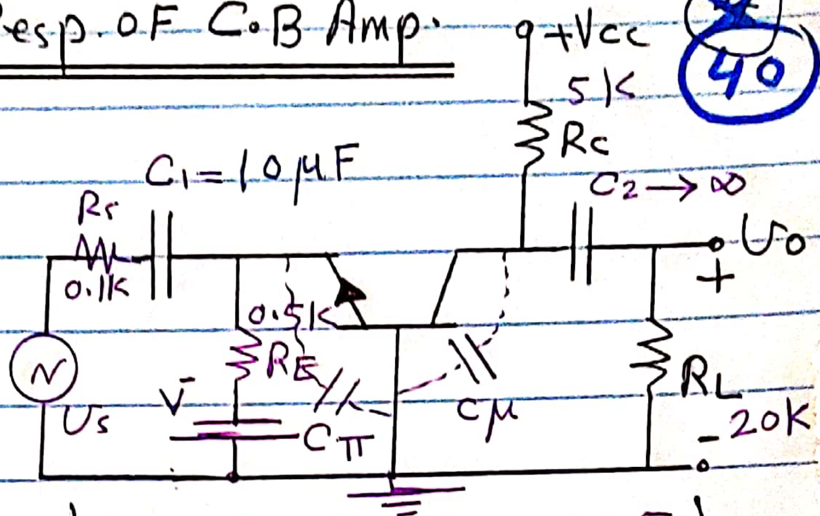
$\therefore \boxed{C_L + C_{M2}} = \dfrac{1}{2\pi \times 500\times10^{3} \times 2\times10^{3}} = \dfrac{10^{-9}}{2\pi} = 159.155\,pF$

$\therefore \boxed{C_L} = 159.155 - 0.2345 = 158.920\,pF$

Frequency Resp. of C.B Amp.

~~8~~ 40

1) Draw MF eqnt cct and Find $|A_{vm}|$.
2) Draw LF eqnt. cct. and Find f_L
3) Draw HF eqnt. cct. & Find f_H.
4) Sketch (Bode Plot of the Amp.).



$C_\pi = 30pF$, $C_\mu = 5pF$
$\beta = 130$, $I_{CQ} = 1mA$
$V_T = 26mV$

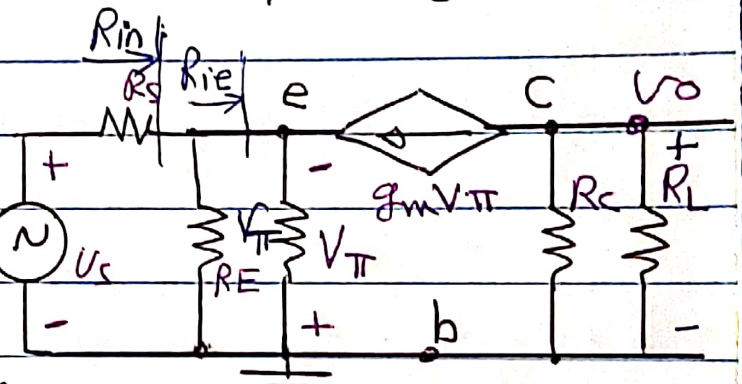
1) MFR (all $C_1, C_2 \to S.C$) & ($C_\pi, C_\mu \to \infty$).

$$A_V = \frac{V_o}{V_\pi} \times \frac{V_\pi}{V_s}$$

$$V_o = -g_m V_\pi (R_C // R_L)$$

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

$$\frac{V_\pi}{V_s} = \frac{-R_{in}}{R_{in}+R_s}, \quad V_\pi = \frac{-V_s R_{in}}{R_{in}+R_s}$$



$$\boxed{g_m} = \frac{I_{CQ}}{V_T} = \frac{1mA}{26mV} = \boxed{38.5 mA/V}$$ M.F. eqnt. cct.

$R_{in} = R_{ie} // R_E$, $R_{ie} = \frac{r_\pi}{\beta+1}$, $r_\pi = \frac{\beta V_T}{I_{CQ}} = 2.6K\Omega$

$\therefore R_{in} = 0.5 // \left(\frac{2.6}{130+1}\right) = 19.23\Omega$

$\therefore A_{vm} = (-) g_m (R_C // R_L) (-) \frac{R_{in}}{R_{in}+R_S} = +38.5 (5 // 20) \frac{19.2}{100+19.2}$

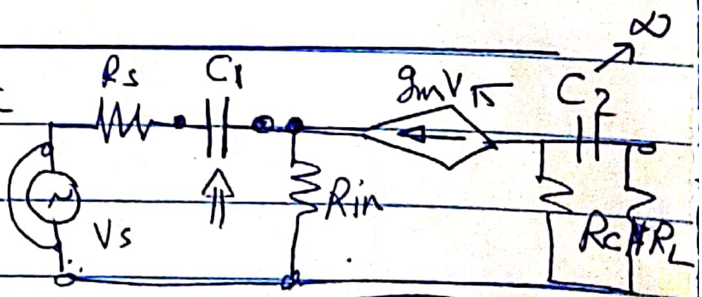
$\therefore \boxed{A_{vm}} = \boxed{24.8}$

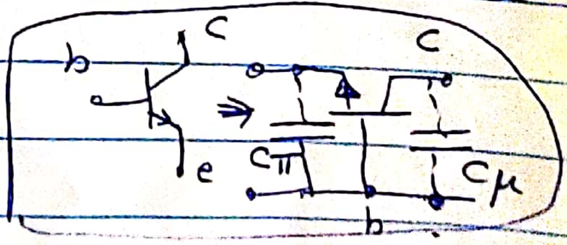
② LFR: $C_\pi, C_\mu \to O.C$, $C_2 \to S.C$

$$f_L = \frac{1}{2\pi C_1 (R_S + R_{in})}$$

$$= \frac{1}{2\pi (0.1 + 0.0192) \times 10 \times 10^{-6}}$$

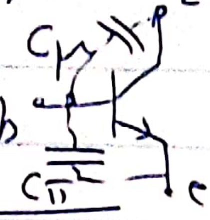
$= 133.5 Hz.$

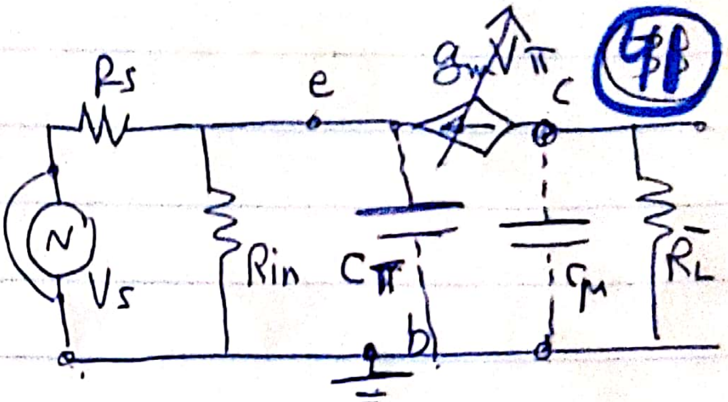




3) HFR: $C_1, C_2 \rightarrow S.C$

C_π, C_μ exist.

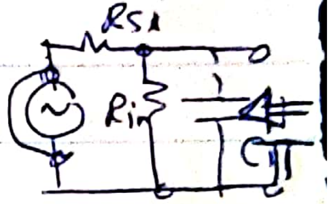




$$f_{Hi} = \frac{1}{2\pi C_\pi R_{eq_i}}$$

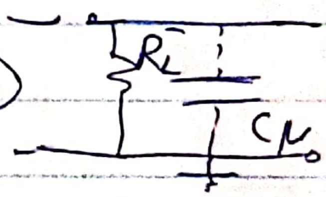
R_{eq_i} = Rth seen by C_π when $V_s = 0$, $V_\pi = 0$, $g_m V_\pi \rightarrow$ o.c

$R_{eq_i} = R_s // R_{in} = 0.1 // 0.0192 \simeq 16\Omega$



∴ $f_{Hi} = \frac{1}{2\pi \times 16 \times 30 \times 10^{-12}} = 331.572$ MHz

$f_{Ho} = \frac{1}{2\pi C_\mu \bar{R_L}}$, $\bar{R_L} = R_C // R_L = 5 // 20 = 4k\Omega$

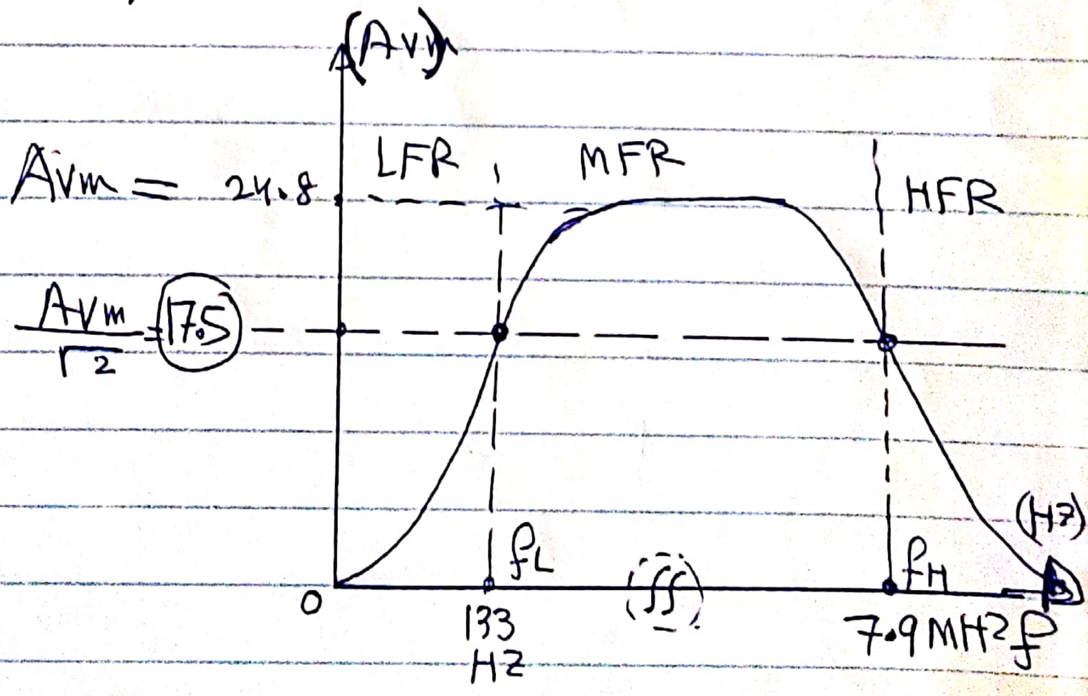


$f_{Ho} = \frac{1}{2\pi \times 5 \times 4 \times 10^3 \times 10^{-12}} = 7.9577$ MHz.

∴ $f_H = 7.9577$ MHz which is due to C_μ?

the B.W $= f_H - f_L \simeq 7.9577$ MHz $- 133$ Hz $\simeq 7.9577$ MHz

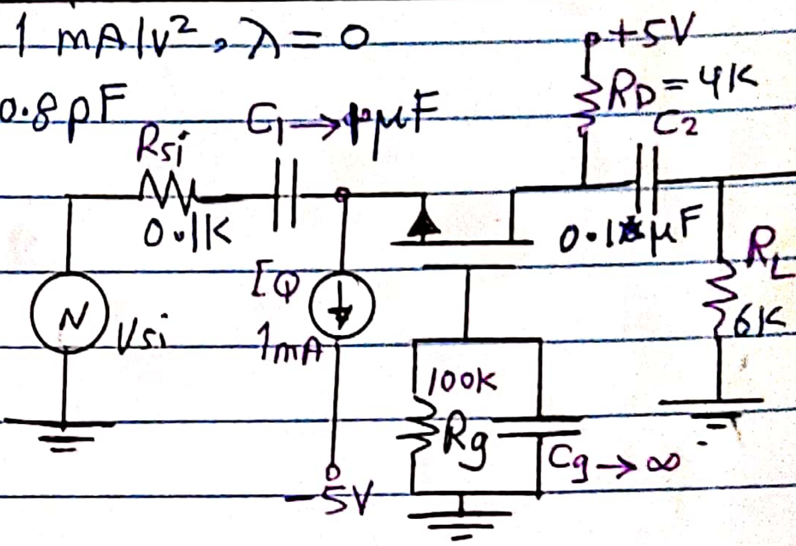
(∴ B.W for C.B > B.W for C.E



Frequency Response of C.G Amp.

Given: $V_{TN} = 1V$, $K_n = 1\ mA/V^2$, $\lambda = 0$

$C_{gs} = 5pF$, $C_{gd} = 0.8pF$



1) Draw MF eqnt. cct. & Find A_{vm}.
2) Draw LF eqnt. cct. and Determine f_L
3) Draw HF eqnt. cct. & Determine f_H.
4) Sketch freq. Resp. of Amp. ($A_V(dB)$ versus freq)

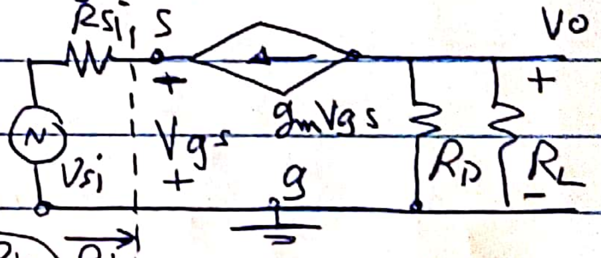
1) MFR: $C_1, C_2, C_g \rightarrow S.C$, C_{gs} & $C_{gd} \rightarrow O.C$

$I_Q = I_D = 1mA$

$g_m = 2\sqrt{K_n I_D} = 2mA/V$

$R_{in} = R_{ig} = \frac{1}{g_m} = \frac{1}{2\times10^{-3}} = 0.5K\Omega$

$A_{vm} = \frac{V_o}{V_{gs}} \times \frac{V_{gs}}{V_{si}} = \frac{-g_m V_{gs}(R_D//R_L)}{-V_{gs}} \frac{R_{in}}{R_{in}+R_{si}}$



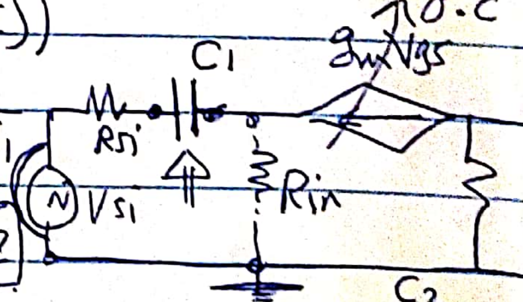
MF eqnt. cct

$\therefore A_{vm} = g_m(R_L//R_D)\frac{R_{in}}{R_{in}+R_{si}} = 2(4//6)\frac{0.5}{0.5+0.1} = 4$

2) LFR: C_{gs} & $C_{gd} = O.C$ ($C_1, C_2, C_g \rightarrow$ exist)

(i) Effect of (C_1) (C_2 & $C_g \rightarrow S.C$)

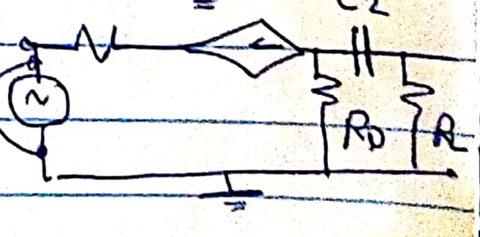
$f_{L1} = \frac{1}{2\pi C_1(R_{si}+R_{in})} = \frac{1}{2\pi(0.1+0.5)KC_1}$



$\boxed{f_{L1}} = \frac{1}{2\pi\times0.6\times10^3\times1\times10^{-6}} = \boxed{265\ HZ}$

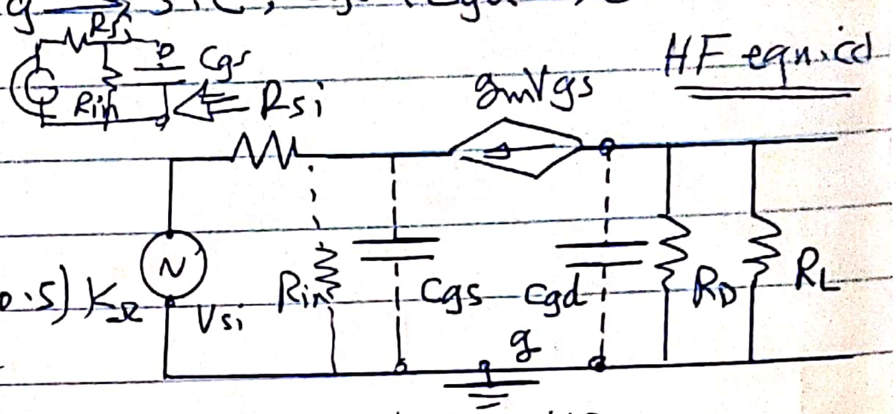
$f_{L2} = \frac{1}{2\pi C_2(R_L+R_D)} = \frac{1}{2\pi\times10\times10^3\times0.1\times10^{-6}}$

$f_{L2} = 159\ HZ$ & $\boxed{f_L = 265\ HZ}$



3) HFR: $C_1, C_2, C_g \rightarrow$ S.C., C_{gs} & $C_{gd} \rightarrow$ exist.

HF equi.cct



$$f_{Hi} = \frac{1}{2\pi C_{gs} R_{eq}}$$

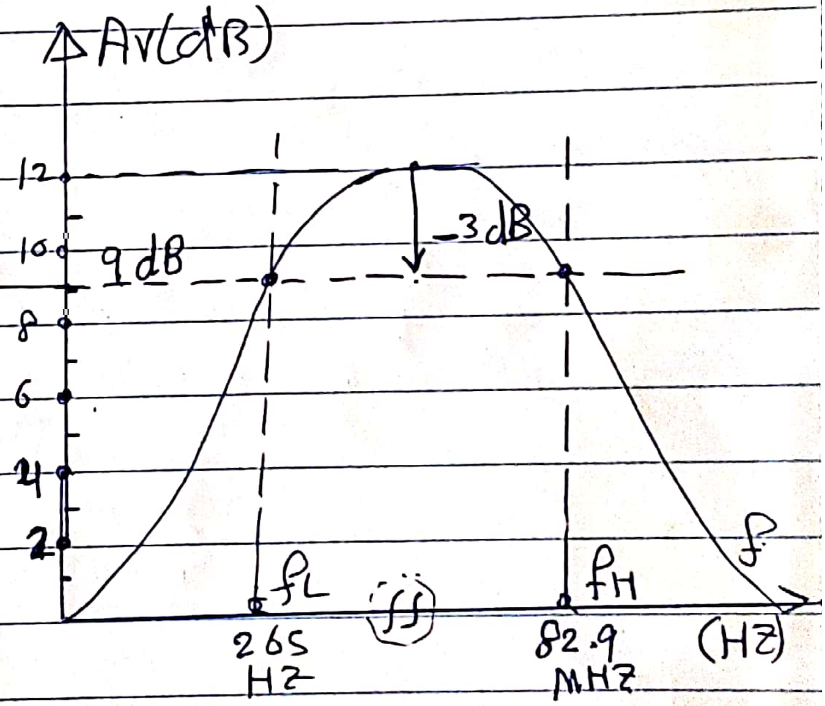
$$R_{eq} = R_{si} \parallel R_{in} = (0.1 \parallel 0.5)\,K\Omega$$
$$= 83.3\,\Omega$$

$$\therefore f_{Hi} = \frac{1}{2\pi \times 5\times10^{-12} \times 83.3} = 382.124\ MHz$$

$$f_{Ho} = \frac{1}{2\pi C_{gd}(R_D \parallel R_L)} = \frac{1}{2\pi \times 0.8\times10^{-12}\times(4\parallel6)\times10^{3}} = \frac{10^9}{12.0637}$$

$$f_{Ho} = 82.9\ MHz$$

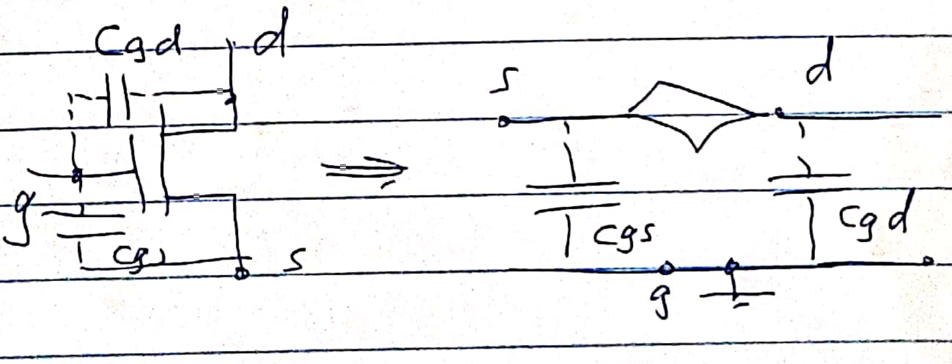
$$\therefore f_H = 82.9\ MHz$$



$(A_{vm} - 3) \longrightarrow 9\ dB$

$A_{vm} = \cancel{3}\ 4$

$A_{vm}(dB) = 20 \log 4$



Freq. Resp. For C.C & C.D Amp.

(Emitter follower & Source f.)

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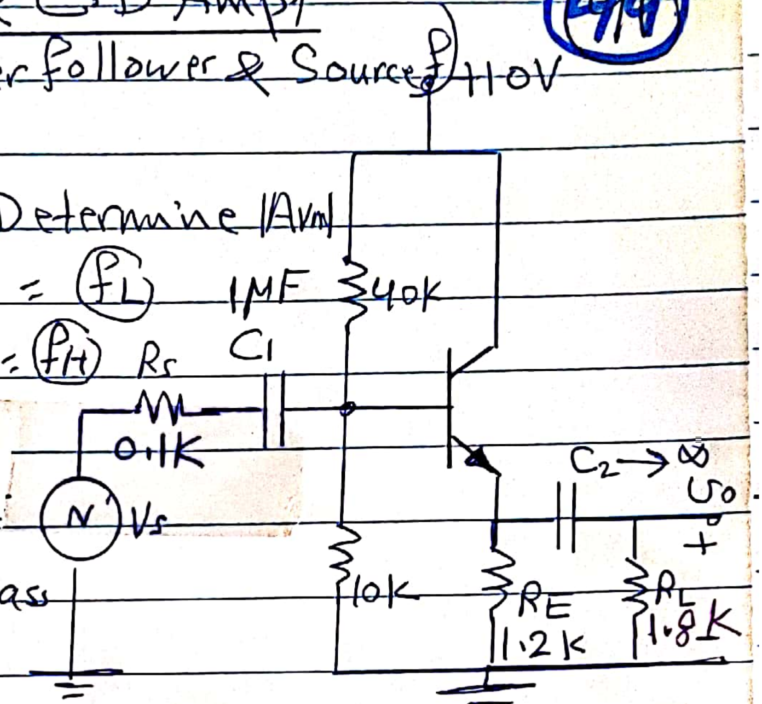
EXA: For the cct. shown,

1) Draw MF eqnt. cct. & Determine $|A_{vm}|$

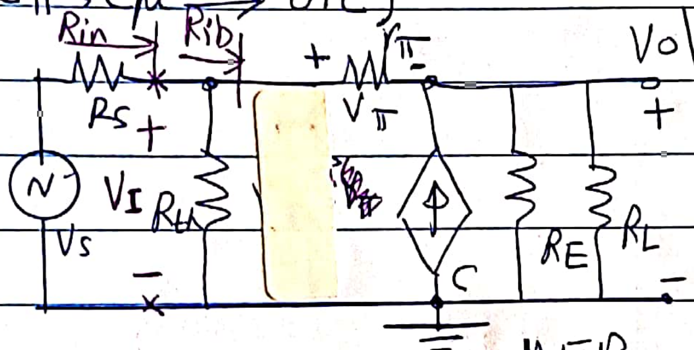
2) " LF " " = f_L

3) " HF " " = f_H



① MFR: all coupling & bypass ($C_1, C_2, C_E \to$ S.C)

($C_\pi, C_\mu \to$ O.C)



$R_L = 10K$, $R_E = 1.2K\Omega$

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

$C_\pi = 40pF$, $C_\mu = 5pF$

$I_{CQ} = 1mA$, $V_T = 26mV$

MFR

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

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = 2.6K$$

$$\frac{V_o}{V_I} = \frac{(\beta+1)(R_L // R_E)}{r_\pi + (\beta+1)(R_L // R_E)}, \quad \frac{V_I}{V_s} = \frac{R_{in}}{R_s + R_{in}}$$

$$R_{in} = R_{th} // R_{ib}, \quad R_{ib} = (\beta+1)(R_L // R_E) + r_\pi$$

$$R_{ib} = 2.6 + 101(1.2 // 1.8) = 75.32K\Omega$$

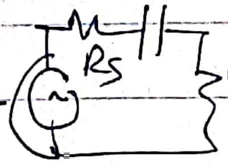
$$R_{th} = 40 // 10 = 8K\Omega \quad \therefore R_{in} = 8 // 75.32K = \boxed{7.232K\Omega}$$

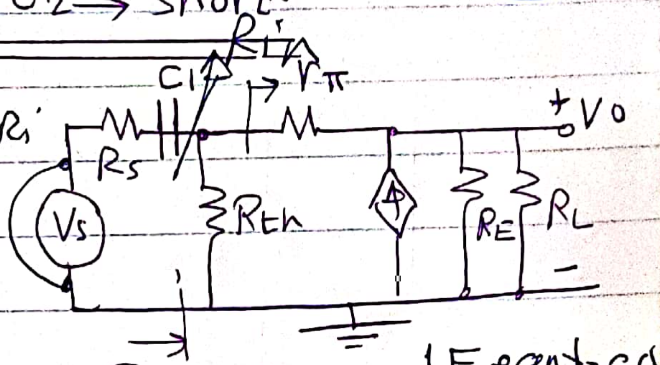
$$\therefore A_{vm} = \frac{(\beta+1)(R_L // R_E)}{r_\pi + (\beta+1)(R_L // R_E)} \cdot \frac{R_{in}}{R_{in} + R_s}$$

$$A_V = \frac{101 \times 0.72}{75.32} \cdot \frac{7.232}{0.1 + 7.232} = \boxed{0.952}$$

② LFR: C_π & $C_\mu \rightarrow$ O.C, $C_2 \rightarrow$ Short.

$$f_{L_1} = \frac{1}{2\pi C_1 (R_s + R_{in})}$$



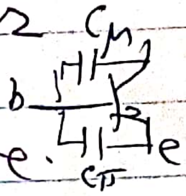


$$= \frac{1}{2\pi \times (0.1 + 7.232) \times 10^3 \times 1 \times 10^{-6}}$$

LF eqnt ccl

$R_{in} = 7.232 \, K\Omega$

$$\boxed{f_L} = \boxed{21.7 \, HZ}$$

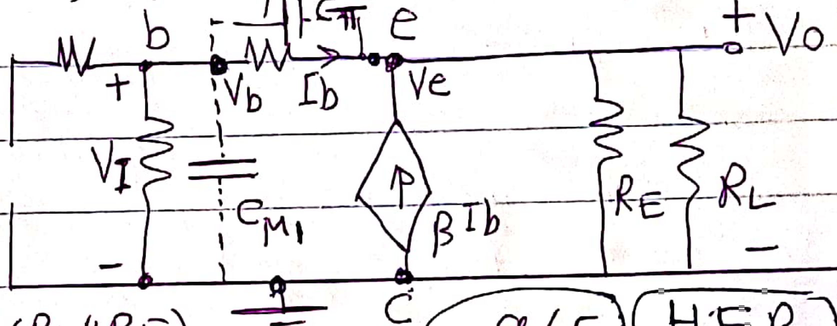


③ HFR: $C_1, C_2 \rightarrow$ S.C, $C_\pi, C_\mu \Rightarrow$ effective.

C_π is divided into C_{M1} & C_{M2}

$C_{M1} = C_\pi (1 - K)$

$C_{M2} = C_\pi \left(1 - \frac{1}{K}\right)$

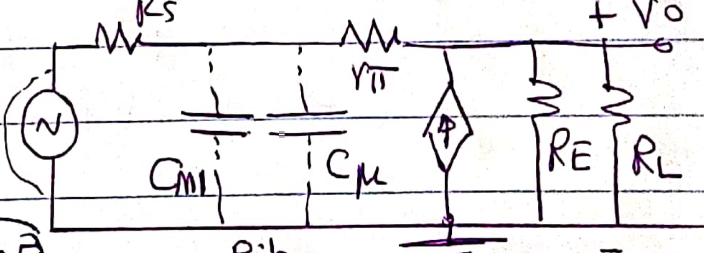


$$K = \frac{V_e}{V_b} = \frac{V_o}{V_I} = \frac{(\beta+1)(R_L \| R_E)}{(r_\pi + (\beta+1)(R_E \| R_L))} = 0.965 \quad \text{HFR}$$

$\therefore C_{M1} = 40(1 - 0.965) = 1.4 \, PF$

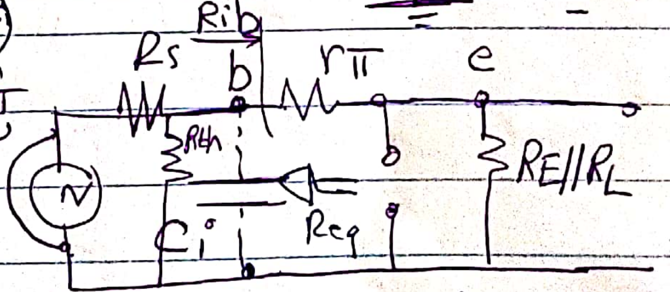
$C_{M2} = 40\left(1 - \frac{1}{0.965}\right) \Rightarrow$ -ve Value $\Rightarrow$ Neglected

$$f_{Hi} = \frac{1}{2\pi C_i R_{eq}}$$



$C_i = C_\mu + C_{M1} = 5 + 1.4 = 6.4 \, pF$

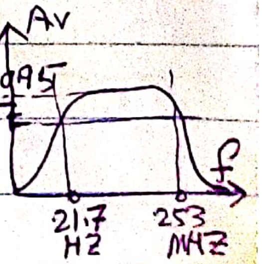
$R_{eq} = (R_s \| R_{th}) \,\|\, \underbrace{(\beta+1)(R_E \| R_L) + r_\pi}_{R_{ib}}$



$= (0.1 \| 8) \,\|\, 101 \times 0.72 + 2.6$

$= 98.7 \, \Omega \,\|\, (75.32K) \simeq 98 \, \Omega$

$$\therefore f_H = \frac{1}{2\pi \times 98 \times 6.4 \times 10^{-12}} = 253.754 \, MHZ$$

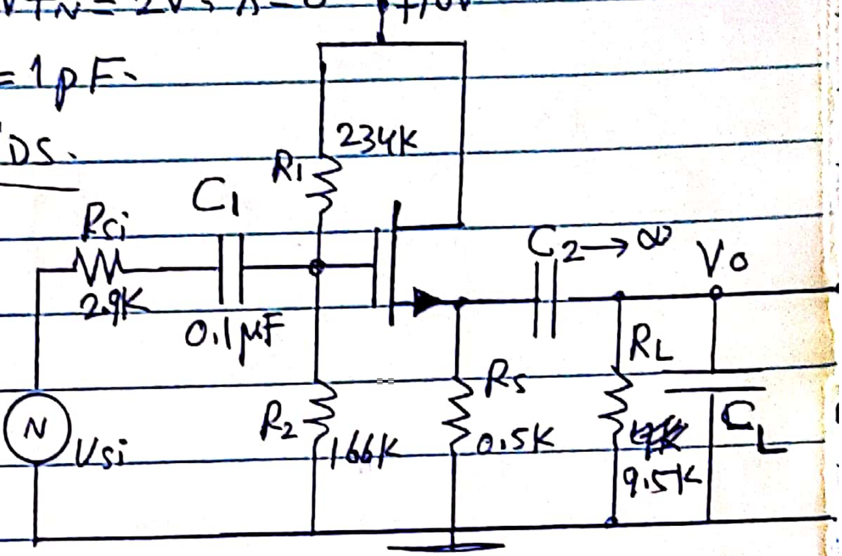


Frequency Response of C.D Amp.

Given: $K_n = 0.5\,mA/V^2$, $V_{TN} = 2V$, $\lambda = 0$

$C_{gs} = 5pF$, $C_{gd} = 1pF$.

1) Calculate V_{GS}, I_D, V_{DS}.
2) Draw MF eqnt. cct. and find A_{VM}?
3) Determine f_L?
4) Determine f_H?
5) Sketch freq. Resp.
6) Calculate C_L which makes $f_H = 1.5\,MHz$.



① For D.C Analysis, all Cap. → O.C

Assume the MOSFET in Sat.

$I_D = K_n(V_{GS} - V_{TN})^2$ ——— ①

$V_{GS} = V_G - V_S = \frac{10\times166}{400} - 0.5 I_D$

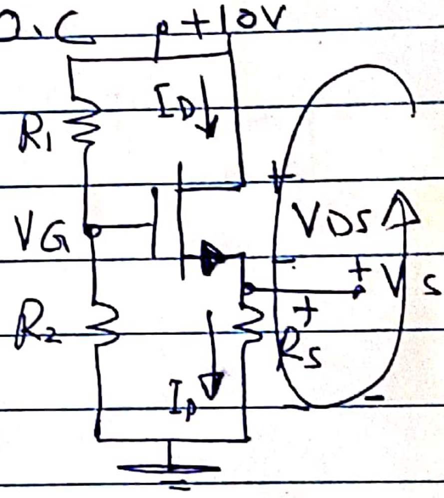
$4.15 - 0.5 I_D = V_{GS}$ ——— ②

$I_D = \frac{4.15 - V_{GS}}{0.5} = 0.5(V_{GS}^2 - 4V_{GS} + 4)$

$4.15 - V_{GS} = 0.25 V_{GS}^2 - \cancel{V_{GS}} + 1$

$0.25 V_{GS}^2 - \cancel{V_{GS}} + \cancel{V_{GS}} - 3.15 =$

$V_{GS} = \mp\sqrt{\frac{3.15}{0.25}} = \mp 3.55V$ ∴ $\boxed{V_{GS} = 3.55V}$



∴ $I_D = \frac{(4.15 - 3.55)V}{0.5K} = 1.2\,mA$.

$V_{DS} = 10 - I_D R_S = 10 - 1.2\times0.5 = 9.4V$

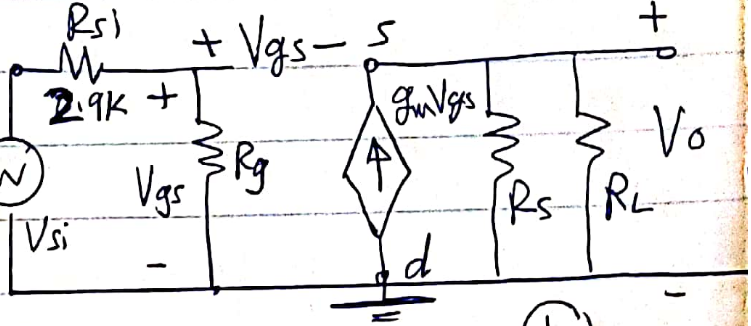
$V_{DS(sat)} = V_{GS} - V_{TN} = 3.45 - 2 = 1.45V$

∴ MOSFET in Saturation Regn.

(2) MFR: $C_1, C_2 \rightarrow S.C$, $C_{gd}, C_{gs} \Rightarrow O.C$

$$A_{vm} = \frac{V_o}{V_{si}} = \frac{V_o}{V_{gs}} \times \frac{V_{gs}}{V_{si}}$$

$$= \frac{g_m R_L'}{1+g_m R_L'} \times \frac{R_g}{R_g+R_{si}}$$



$g_m = 2\sqrt{K_n I_D} = 1.55 \frac{mA}{V}$ $R_g = R_1 // R_2 = 97.1 K\Omega$

$R_L' = R_s // R_L = 0.5 // 9.5 = 0.475 K\Omega$

$$\therefore \boxed{A_{vm}} = \frac{1.55 \times 0.475}{1+1.55\times0.475} \cdot \frac{97.1}{2.9+97.1} = \boxed{0.411}$$

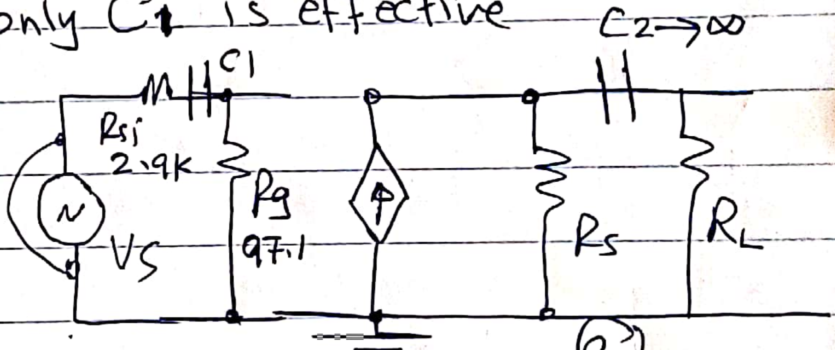
(3) LFR: C_{gs} & $C_{gd} \rightarrow O.C$, C_1 & $C_2 \rightarrow$ exist

but $C_2 \rightarrow \infty$, so only C_1 is effective

$$f_L = \frac{1}{2\pi(R_{si}+R_g)C_1}$$

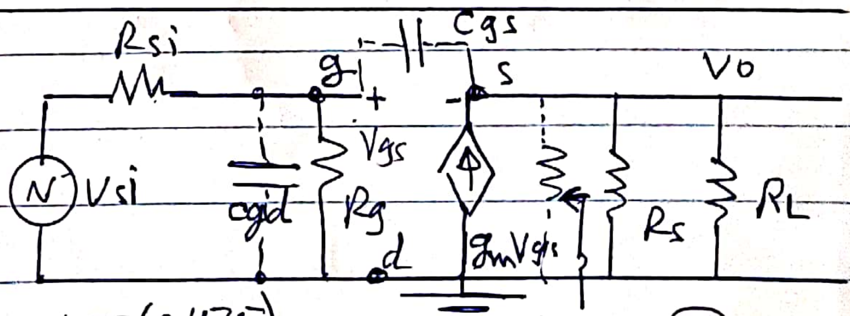
$$f_L = \frac{1}{2\pi \times 100K \times 0.1 \times 10^{-6}}$$

$f_L \simeq 16 HZ$.



$C_1 = 0.1 \mu F$

(4) HFR: $C_1 \rightarrow S.C$, $C_2 \rightarrow S.C$, $C_{gd}, C_{gs} \rightarrow$ exists.



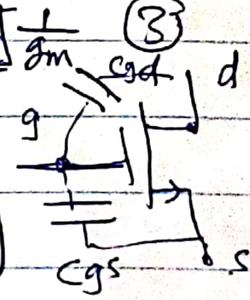
Cgs will be divide into

$C_{M1} = C_{gs}(1-K)$

$C_{M2} = C_{gs}(1-\frac{1}{K})$

$$K = \frac{V_o}{V_{gs}} = \frac{g_m(R_L//R_s)}{1+g_m(R_L//R_s)} = \frac{1.55(0.475)}{1+(1.55\times0.475)} = \boxed{0.424}$$

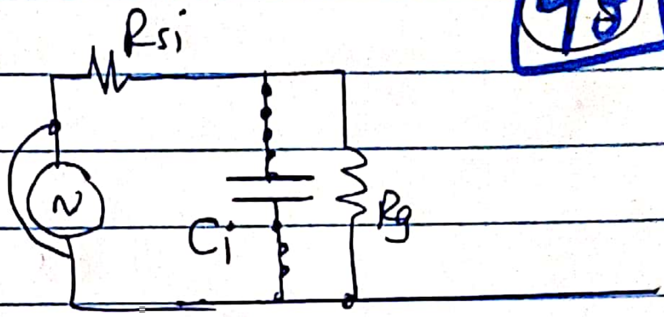
3



$C_{M1} = 5(1-0.424) = 2.88 PF$

$C_{M2} = 5(1-\frac{1}{0.424}) < 0$ (−ve Neglected)

$$f_{Hi} = \frac{1}{2\pi C_i R_{eq}}$$



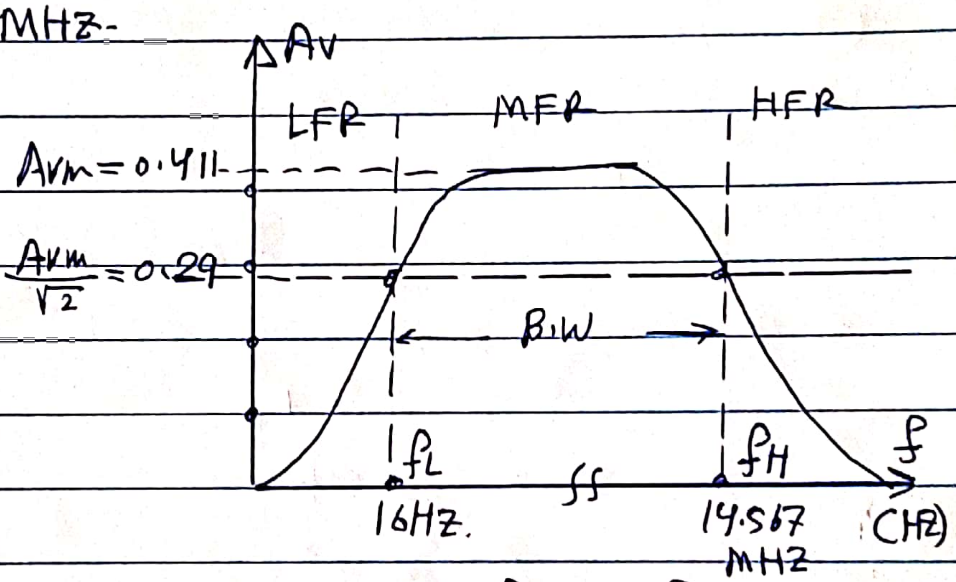
$R_{eq} = R_{si} \| R_g = 2.9 \| 97.1$

$= 2.816\ K\Omega$

$$f_{Hi} = \frac{1}{2\pi \times 2.816 \times 10^{3} \times 3.88 \times 10^{-12}}$$

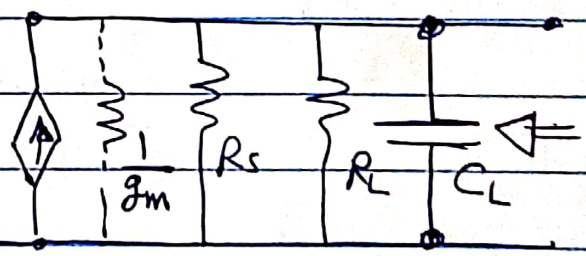
$C_i = C_{M1} + C_{gd} = 3.88\,pF$

$= 14.567\ MHz.$



$B.W = f_H - f_L \simeq f_H$

(5) $$f_H = \frac{1}{2\pi C_L R_{eq}}$$



$R_{eq} = \frac{1}{g_m} \| R_s \| R_L$

$\frac{1}{g_m} = \frac{1000}{1.55} = 0.645\,K\Omega$

$R_{eq} = 0.645 \| 0.5 \| 9.5 = 0.645 \| 0.475 = 0.273\,K\Omega$

$$\therefore C_L = \frac{1}{2\pi f_H R_{eq}} = \frac{1}{2\pi \times 1.5 \times 10^{6} \times 0.273 \times 10^{3}}$$

$C_L = 388\ pF$