Amplifiers Notebook
Dr.Ra'ed Al-zoubie

By . Lara Abu Soufa

بأفكارنا_نُبدع

1st & 2nd week

No.

Review:

n-type : concentration of electronics > concentration of holes.

P-type : holes > electrons

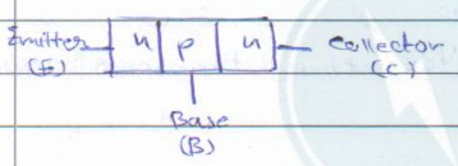
⇒ we ~~can~~ use process to get these materials.

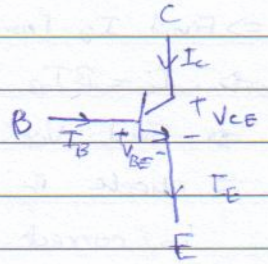
⇒ Transister : → Bipolar Junction transistor (BJT).

↳ Field ~~Junction~~ effect transistor (FET)

⇒ BJT

: npn





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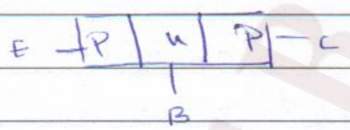
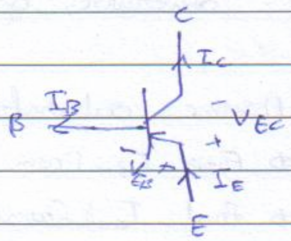




* Modes of operation for BJT:-

① forward-active mode ⇒ $V_{BE} = V_{BE(ON)} \simeq 0.7$ V

B.E forward-biased $I_C = \beta I_B$

B.C Reverse-biased $V_{CE} > V_{CE(sat)} \simeq (0.2 - 0.3)$

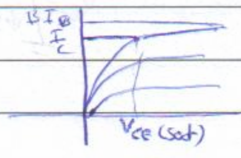
App: Amplifier.

② Saturation mode :- ⇒ $V_{BE} = V_{BE(ON)} = 0.7$ V

B.E f.w $I_C < \beta I_B$

B.C f.w $V_{CE} = V_{CE(sat)} = 0.2$

App: Switch



No.

$50 \le \beta \le 300$ $\simeq 0.99$

$\alpha = \frac{\beta}{1+\beta}$

$I_C = \beta I_B$ ~> Forward

$I_E = I_C + I_B = \beta I_B + I_B$

$I_E = (1+\beta) I_B$

$I_E = \frac{1+\beta}{\beta} I_C = \frac{I_C}{\alpha}$

(4) Inverse active Mode :

B-E Reverse-biased.

B-C Forward-biased.

=> How to find the Mode operation :

(1) Assume forward active Mode

=> Find I_B from input loop.

=> $I_C = \beta I_B$

=> Find V_{CE} from output loop.

=> check if $I_B > 0$ and $V_{CE} > V_{CE(sat)}$, then our assumtion is correct.

otherwise, go to step (2).

(2) Assume saturation Mode:

=> Find I_B from input Loop.

=> Find I_C from output Loop.

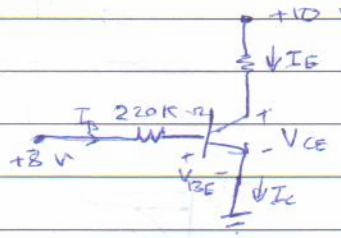
using $V_{CE} = V_{CE(sat)}$

=> check if $I_C < I_B \beta$, then our assumtion is correct.

otherwise, the mode of the operations is cuttoff.

Example 1 [a] Find the Mode operation in this cct :

Given : $V_{CE(sat)} = 0.2$ V , $\beta = 100$ V , $V_{BE(ON)} = 0.7$ V.



phasor I_b DC I_B ac+dc i_B ac i_b

No.

⇒ Assume F.W

→ input Loop:

$-8 + 220 I_B + 0.7 = 0$

$I_B = \frac{8-0.7}{220} = 33.2 \ \mu A.$

$I_C = \beta I_B = 3.32 \ mA.$

→ Output loop:

$-10 + 4 I_C + V_{CE} = 0$

$V_{CE} = 10 - 4 I_C = -3.28 \ V$

⇒ since $V_{CE} < V_{CE(sat)}$ (0.2) ⇝ then our assumption is incorrect.

⇒ Assume Saturation Mode:

→ input loop:

$I_B = 33.2 \ \mu A$

→ output loop:

$-10 + 4 I_C + 0.2 = 0$

$I_C = 2.45 \ mA$

⇒ check $I_C \overset{?}{<} \beta I_B$ Yes ⇝ ∴ Saturation Mode

(we can't use it as amplifier).

[b] Find the Q-point values (Quiescent point/operation point):

$I_{BQ} = 33.2 \ \mu A$

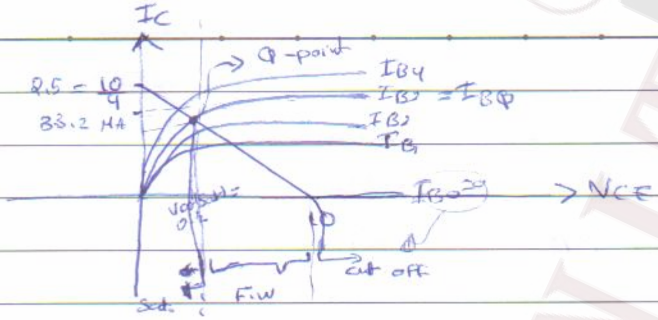
$I_{CQ} = 2.45 \ mA$

$V_{CEQ} = 0.2 \ V$

[c] Find the DC load line (I_C & V_{CE})?

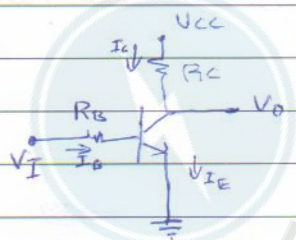
$-10 + 4 I_C + V_{CE} = 0$

$I_C = \frac{10}{4} - \frac{V_{CE}}{4}$



* The Transistor should be in the forward-active mode to work as amplifier, why?

ANS:-



Draw the relationship between V_O & V_I :-

⇒ Cutoff:

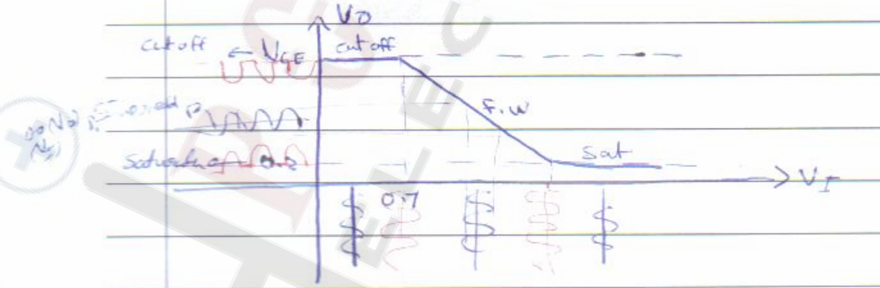
$I_B = I_C = I_E = 0$ A

So, $V_O = V_{CC}$

⇒ Saturation:

$V_{CE} = V_{CE(sat)} = 0.2$ V

So, $V_O = V_{CE(sat)} = 0.2$ V.



⇒ input loop: $-V_I + I_B R_B + 0.7 = 0$

$$I_B = \frac{V_I - 0.7}{R_B}$$

No.

$$I_C = \beta I_B = \frac{\beta (V_I - 0.7)}{R_B}$$

→ output loop:-

$$-V_{CC} + \underbrace{I_C}_{\frac{\beta (V_I - 0.7)}{R_B}} R_C + V_o = 0$$

$$-V_{CC} + \beta \frac{R_C}{R_B} (V_I - 0.7) + V_o = 0$$

$$V_o = V_{CC} + \beta \frac{R_C}{R_B} (0.7) - \beta \frac{R_C}{R_B} V_I$$

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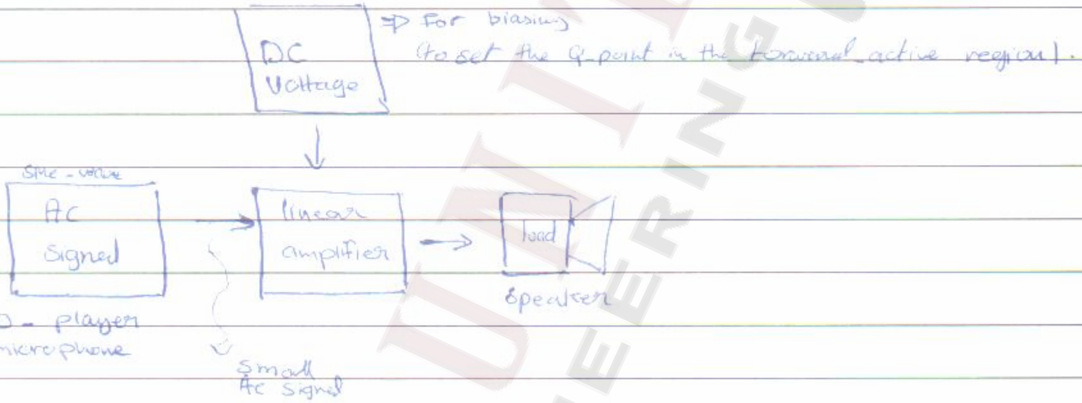
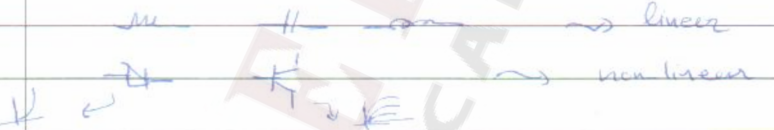
* Basic BJT Amplifier :



⇒ linear Amplifier : $V_o = \text{constant} \times V_I$
Gain

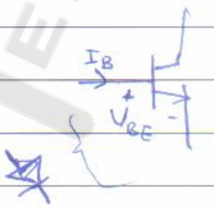
↳ why? to get a clear amplification.

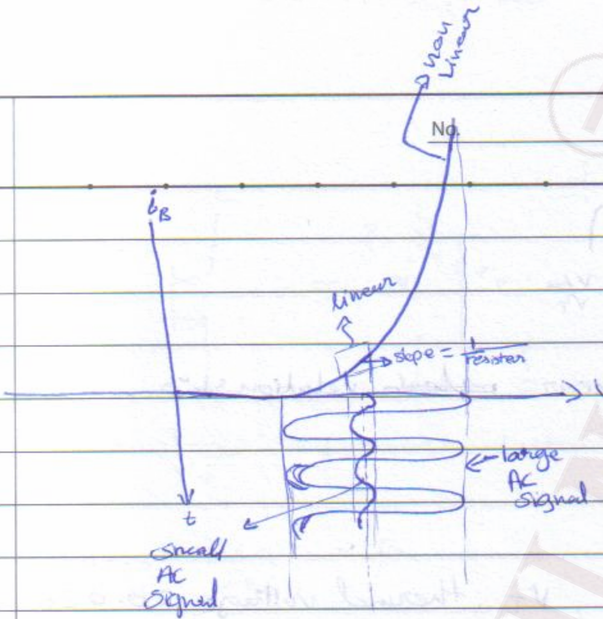
⇒ linear circuits : all its components are linear.
→ linear elements → $V \propto I$ is linear.

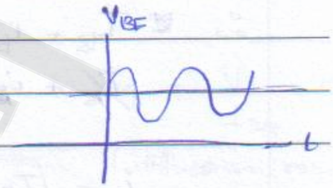


but, amplifier circuit has transistor which is not linear element.
⇒ So we need a solution to get a linear amplifier.
⇒ Solution : Small AC signals.
⇒ Transistor will act as a linear device at small AC signals, why?

answer :- Graphically :~







At small AC signal :-

$\equiv$ -\/\/\/-

So, at small AC signal the junction B.E is represented by a resister called $\boxed{r_\pi}$.

Mathematically :-

$$i_B = \frac{I_s}{1+\beta} e^{\left(\frac{V_{BE}}{V_T}\right)} \quad \text{(From electronics 1)}.$$

saturation current

$$\underset{DC}{I_B} + \underset{AC}{i_b} = \frac{I_s}{1+\beta} e^{\left(\frac{v_{be} + V_{BE}}{V_T}\right)}$$

$$I_B + i_b = \underbrace{\frac{I_s}{1+\beta} e^{\frac{V_{BE}}{V_T}}} . e^{\frac{v_{be}}{V_T}}$$

$$I_B + i_b = I_B . e^{\frac{v_{be}}{V_T}}$$

* Taylor series : $e^\theta = 1 + \frac{\theta}{1!} + \frac{\theta^2}{2!} + \frac{\theta^3}{3!} + \dots$

If $\theta \ll 1 \Rightarrow e^\theta = 1 + \theta$

So, if $\frac{v_{be}}{V_T} \ll 1 \longrightarrow \frac{v_{be}}{V_T} < 1 \rightsquigarrow v_{be} < V_T$

then $e^{\frac{v_{be}}{V_T}} \simeq 1 + \frac{v_{be}}{V_T}$

$\rightsquigarrow$

No.

$\therefore\ I_B + i_b = I_B\left(1 + \frac{v_{be}}{V_T}\right)$

$\cancel{I_B} + i_b = \cancel{I_B} + I_B \frac{v_{be}}{V_T}$

$i_b = \boxed{\frac{I_B}{V_T}}\ v_{be}$ ⇒ linear ~~relation~~ relationship.

$\downarrow$

$\frac{1}{r_\pi}$

$\therefore\ \boxed{r_\pi = \frac{V_T}{I_B}\ \Omega}$, V_T thermal voltage $= 0.026$ v at room temperature (300°K).

⇒ Since we have a linear amplifier, then we can ~~appli~~ apply super position to analyze the amplifier circuit by doing ~~AC~~ DC then ~~AC~~ AC analysis.

⇒ To analyze an amplifier circuit :-

Step. 1. DC analysis.

① Draw the DC equivalent cct

→ Kill all the sources.

→ replace all capacitor by open cct.

② Find I_B, I_C, V_{CE}

input loop, βI_B, output loop.

Step 2. AC analysis.

① Draw the AC equivalent cct.

→ Kill all DC sources.

→ replace all capacitor by short cct.

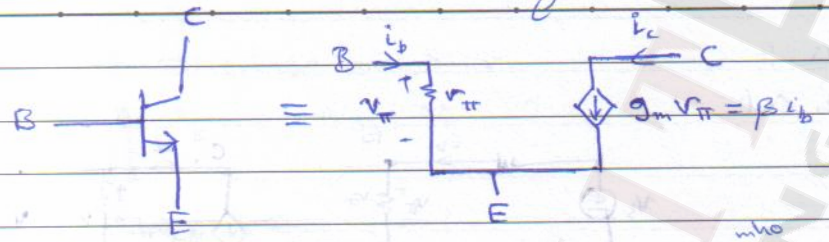
→ replace the transistor by its small AC - signal (hybrid - π equivalent circuit.

different units of ~~ss~~ parameter.

Q-point ← DC anys يستخدم

No.

linear cct



$r_\pi = \frac{V_T}{I_{BQ}}$ Ω

(diffusion resistance)

$g_m = \frac{I_{CQ}}{V_T}$ (transconductance). mho (℧) (S)

↳ siemens.

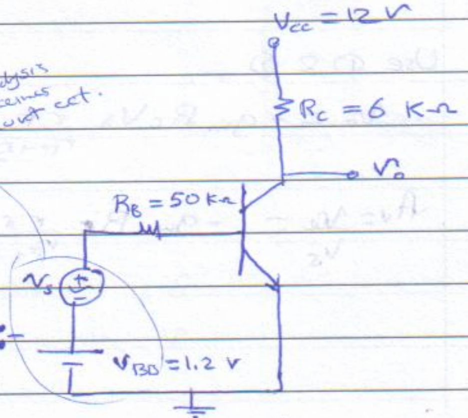
$r_\pi g_m = \frac{I_{CQ}}{I_{BQ}} = \beta$

$\therefore \boxed{\beta = r_\pi g_m}$

$\leadsto g_m v_\pi = \frac{\beta}{\cancel{r_\pi}} \cdot i_b \cancel{r_\pi} = \beta i_b$.

Example:-

at AC analysis its becomes a short cct.



$\beta = 100$

$V_{BE(on)} = 0.7\ V$

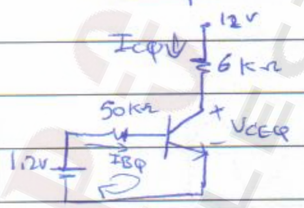
a) Find the Voltage gain ($A_v = \frac{V_o}{V_s}$):-

AC

it's not practical :- because there is no capacitor ...

→ DC analysis:-

DC eq. cct



input loop:

$-1.2 + 50\, I_{BQ} + 0.7 = 0$

$I_{BQ} = 10\ \mu A$.

$\rightarrow I_{CQ} = \beta I_{BQ} = 1\ mA$.

output loop:

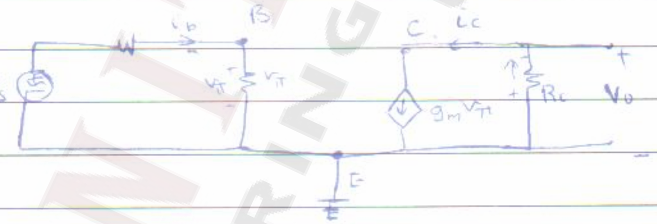
$-12 + 6\, I_{CQ} + V_{CEQ} = 0$

$\boxed{V_{CEQ} = 6\ V}$ > 0.3 Forward

No.

→ AC analysis :

⇒ AC eq. cct :



$$r_\pi = \frac{V_T^{\,0.026}}{I_{BQ}} = 2.6\,k\Omega$$

$$g_m = \frac{I_{CQ}}{V_T} = 38.5\ mA/V$$

$$V_o = -g_m v_\pi R_c \quad \text{——} \quad (1)$$

$$v_\pi = V_s \frac{r_\pi}{r_\pi + 50} \quad \text{——} \quad (2)$$

Use (1) & (2) :

$$V_o = -g_m R_c V_s \frac{r_\pi}{r_\pi + 50}$$

$$A_v = \frac{V_o}{V_s} = -g_m R_c \frac{r_\pi}{r_\pi + 50} \simeq -11.4$$

180° phase-shift between V_s & V_o

No.

ⓑ if $v_s(t) = 0.25 \sin\omega t$ V

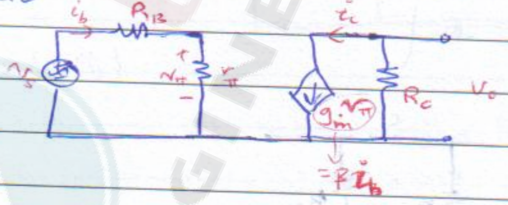
Find i_B, i_C, V_{CE}, V_o ?

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

I_{BQ}: DC $\rightarrow$ $10\ \mu A$

i_b: AC $\rightarrow$ $\dfrac{v_s}{R_B + r_\pi}$

$\therefore i_B = 10 + \dfrac{0.25 \sin\omega t}{50 + 2.6} = 10 + 4.75 \sin\omega t\ \mu A$



$i_C = \beta i_B$

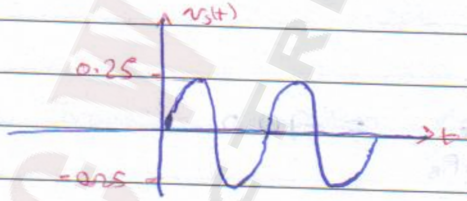
$= 1 + 0.475 \sin\omega t$ mA

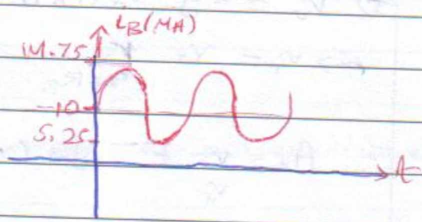
$v_{CE} = V_{CEQ} + v_{ce} = 6 + (-i_c R_C)$

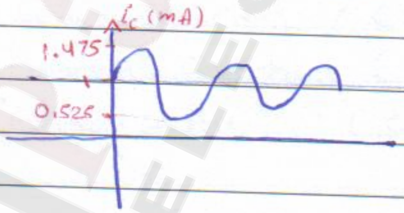
$= 6 - 0.475 \sin\omega t * 6$

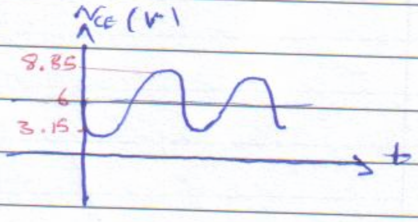
$= 6 - 2.85 \sin\omega t$ V

$\Rightarrow V_o = v_{CE} = 6 - 2.85 \sin\omega t$ V

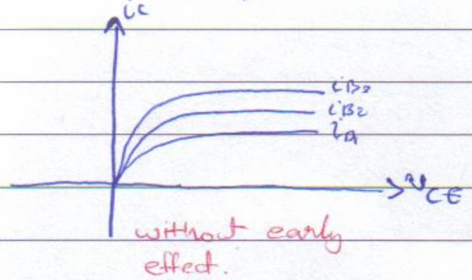


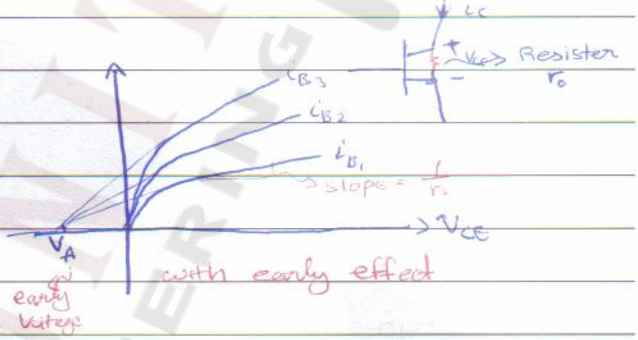






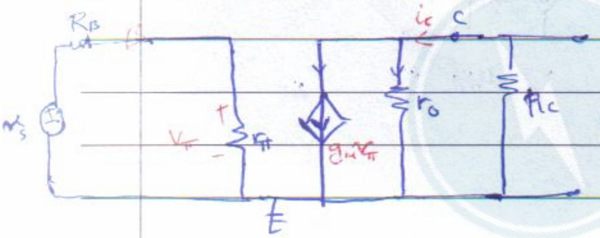
* Hybrid-π equivalent circuit with the early effect.





very large value

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



Ex: For the last example, if $V_A = 50$ V find A_v.

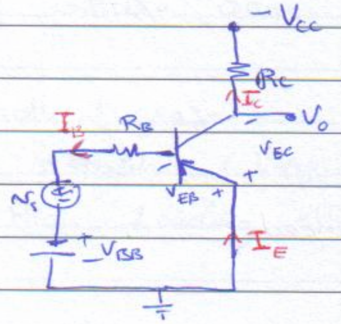
$v_o = -g_m v_\pi (r_o // R_C)$

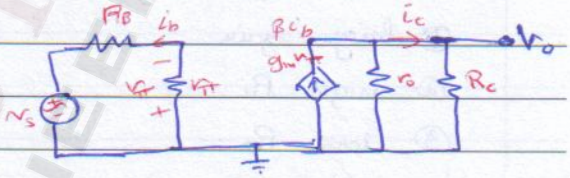
$\rightarrow v_\pi = v_s \frac{r_\pi}{r_\pi + R_B}$

$\therefore A_v = \frac{v_o}{v_s} = -g_m (r_o // R_C) \frac{v_\pi}{r_\pi + R_B} = -10.2$

No.

PnP BJT :-





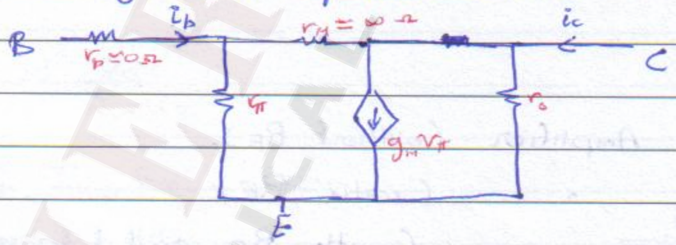
⇒ AC circuit :-

$$\Rightarrow v_o = g_m v_\pi \, (r_o \parallel R_c)$$

$$v_\pi = -\frac{v_s \, r_\pi}{r_\pi + R_B}$$

$$\hookrightarrow A_v = -g_m \, (r_o \parallel R_c) \frac{r_\pi}{r_\pi + R_B}$$

(*) Expanded Hybrid-π equivalent circuit :-

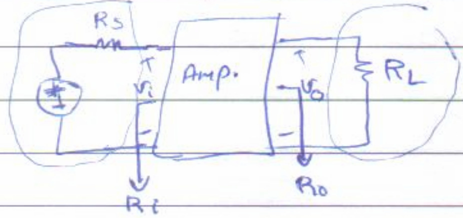


(*) Basic Transistor amplifier (practical amplifiers) configurations :-

1. Common-emitter (CE) Amplifier,
2. Common-collector (CC) Amplifier,
3. Common-base (CB) ,

الطرف اللي مش موصل له كل من input أو output هو بيكون في الـ common amplifier.

No.



* For a good Voltage Amplifier, we need:
  1. high gain
  2. high Ri
  3. low Ro

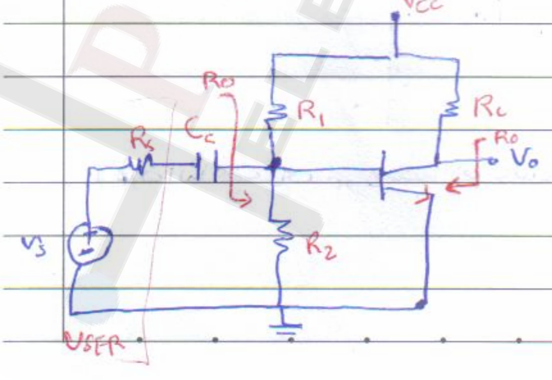
* For a good current Amplifier; we need;
  1. high gain
  2. low Ri
  3. high Ro

* CE Amplifier:-

Types:

1. Basic CE Amplifier (without R_E).
2. " " " (with R_E)
3. " " " (with R_E and bypass capacitor).
4. Advanced CE amplifier.

→ Basic CE amplifier (without R_E):-



C_c: coupling capacitor to block any DC value from the user (so, the user can not change the position of Q-point).

No.

→ Advantages :-

High voltage gain.

→ Disadvantages:-

① Unstable (Very sensitive to $V_{BE(on)}$).

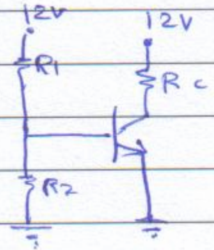
② High Loading effect. (R_i is not very high).

Example: IF $V_{CC} = 12\,v$, $R_C = 6K\,\Omega$, $R_1 = 93.7\,K\Omega$, $R_2 = 6.3\,K\Omega$

$\beta = 100$, $V_{BE(on)} = 0.7\,v$, $V_A = 100\,v$ → calculate r_o

Find the voltage gain, R_i, R_o ??

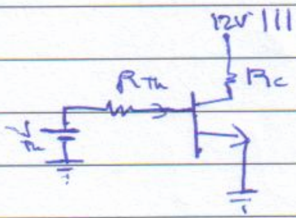
* DC analysis :-



→ open circuit

$R_{Th} = R_1 // R_2 =$

$V_{Th} = 12 \cdot \frac{R_2}{R_1 + R_2}$



→ $-V_{Th} + I_{BQ} R_{Th} + 0.7 = 0$

$I_{BQ} = 9.5\,\mu A$

$I_{CQ} = 0.95\,mA$

$\boxed{V_{CEQ} = 6.31\,v} > V_{CE(sat)}$

✓ (Forward)

* AC analysis:-

→ short circuit

POWER UNIT

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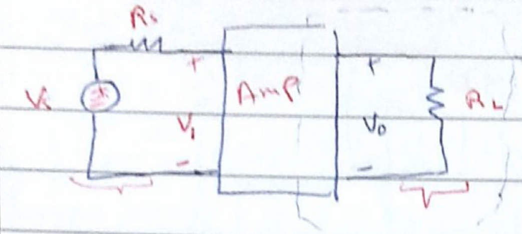
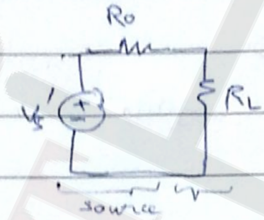
3 &4 week

No.





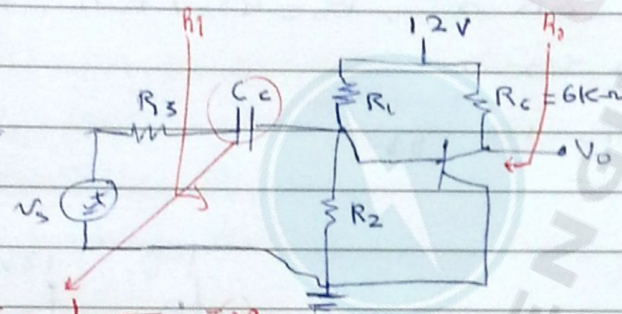
⇒ $V_i \simeq V_s$ → (small loading effect, good)

$V_i \ll V_s$ → (high loading effect, bad).

⇒ $V_o \simeq V_s$ → (small loading effect)

$V_o \ll V_s$ → (high loading effect).

Ex

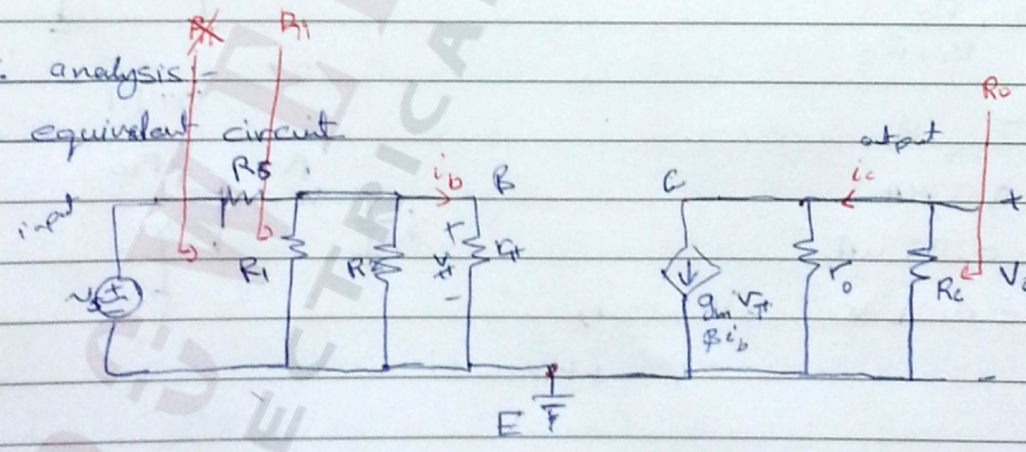


$Z_C = \frac{1}{j2\pi f C} = \infty$ → short cct.

DC → f = zero

* AC analysis:-

AC equivalent circuit



$r_\pi = \frac{V_T}{I_{BQ}} = 2.74\ K\Omega$

$g_m = \frac{I_{CQ}}{V_T} = 36.5\ mA/V$

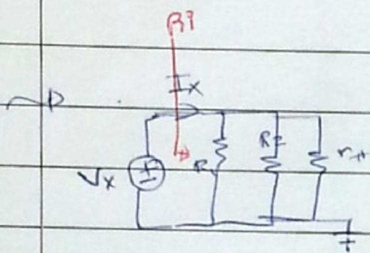
$r_o = \frac{V_A}{I_{CQ}} = 105\ K\Omega$

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

$V_o = -g_m V_\pi (r_o // R_c)$ ——— ①

$V_\pi = \frac{V_s (r_\pi // R_1 // R_2)}{(r_\pi // R_1 // R_2) + R_S}$ ——— ②

$A_v = -g_m \frac{(r_o // R_c)(r_\pi // R_1 // R_2)}{(r_\pi // R_1 // R_2) + R_S} = -163$



and kill all independent sources.

$R_i = \frac{V_x}{I_x}$

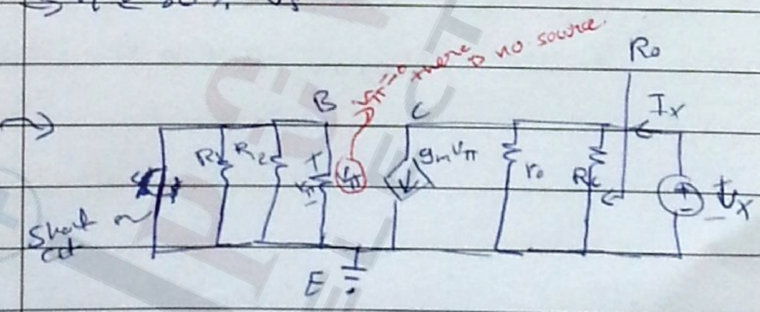
$-V_x + I_x(R_1 // R_2 // r_\pi) = 0$

$\rightarrow R_i = \frac{V_x}{I_x} = R_1 // R_2 // r_\pi = 1.87\ K\Omega$

$R_i \not> R_s \rightarrow$ so high loading effect

$V_i = V_s \times \frac{R_i}{R_i + R_s} = 0.789\ V_s$

$\rightarrow V_i < 80\%\ V_s$



ما بتفرق معها الـ high load
low

[illegible] R_L [illegible]

V_s = short cct $\Rightarrow V_\pi$ = zero

$\Rightarrow g_m V_\pi$ = zero (open cct).

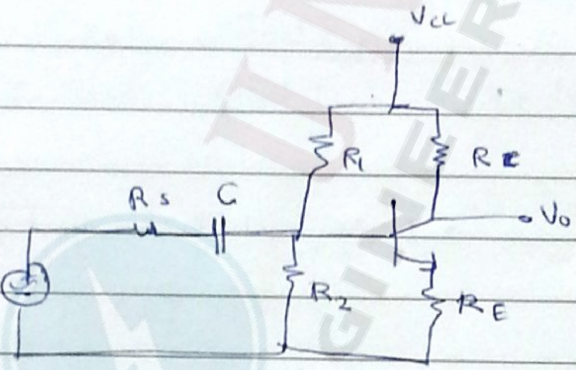
$R_o = \frac{V_x}{I_x} = r_o // R_c$, so $\rightarrow R_o = 5.68\ K\Omega$

its sensetive for $V_{BE(ON)}$:-

⇒ for $V_{BE(ON)} = 0.7\ v$ ⟶ $V_{CEQ} = 6.51\ v$ (Forward active Mo...

⇒ For $V_{BE(ON)} = 0.6\ v$ ⟶ $V_{CEQ} = -3.6\ v$ (not in Forward ad...

⊗ CE Amplifier with R_E :-



Advantages :

① Stable Amplifier (A_v is less dependent on β).

② Small loading effect (R_i is high).

Disadvantage :-

Small A_v

Ex :-

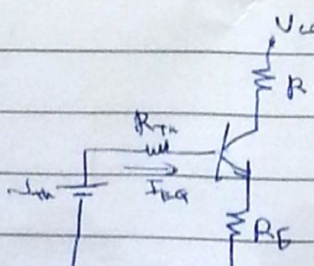
$V_{CC} = 10\ v$, $R_C = 2\ K\Omega$, $R_1 = 56\ K\Omega$, $R_2 = 12.2\ K\Omega$

$R_E = 0.4\ K\Omega$, $R_S = 0.5\ K\Omega$, $\beta = 100$, $V_{BE(ON)} = 0.7\ v$

$(V_A = \infty)$, $r_o = \infty$ (open cct)

Find A_v and R_i ?

⇒ DC analysis :-



⇒ $R_{Th} = R_1 // R_2 = 10\ K\Omega$

⇒ $V_{Th} = V_{CC} \dfrac{R_2}{R_2 + R_1} = 1.785$

No.

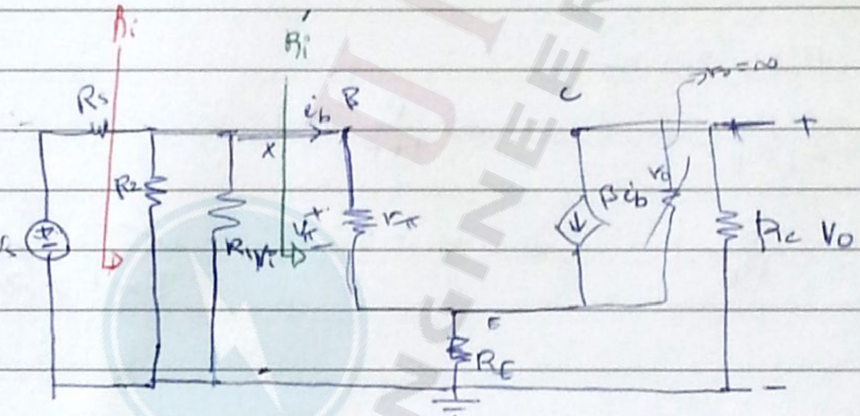
⇒ $-V_{th} + R_{th} I_{BQ} + 0.7 + R_E \overset{(1+\beta)I_{BQ}}{I_{EQ}} = 0$

$I_{BQ} = 21.6\ \mu A$

$I_{CQ} = \beta I_{BQ} = 2.16\ mA$

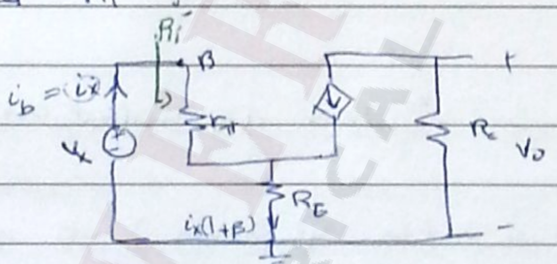
⇒ $V_{CEQ} = 4.81\ V > V_{CE(sat)}$ ✓ Forward.

AC analysis



$R_i = R_1 // R_2 // R_i'$

→ to Find R_i' :-



$-V_x + i_x r_\pi + (1+\beta) i_x R_E = 0$

$R_i' = \frac{V_x}{I_x} = r_\pi + (1+\beta) R_E = 41.6\ K\Omega$

$R_i = R_1 // R_2 // R_i' = 8.06\ K\Omega \gg R_s$ (small loading effect).

⇒ $A_v = \frac{V_o}{V_i}$

$V_o = -\beta i_b R_c$ — ①

$V_i = V_s * \frac{(R_1 // R_2 // R_i')}{R_1 // R_2 // R_i' + R_s}$

⇒ $i_b = \frac{V_i}{R_i'}$

$\therefore A_v = \dfrac{v_o}{v_i} = \dfrac{-\beta R_C}{r_\pi + (1+\beta)R_E} \left(\dfrac{R_i}{R_i + R_s}\right)$

$= -4.53$ (small gain).

$\Rightarrow$ since $R_i >> R_s$

$A_v \simeq \dfrac{-\beta R_C}{r_\pi + (1+\beta)R_E}$ (1)

also, $(1+\beta)R_E >> r_\pi$

$\therefore A_v \simeq \dfrac{-\beta R_C}{(1+\beta)R_E}$ $\rightarrow \dfrac{\beta}{1+\beta} \simeq 1$

$\boxed{\therefore A_v \simeq \dfrac{-R_C}{R_E}}$ $\rightarrow \simeq -5$ ✓ بيستخدمو

بس بيعطيني رقم مو Exact.

β	$\rightarrow A_v$
50	-4.41
100	-4.53
150	-4.57

$\rightarrow \therefore$ less dependant on β.

For stability : (to get a stable Q-points), we need

~~$(1+\beta)R_E >> r_\pi$~~

$(1+\beta) R_E >> R_{Th}$

$\rightarrow R_{Th} = 0.1 (1+\beta) R_E$

$R_{Th} \rightarrow R_1 // R_2$

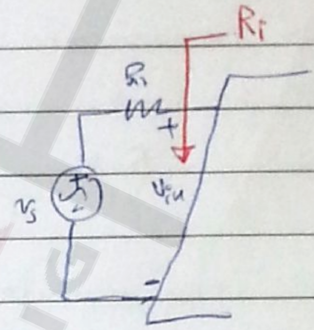
No.

For the last examples:-

loading effect:

$$V_{in} = ?\; V_s \frac{\overset{8.06}{R_i}}{R_i + \underset{0.5}{R_s}} = 0.942\, V_s$$

$V_{in} = 94.2\,\%\; V_s$ (small loading effect)



④ Common E, CE amplifier with R_E and bypass capacitor:-

C_C: Coupling Capacitor

C_E: bypass Capacitor. Why?

for CE with R_E ⇒

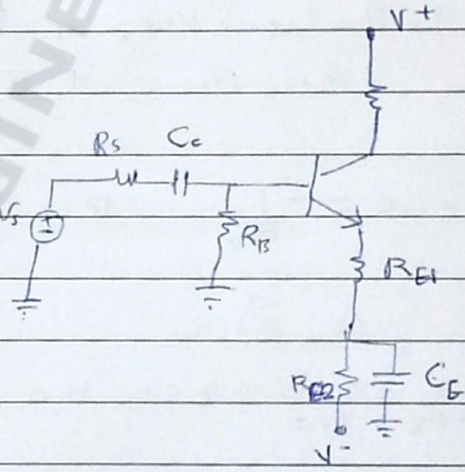
we need $(1+\beta)R_E \gg R_{th}$

(for stable Q-point),

so, we need high R_E

⇒ but, we also need high gain $A_v = -\frac{R_C}{R_E}$ ⇒ so, we need small R_E.

So, we use the bypass capacitor to satisfy both AC and DC requirment.



Ex:- Consider CE amplifier with R_E. Use the approximate gain $A_v = -\frac{R_C}{R_E}$, given that $I_{CQ} = 1\,mA$, $V_{CEQ} = 5\,V$, $\beta = 99$, $V_{CC} = 9\,v$.

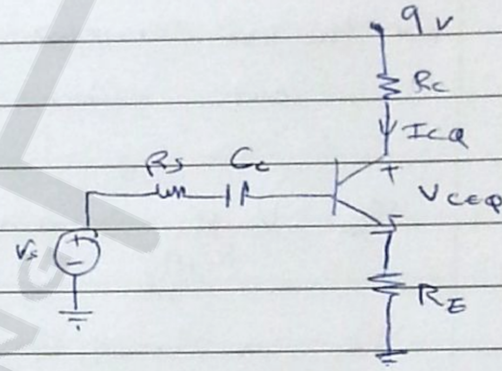
and $A_v = -8$, $R_i = 27.5\,k\Omega$

$R_1 \parallel R_2 \approx \infty$ (open cct)

$I_{CQ} \approx I_{EQ}$

Find R_E and R_C.

No.



$\Rightarrow$ DC requirements :-

① $I_{CQ} = 1\,mA$

② $V_{CEQ} = 5\,V$

$\Rightarrow$ AC requirments :-

① $A_v = -8$

② $R_i = 27.5\ K\Omega$

$\Rightarrow$ output loop

$$-9 + R_C I_{CQ} + V_{CEQ} + R_E \underbrace{I_{EQ}}_{\simeq I_{CQ}} = 0$$

$$\boxed{R_C + R_E = 4\ K\Omega} \quad \text{——— (1)}$$

$\Rightarrow A_v = -8 = -\frac{R_C}{R_E} \Rightarrow \boxed{R_C = 8 R_E}$

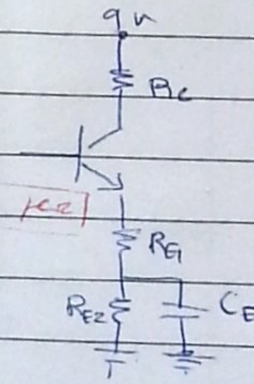
$$\underset{27.5k}{R_i} = r_\pi + (1 + \overset{99}{\beta}) R_E$$

$$\frac{V_T}{I_{BQ}} = \frac{V_T(\beta)}{I_{CQ}} \simeq 2.574\ K\Omega \qquad \Rightarrow \boxed{R_E = 0.25\ K\Omega}$$

$R_C = 8(R_E) = 2\ K\Omega$

$R_C + R_E = 4\ K\Omega \xrightarrow[\text{conflict}]{} \text{problem} \Rightarrow$ sol: use bypass capacitor.

$\Rightarrow$ Bypass Capacitor (on R_E)



$\Rightarrow$ DC requirment: (C_E open cct)

$R_C + R_{E1} + R_{E2} = 4$ ——— (1) $\longrightarrow \boxed{R_{E_2} = 1.75\ K\Omega}$

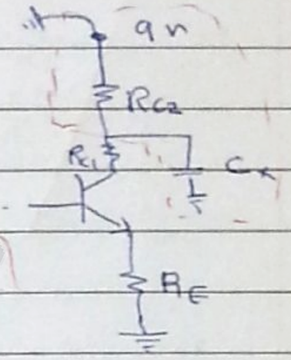
$\Rightarrow$ AC requirment : (C_E short cct)

$R_C = 8\ R_{E1}$ ——— (2) $\longrightarrow \boxed{R_c = 2\ K\Omega}$

$R_i = r_\pi + (1+\beta) R_{E1} \Rightarrow \boxed{R_{E1} = 0.25\ K\Omega}$

No.

Bypass Capacitor on R_C :-



$\Rightarrow$ DC requirment:-

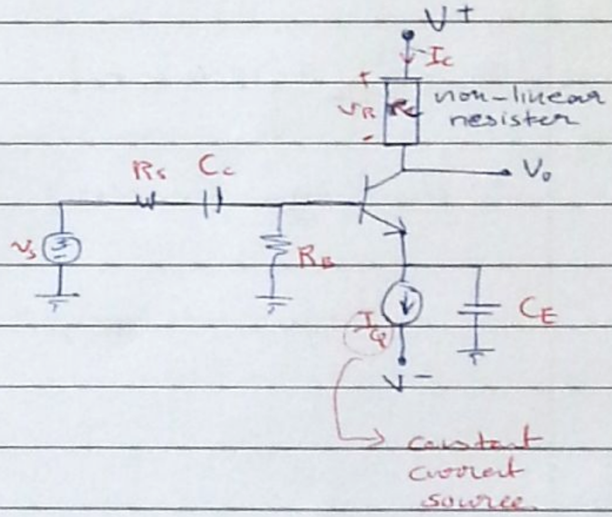
$R_{C1} + R_{C2} + R_E = 4$ ...... (1) $\rightarrow$ $\boxed{R_{C2} = 1.75\ K\Omega}$

$\Rightarrow$ AC requirment:

$R_{C1} = 8\ R_E$ $\longrightarrow$ $\boxed{R_{C1} = 2\ K\Omega}$

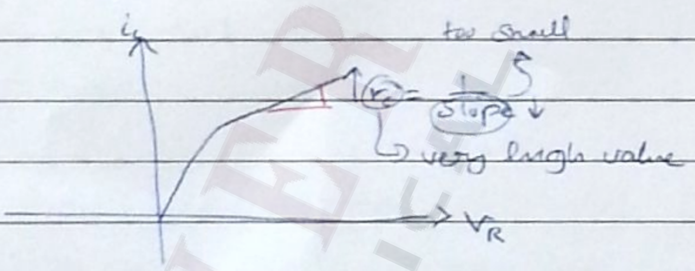
$\rightarrow R_i = r_\pi + (1+\beta) R_E \Rightarrow \boxed{R_E = 0.25\ K\Omega}$

(*) Advanced CE amplifier :-



~~Advantage :-~~

Very high A_v (voltage gain).



Ex :- if $I_Q = 0.5\ mA$, $\beta = 120$, $V_A = 80\ v$, $V_C = 120\ K\Omega$,

$R_S \simeq 0\ \Omega$, Find $A_v = \frac{v_o}{v_S}$?!

DC analysis :-

$\Rightarrow I_{EQ} = I_Q = 0.5\ mA$ (C_E open cct)

$I_{CQ} = \frac{\beta}{1+\beta} I_{EQ}$

$I_{CQ} \simeq I_{EQ} = 0.5\ mA$.

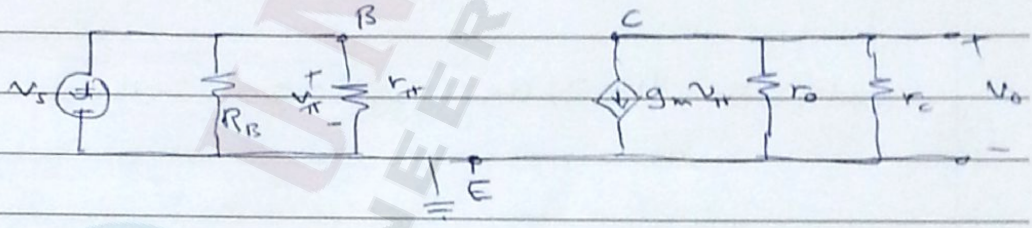
No.

AC analysis:

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

$$g_m = \frac{I_{CQ}}{V_T} = 19.2\ mA/V$$

$$r_o = \frac{V_A}{I_{CQ}} = 160\ k\Omega$$



$$A_v = \frac{v_o}{v_s} \Rightarrow$$

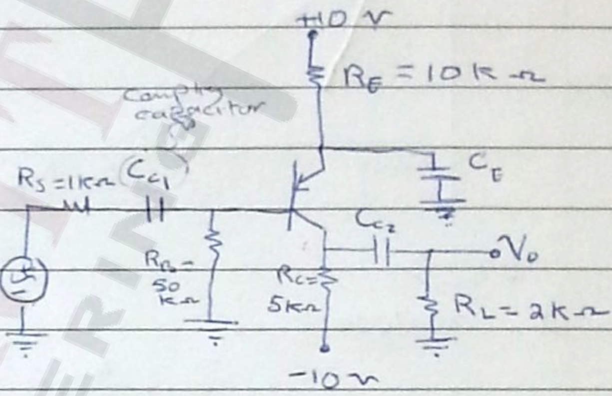
$$v_o = -g_m \underset{\overset{\shortparallel}{V_s}}{v_\pi} (r_o // r_c)$$

$\therefore A_v = -g_m (r_o // r_c) = -1317$ (very high gain)

↳ (two r_c very high

No.

AC load line :- (i_c ∝ v_{ec})



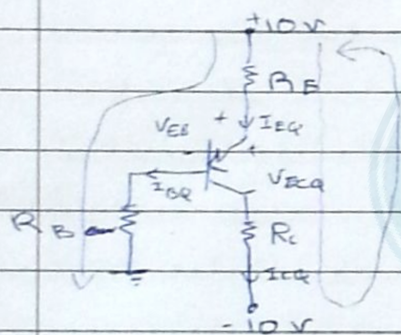
Ex: Given $V_{EB(ON)} = 0.7$ v

$\beta = 150$

$V_A = \infty \rightarrow r_o = \infty$

⇒ Draw DC & AC load lines.

⇒ DC analysis :-



input loop :- $-10 + R_E \underbrace{I_{EQ}}_{(1+\beta) I_{BQ}} + 0.7 + R_B I_{BQ} = 0$

⇒ $I_{BQ} = 5.96\ \mu A$.

⇒ $I_{CQ} = \beta I_{BQ} = 0.894$ mA

output loop :- $-10 + R_E I_{EQ} + V_{ECQ} + R_C I_{CQ} + -10 = 0$

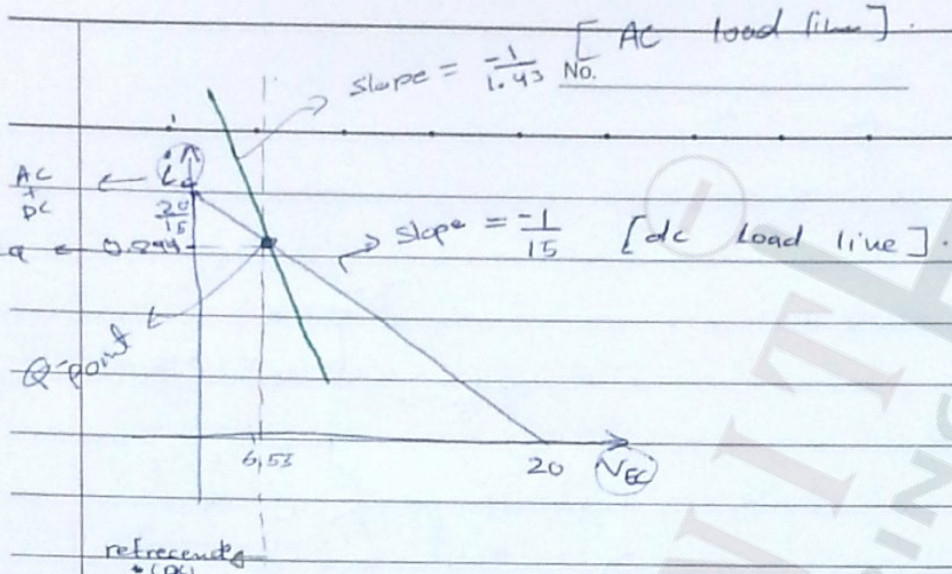
$V_{ECQ} = 6.53$ v.

→ DC load line : (I_C ∝ V_{EC})

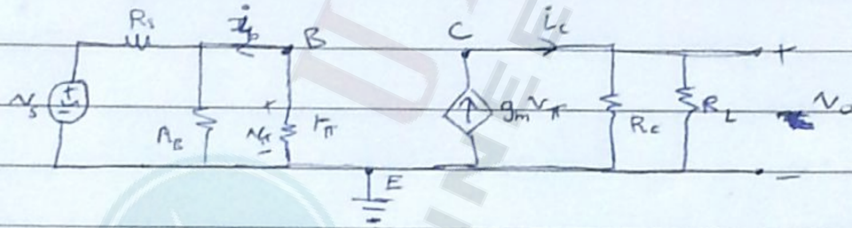
from output loop :- $-10 + R_E \underbrace{I_E}_{\frac{I_C}{\alpha}} + V_{EC} + R_C I_C - 10 = 0$

$$I_C \left[R_E \frac{(1+\beta)}{\beta} + R_C \right] = 20 - V_{EC}$$

$$\boxed{I_C = \frac{20}{R_E \frac{(1+\beta)}{\beta} + R_C} - \frac{1}{R_E \frac{(1+\beta)}{\beta} + R_C} V_{EC}}$$



AC analysis:



$r_\pi = \frac{V_T}{I_{BQ}} = 4.36\ K\Omega$

$g_m = \frac{I_{CQ}}{V_T} = 34.4\ mA/V$

AC load line - (i_c & V_{EC})

$$\boxed{i_c = -\frac{V_{EC}}{R_L // R_C}}$$

$$Slope = \frac{-1}{R_L // R_C}$$

⇒ AC load line (slope) ← اللي بصير عليها ال amplification

Note :-

The best value for $V_{CEQ} = \frac{V^+ - (V^-)}{2}$,

to get the Q point in the mide of forward active region.

(*) Common Collector Amplifier :- (CC amplifier)

Feature:-

① high R_i

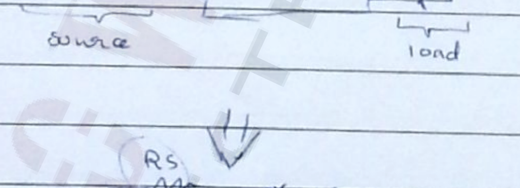
② Low R_o

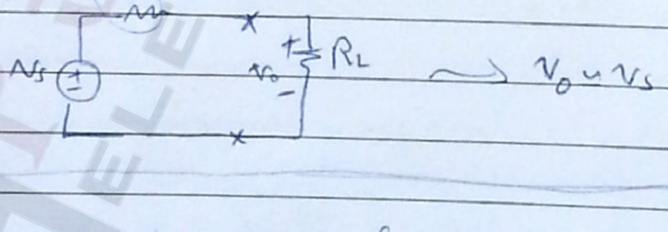
③ $V_o \approx V_s$ ($A_v \approx 1$)

④ Used as the output stage of multistage amplifier.

⑤ R_1 and R_2 should be very large to take the advantage of high R_{ib}. → $R_i = R_1 // R_2 // R_{ib}$

→ due to ① & ②, it is called impedance transformer. OR (buffer)





↓ or (emitter follower) → [the voltage at the emitter follows the input voltage in phase and magnitude].

POWER UNIT

Amplifiers

NoteBook

Dr. Ra'ed Al Zo'ubi
By: Lara Abu Sofa

بأفكارنا_نُبدع

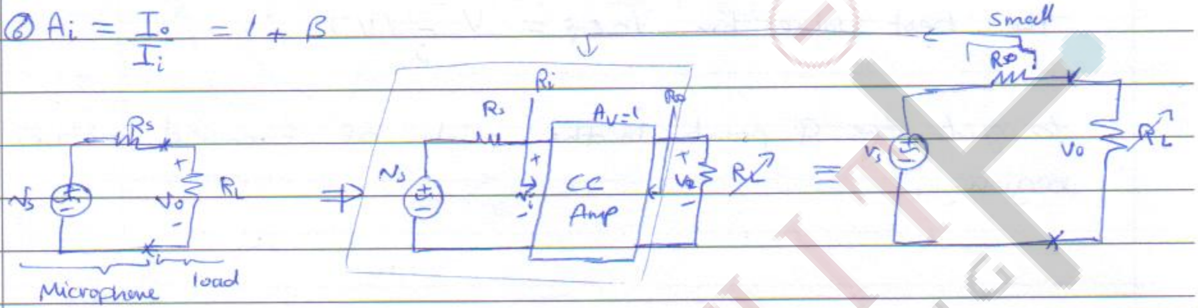
NoteBook

5th week

No.

[redacted]

⑥ $A_i = \frac{I_o}{I_i} = 1 + \beta$



R_i very high $V_i = V_o$ small $R_o \Rightarrow \boxed{V_o \simeq V_s}$

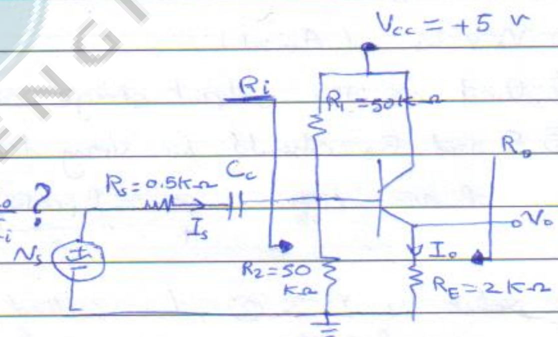
$V_o = V_s \frac{R_L}{R_L + R_s}$

Ex:-

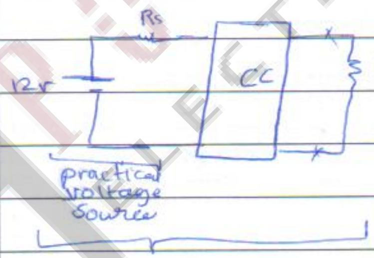
$\beta = 100$

$V_A = 80\ v$

find $A_v = \frac{V_o}{V_s}$, R_i, R_o, $A_i = \frac{I_o}{I_i}$?



Note ⇒ Practical to Ideal source (use CC Amp).



→ Ideal Voltage source

⇒ DC analysis:-

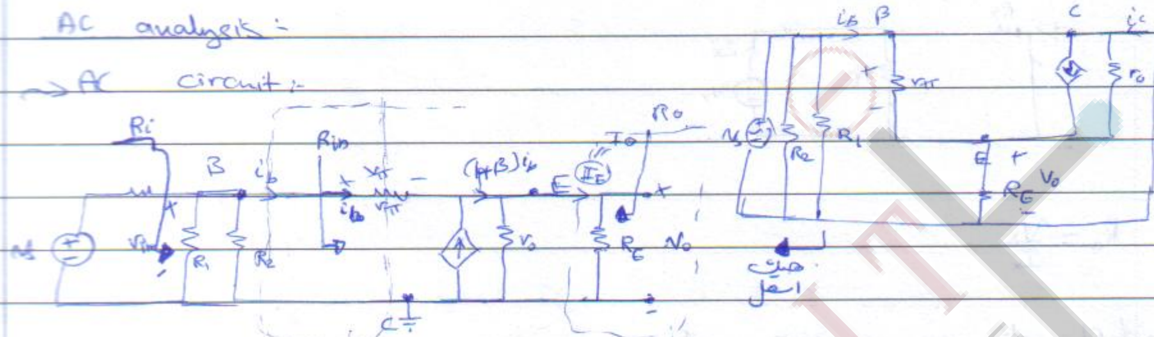
$I_{CQ} = 0.793$ mA

$V_{ECQ} = 3.4$ v

No.

AC analysis :-

→ AC circuit :-



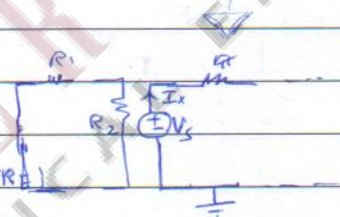
$r_\pi = \frac{\beta V_T}{I_{CQ}} = 3.28\ K\Omega$

$g_m = \frac{I_{CQ}}{V_T} = 30.5\ mA/V$

$r_o = \frac{V_A}{I_{CQ}} = 100\ K\Omega$

→ $R_i = R_1 // R_2 // R_{ib}$

→ $R_{ib} = \frac{V_x}{I_x}$



$-V_x + r_\pi I_x + (1+\beta) I_x (r_o // R_E) = 0$

$R_{ib} = \frac{V_x}{I_x} = r_\pi + (1+\beta)(r_o // R_E) = 201\ K\Omega$

$R_i = 22.2\ K\Omega$

→ (ونرجع ال cct الأصلية نشيل ال I_x و V_x ونرجع)

→ $A_v = \frac{V_o}{V_s}$

$V_{in} = V_s \cdot \frac{R_i}{R_i + R_s}$

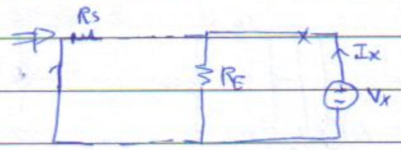
$i_b = \frac{V_{in}}{R_{ib}}$

$V_o = (1+\beta) i_b (r_o // R_E)$

⇒ $A_v = \frac{(1+\beta)(r_o // R_E)}{r_\pi + (1+\beta)(r_o // R_E)} \cdot \left(\frac{R_i}{R_i + R_s}\right) = 0.962 \simeq 1$

~> CH:4 Ex 4.12 (CC Amp)

No.



$R_o = \frac{V_x}{I_x}$

→ KCL at the emitter node:

$\sum i_{in} = \sum i_{out}$

$i_x + g_m v_\pi + \frac{v_\pi}{r_\pi} = \frac{V_x}{R_E} + \frac{V_x}{r_o}$

$v_\pi = -V_x \cdot \frac{r_\pi}{r_\pi + R_S // R_1 // R_2}$

$\Rightarrow R_o = \frac{V_x}{i_x} = \left(\frac{r_\pi + R_1 // R_2 // R_S}{1+\beta}\right) // R_E // r_o = 36.6\ \Omega$ small

~> $A_i = \frac{I_o}{I_s}$

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

$I_b = I_s \frac{R_1 // R_2}{R_{ib} + R_1 // R_2}$

$A_i = (1+\beta)\left(\frac{R_1 // R_2}{R_1 // R_2 + R_{ib}}\right)\left(\frac{r_o}{r_o + R_E}\right)$

$A_i \simeq (1+\beta)$ if $R_1 // R_2 \gg R_{ib}$

No.

Common Base Amplifier (CB) :-

Feature :-

① $A_v > 1$ (+ve value)

② $A_i \leq 1$ (α)

③ Used if the input signal is a current.

④ Small R_i

⑤ ~ high R_o

⑥ It looks almost like Ideal current Source.

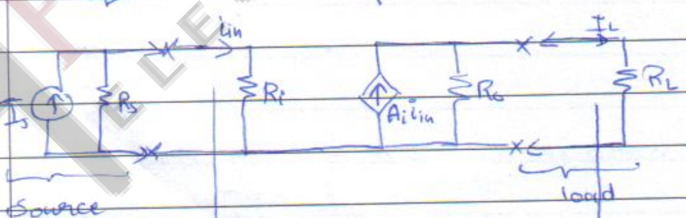
Note:- Any amplifier circuit can be represented by a two port network.

⇒ Voltage amplifier

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

$$V_L = V_i A V \frac{R_L}{R_L + R_o} \downarrow$$

⇒ Current amplifier



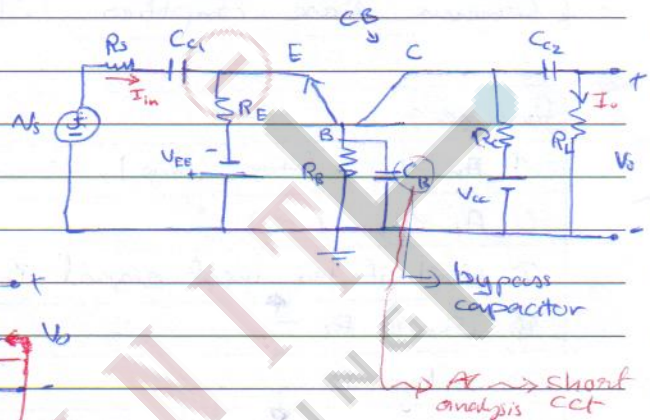
$$i_{in} = I_s \frac{R_s}{R_s + R_i}$$

$$I_L = A_i i_{in} * \frac{R_o}{R_o + R_L}$$

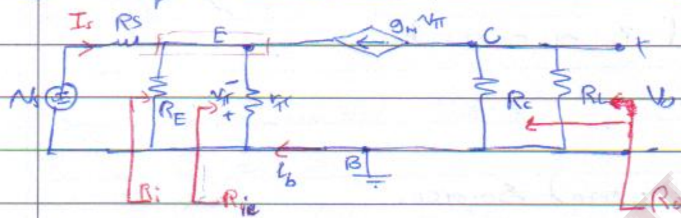
No.

Example :-

Find R_i, R_o, A_i, A_v ?



→ AC equivalent circuit :-



* $A_v = \frac{v_o}{v_s}$

$\Rightarrow v_o = -g_m v_\pi (R_c // R_L)$ ——— (1)

KCL at node E :-

$\Sigma i_{in} = \Sigma i_{out}$

$g_m v_\pi + \frac{v_\pi}{r_\pi} + \frac{v_\pi}{R_E} + \frac{v_s - (-v_\pi)}{R_s} = 0$ ——— (2)

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

→ $A_v = \frac{v_o}{v_s} = +g_m \left(\frac{R_c // R_L}{R_s}\right)\left[\left(\frac{r_\pi}{1+\beta}\right) // R_E // R_s\right]$

→ If $R_s \to 0\,\Omega$

$A_v \simeq +g_m (R_c // R_L)$

* $A_i = \frac{I_o}{I_s}$

$I_o = -g_m v_\pi \frac{R_c}{R_c + R_L}$ ——— (1)

KCL at node E :-

$I_s + g_m v_\pi + \frac{v_\pi}{R_E} + \frac{v_\pi}{r_\pi} = 0$ ——— (2)

No.

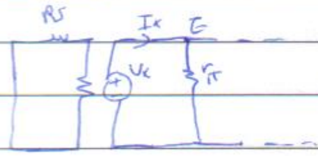
$$v_\pi = \frac{-I_s}{g_m + \frac{1}{R_C} + \frac{1}{r_\pi}}$$

$$\rightarrow A_i = g_m \left(\frac{R_C}{R_C + R_L}\right)\left[\left(\frac{r_\pi}{1+\beta}\right) \parallel R_E\right]$$

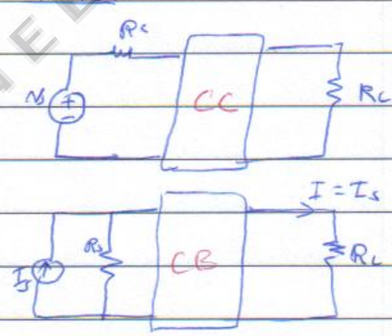
$\Rightarrow$ IF $R_E \to \infty$

$R_L \to 0$

$$\therefore A_i = \frac{g_m r_\pi}{1+\beta} = \frac{\beta}{1+\beta} = \alpha$$



Note:



$$R_i = R_E \parallel R_{ie}$$

$$R_{ie} = \frac{V_x}{I_x}$$

$\rightarrow$ KCL at E :-

$$I_x - \frac{V_x}{r_\pi} - g_m V_x = 0$$

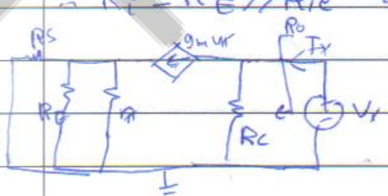
$$I_x = V_x\left(\frac{1}{r_\pi} + g_m\right)$$

$$= V_x\left(\frac{1+\beta}{r_\pi}\right)$$

$$\rightarrow R_{ie} = \frac{V_x}{I_x}$$

$$= \frac{r_\pi}{1+\beta}$$

$\therefore R_i = R_E \parallel R_{ie} \simeq R_{ie}$ (very small value).



$$R_o = \frac{V_x}{I_x}$$

KCL at E :- $g_m v_\pi + \frac{v_\pi}{r_\pi} + \frac{v_\pi}{R_E} + \frac{v_\pi}{R_S} = 0 \longrightarrow$

No.

$$v_\pi \left(g_m + \frac{1}{r_\pi} + \frac{1}{R_E} + \frac{1}{R_S} \right) = 0$$

$v_\pi = 0 \rightarrow g_m v_\pi = 0 \rightsquigarrow \boxed{R_O = R_C}$

Amplifiers

NoteBook

Dr. Ra'ed Al Zo'ubi
By: Lara Abu Sofa

بأفكارنا_نُبدع

NoteBook

6th Week

No.

$$v_\pi \left(g_m + \frac{1}{r_\pi} + \frac{1}{R_E} + \frac{1}{R_S} \right) = 0$$

$$v_\pi = 0 \rightarrow g_m v_\pi = 0 \quad \rightarrow \boxed{R_o = R_C}$$

(coupling capacit) DC analysis R_L + [illegible]

Multi-stage amplifier :

[illegible] coupling capacitor R_i stage [illegible] DC analysis stage [illegible]

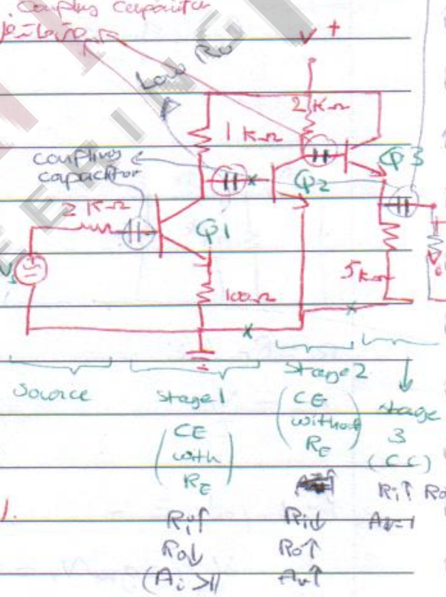
Ex :-

Given For Q1, Q2, Q3, $\beta = 100$

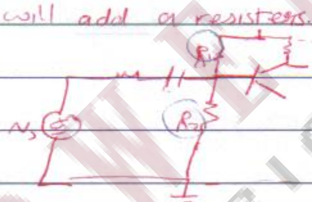
for Q1 $r_\pi = 1\ k\Omega$

for Q2, Q3 $r_\pi = 0.5\ k\Omega$

Find $A_v = \frac{v_o}{v_s}$?



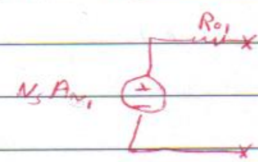
→ In DC analysis → $I_B = 0$ → so we will add a resisters. (If it was practical).



[illegible]

ANS :

⇒ Stage 1 CE with R_E



$\Rightarrow R_o = R_C = 1\ k\Omega$

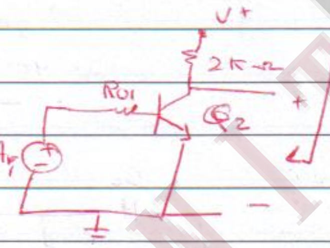
$$\Rightarrow A_{v1} = \frac{-\beta R_C}{r_\pi + (1+\beta) R_E} \left(\frac{R_i}{R_i + R_s} \right)$$

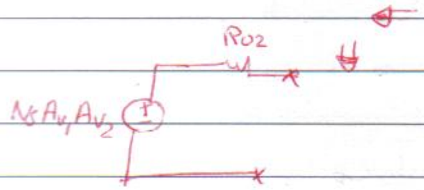
$$R_i = \underbrace{R_1 // R_2}_{\infty} // (r_\pi + (1+\beta) R_E) = r_\pi + (1+\beta) R_E$$

No.

$\Rightarrow A_{v_1} = -7.63$

$\Rightarrow$ stage 2 : (CE without R_E)

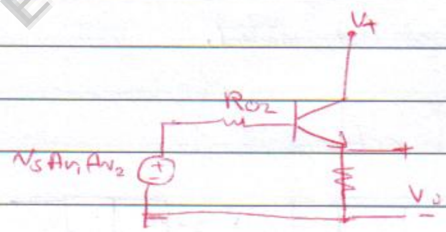




$R_{o_2} = r_o \,//\, R_c = R_c = 2\,k\Omega$
$r_o \to \infty$

$A_{v_2} = -g_m \left(\dfrac{R_1 // R_2 // r_\pi}{R_1 // R_2 // r_\pi + R_s} \right) (r_o // R_c) = -133$
$\infty \quad R_{o1} \quad \infty$

$\Rightarrow$ stage 3 : (CC)
$A_{v_3} = 1$



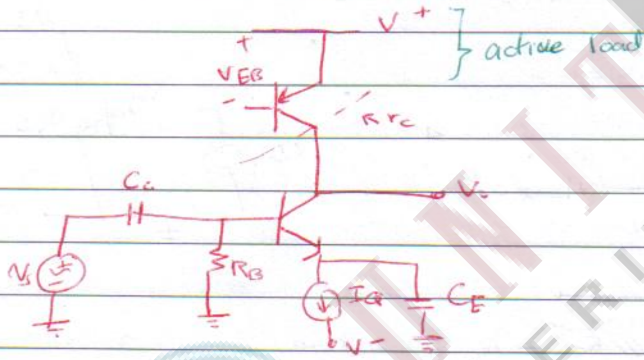
$V_o = (V_s A_{v_1} A_{v_2}) A_{v_3}$
$A_v = \dfrac{V_o}{V_s} = A_{v_1} A_{v_2} A_{v_3}$
$\boxed{A_v = +1010}$?

$\Rightarrow$ [A_v, R_o] → ← كل Stage بحسبولها
وآخر stage بنضربهم ببعض A_v.

No.

* Special Circuits :-

⇒ Advanced CE Amplifier using active load.



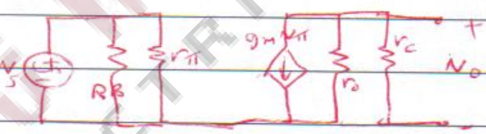
why do we use active load ?

① small size, so it can be used inside ICs.

② r_c is very high ⇒ A_v = very high value

③ Resistors will need bypass capacitor but active load does not need.

AC eq. cct :-



$\Rightarrow V_o = -g_m v_\pi (r_o // r_c)$

$\Rightarrow v_\pi = V_i$

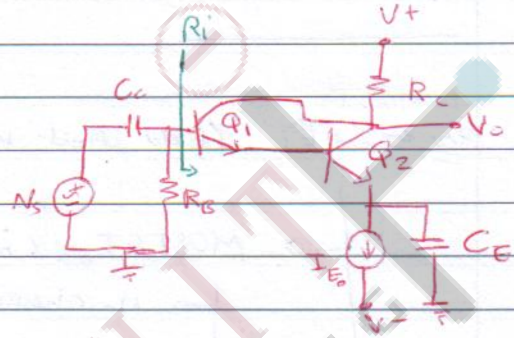
$\Rightarrow A_v = -g_m (r_o // r_c) \rightarrow$ high A_v

↑ First

No.

[illegible] analysis

⇒ Darlington pair circuit :-



→ Features:-

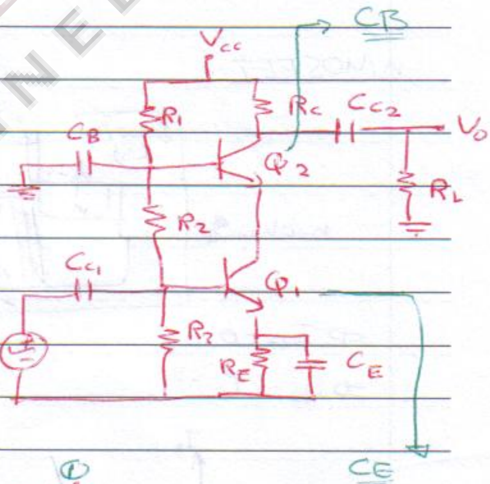
① high Current gain

$A_i \simeq \beta_1 \beta_2$

② Input resistance is large $(R_i \simeq 2\beta_1 r_{\pi_2})$

⇒ Cascode Configuration :-

(Cascade ← كل ما بين)



→ Features:-

CB has bandwidth wider than CE, but low input impedance of CB is a limitation for many applications.

⇒ but cascode configuration ~~has~~ has ① wide Bandwidth, ② moderatly high input impedance, high ③ output impedance, ④ high gain as CE.

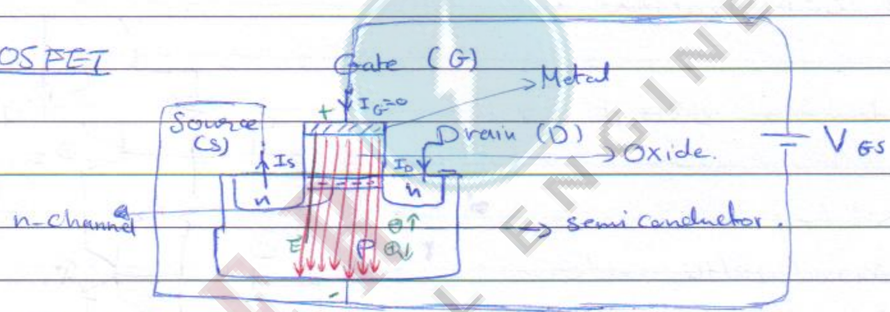
No.

FET Amplifiers :

Review : FET (field effect transistor)

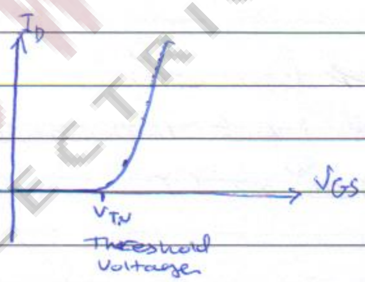
- ① MOSFET (metal - oxide semiconductor FET)
  - → n-channel MOSFET (nMOSFET) (enhancement, depletion)
  - → p-channel MOSFET (PMOSFET) (" , ").
- ② JFET (Junction FET).

nMOSFET

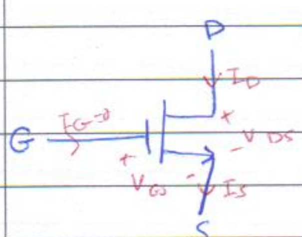


$\Rightarrow I_G = 0$

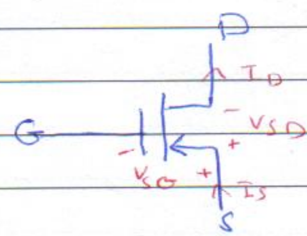
$\Rightarrow I_D = I_S$



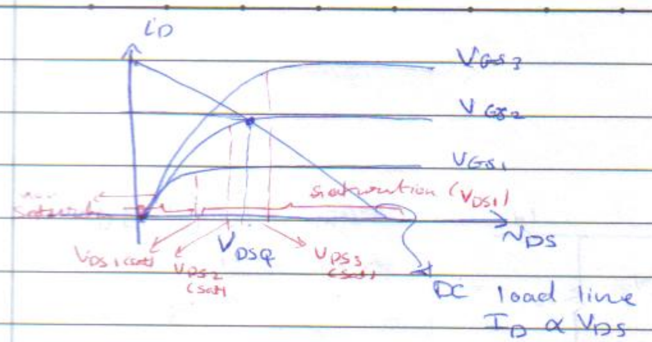
nMOSFET



pMOSFET



No.



→ كل curve ال $V_{DS(sat)}$ مختلف

⇒ MOSFET Amplifier configuration :

1. Common Gate
2. Common Source
3. Common Drain.

* Advantage of using MOSFET (compared with BJT).

1. Small size
2. low power dissipation.
3. high Input Impedance.

* But, g_m of MOSFET $\ll g_m$ of BJT.

$\Rightarrow A_{v(BJT)} \gg A_{v(FET)}$

* DC analysis:

$\Rightarrow I_G = 0$

$\Rightarrow I_D = I_S$

$\Rightarrow I_{DQ} = K_n (V_{GQ} - V_{TN})^2$

K_n: conduction parameter (mA/V2)

⇒ FET to work as amplifier, it should be in saturation mode

IF $V_{DS} > \boxed{V_{DS(sat)}}$, then FET is in saturation mode

$$V_{DS(sat)} = V_{GS} - V_{TN}$$

No.

FET Amplifiers :

Review : FET (field effect transistor)

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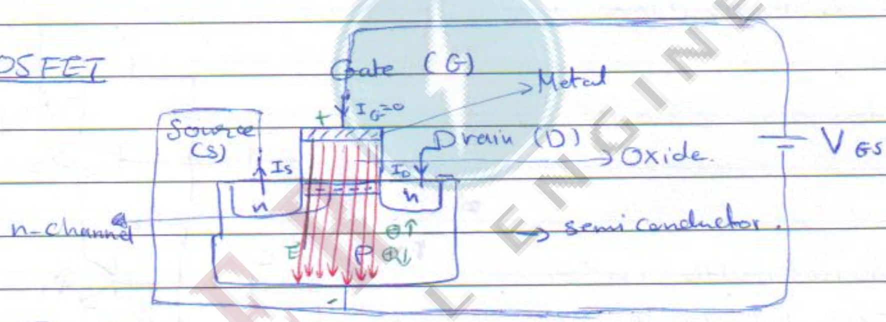
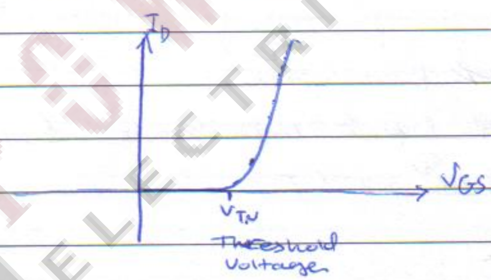
  - n-channel MOSFET (nMOSFET) (enhancement, depletion)
  - p-channel MOSFET (PMOSFET) (" , ").
- ② JFET (Junction FET).

nMOSFET

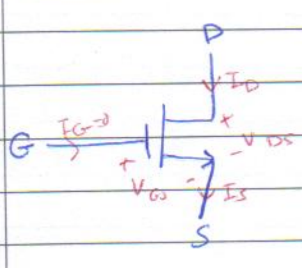


$\Rightarrow I_G = 0$

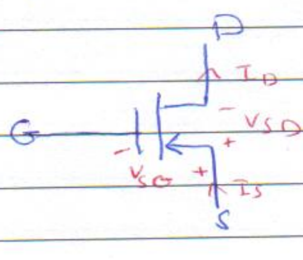
$\Rightarrow I_D = I_S$

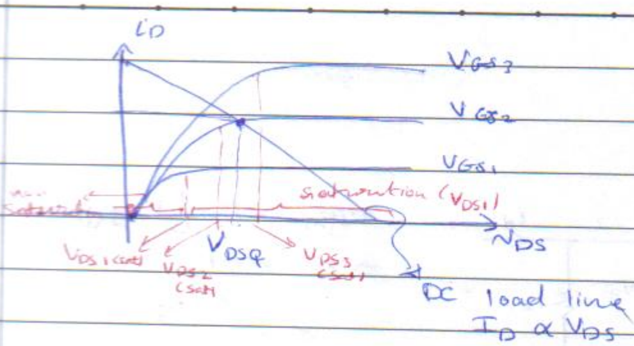


nMOSFET



pMOSFET





→ Calc $V_{DS(sat)}$ لكل curve

⇒ MOSFET Amplifier configuration :

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2. Common Source
3. Common Drain.

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  1. Small size
  2. low power dissipation
  3. high Input Impedance.

* But, g_m of MOSFET $\ll$ g_m of BJT.

$$\Rightarrow A_{v(BJT)} \gg A_{v(FET)}$$

* DC analysis :

⇒ $I_G = 0$

⇒ $I_D = I_S$

⇒ $I_{DQ} = K_n (V_{GQ} - V_{TN})^2$

K_n : conduction parameter (mA/V^2)

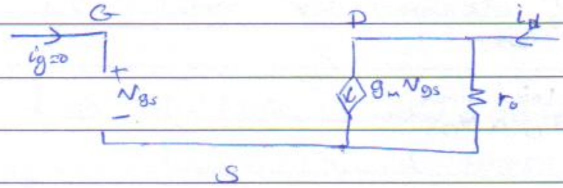
⇒ FET to work as amplifier , it should be in saturation mode
IF $V_{DS} > \boxed{V_{DS(sat)}}$, then FET is in saturation mode

$$V_{DS(sat)} = V_{GS} - V_{TN}$$

No.

* AC analysis :

nMOS

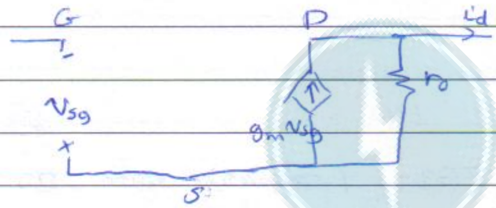


$\Rightarrow g_m = 2K_n\left[V_{GSQ} - V_{TN}\right]$

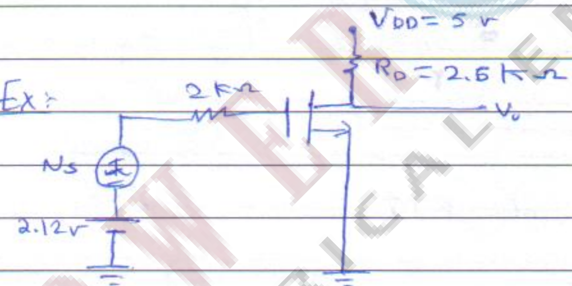
$\Rightarrow r_o = \dfrac{1}{\lambda I_{DQ}}$

λ: the channel length modulation parameter (Positive value) (V^{-1})

pMOS



Ex :



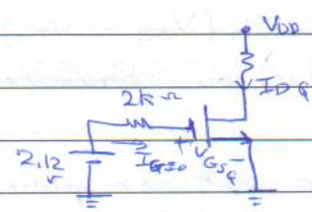
(Common source amplifier)

$V_{TN} = 1\ v$, $K_n = 0.8\ mA/v^2$

$\lambda = 0.02$

Find $A_v = \dfrac{v_o}{v_s}$?

* DC analysis



Input loop :

$V_{GSQ} = 2.12\ v$

No.

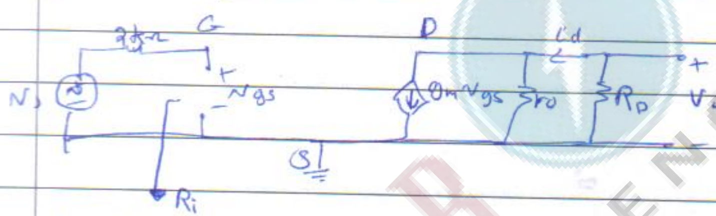
$\Rightarrow I_{DQ} = K_n(V_{GSQ} - V_{TN})^2$
$= 1\ mA$

$\Rightarrow$ Output loop :-

$-5 + 2.5\, I_{DQ} + V_{DSQ}$
$V_{DSQ} = 2.5\ v$

$\Rightarrow V_{DS(sat)} = V_{GSQ} - V_{TN} = 2.12 - 1 = 1.12\ v$
$\therefore V_{DSQ} > V_{DS(sat)} \rightarrow$ saturation mode

* AC analysis :



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

$g_m = 2K_n(V_{GSQ} - V_{TN})$
$= 1.079\ mA/v$

$V_o = -g_m V_{gs}(R_D // r_o)$
$V_{gs} = V_s$
$\therefore A_v = -g_m (R_D // r_o)$

$r_o = \frac{1}{\lambda I_{DQ}} = 50\ k\Omega$

$\boxed{A_v = -4.26}$
$\rightarrow$ phase shift between V_s and $V_o = 180°$.

$R_i = \infty$
$R_o = R_D // r_o$