



Islamic University of Gaza
Faculty of Engineering
Electrical Engineering Department

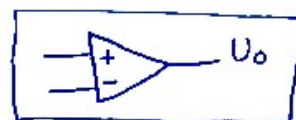
Summary of:
“ Electronic Circuits (2) “

By:
“ Muhammad Hashim Iyad Jabr “

ما كان به صواباً فمن الله، وإن كان هناك خطأ فمني ومن الشيطان..

Ch8: (Op-Amp)

Electronics II
Huh Jabr



$$V_{out} = A_o (V_{in}^+ - V_{in}^-)$$

open loop gain

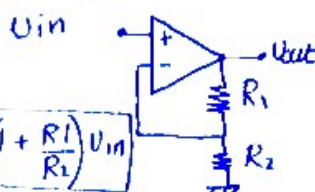
** Op-amp based circuits:

① unity gain (buffer)



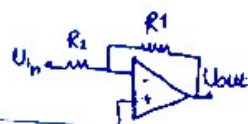
$$V_{out} = \left(\frac{A_o}{1 + A_o} \right) V_{in}$$

② non-inverting



$$V_{out} \approx \left(1 + \frac{R_1}{R_2} \right) V_{in}$$

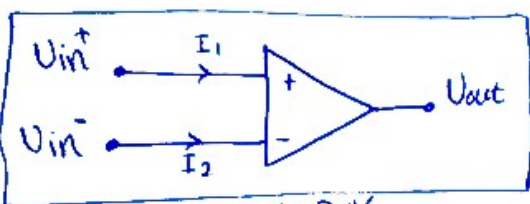
③ inverting



$$V_{out} \approx \left(-\frac{R_1}{R_2} \right) V_{in}$$

op-amp ideal op-amp

valid for ideal op-amp



BACK BOX

$$\begin{aligned} V_{in}^+ &= V_{in}^- \\ I_1 &= I_2 = 0 \end{aligned}$$

black box

terminology

* the nominal gain for the circuit = V_o/V_i
Op Amp = A_o

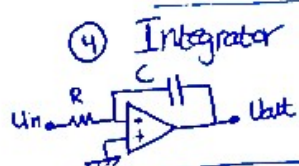
خارجة عن النطاق

* the closed loop gain = V_o/V_i , the open loop gain = A_o

قلم

"out of the scope of this course" تعبر، error gain error

** Continue to the op-amp based circuits:

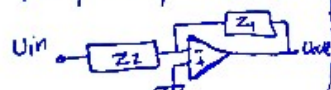


$$V_{out} = \left(\frac{-1}{RCs} \right) V_{in}$$

$$V_{out} = -\frac{1}{RC} \int u_{in} dt$$

$$\text{Pole frequency} = S_p = \frac{-1}{(A_o + 1) RC}$$

to generalize it for multiple impedances



$$V_{out} \approx \left(-\frac{Z_1}{Z_2} \right) V_{in}$$

⑤ Differentiator

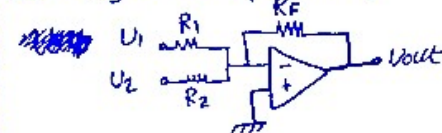


$$V_{out} = (-RC) \frac{dV_{in}}{dt}$$

$$V_{out} = -RC \frac{dV_{in}}{dt}$$

$$\text{pole frequency} = S_p = \frac{A_o + 1}{RC}$$

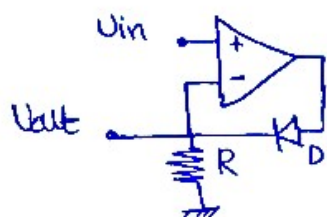
⑥ Voltage adder (summer)



$$V_{out} = -R_F \left(\frac{U_1}{R_1} + \frac{U_2}{R_2} + \dots + \frac{U_n}{R_n} \right)$$

** Non-linear op-amp based circuits :

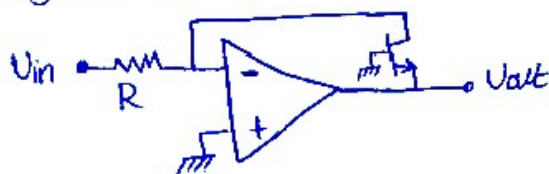
① precision rectifier



• Apparently

$$U_{out} = \begin{cases} U_{in}, & U_{in} \geq 0 \\ 0, & U_{in} < 0 \end{cases}$$

② Logarithmic amplifier



$$V_{out} = -V_T \ln\left(\frac{V_{in}}{R I_s}\right)$$

يتوقع الدلتور ~~غير~~ غير لهم (فقط للمعرفة تم سرحا)

{ DC offset
 speed limitation
 Input bias current $\rightarrow$ $\bar{V}_{in}$ $\bar{V}_{out}$ *

(Modeling of the op-amp)

⇒ فائدة مهمة جدًا :

$$V_{\text{out}} = A_o (V_{\text{in}^+} - V_{\text{in}^-})$$

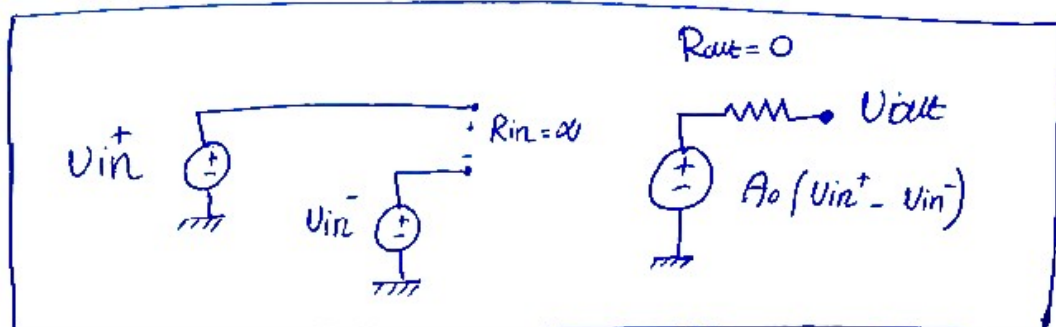
① تعني استعمال ال op-amp عنصر جبرده ففقهه كمدسه

op-amp exhibits a finite input impedance

so we set R_{in} between the the + & - terminals of the op-amp !!

Vote yes, if, we are happy: finish despite impedance 391 e 32 units,

⇒ General model (ideal model)



و یفیدل یم R_{att} ، R_{in} Σ عدد استوار

...میں

an, dan, je

(design) * في مسجل 1

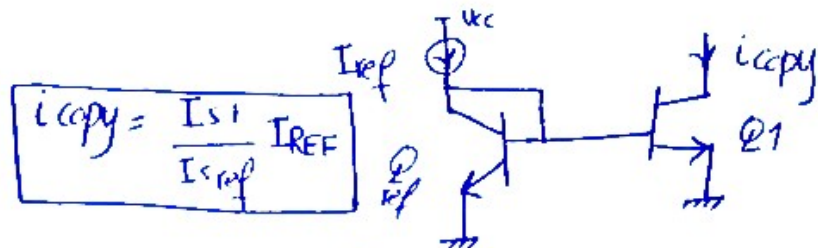
$$\Rightarrow I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{gs} - V_{th})^2$$

$$\Rightarrow V_{ov} = V_{gs} - V_{th}$$

$$\Rightarrow g_m = \frac{2 I_D}{V_{ov}}$$

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

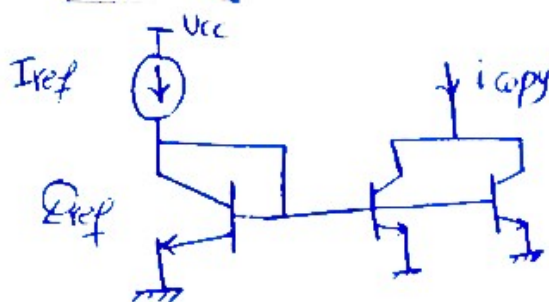
* Current mirror



$$i_{copy} = \frac{I_{s1}}{I_{sref}} I_{REF}$$

[انواع Copies]

larger copies of I_REF

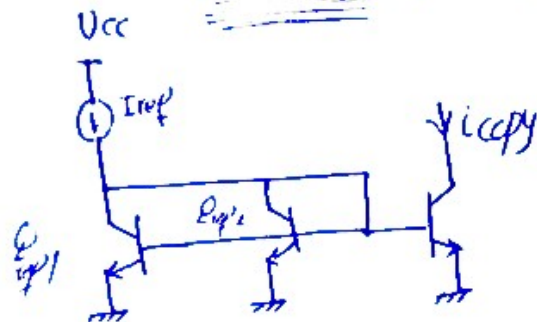


$$i_{copy} = N I_{ref}$$

Copied BJTs, N, as N sup

$$N = \frac{\text{number of copies}}{\text{number of ref}}$$

Fraction copies of I_REF



$$i_{copy} = \frac{1}{N} I_{ref}$$

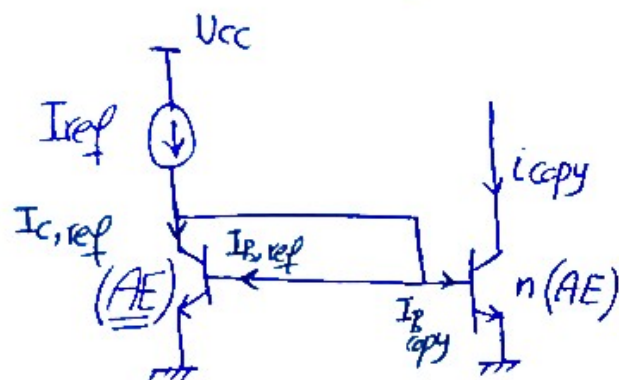
ref BJTs, 1/N, as N sup

* ملاحظة مهمة جداً: يجب السؤال اعتماد وجود base current

$$I_{B, copy} = \frac{i_{copy}}{\beta}$$

$$I_{B, ref} = \frac{I_{C, ref}}{\beta}$$

$$i_{copy} = I_{C, ref} n$$



PNP نوع آخر

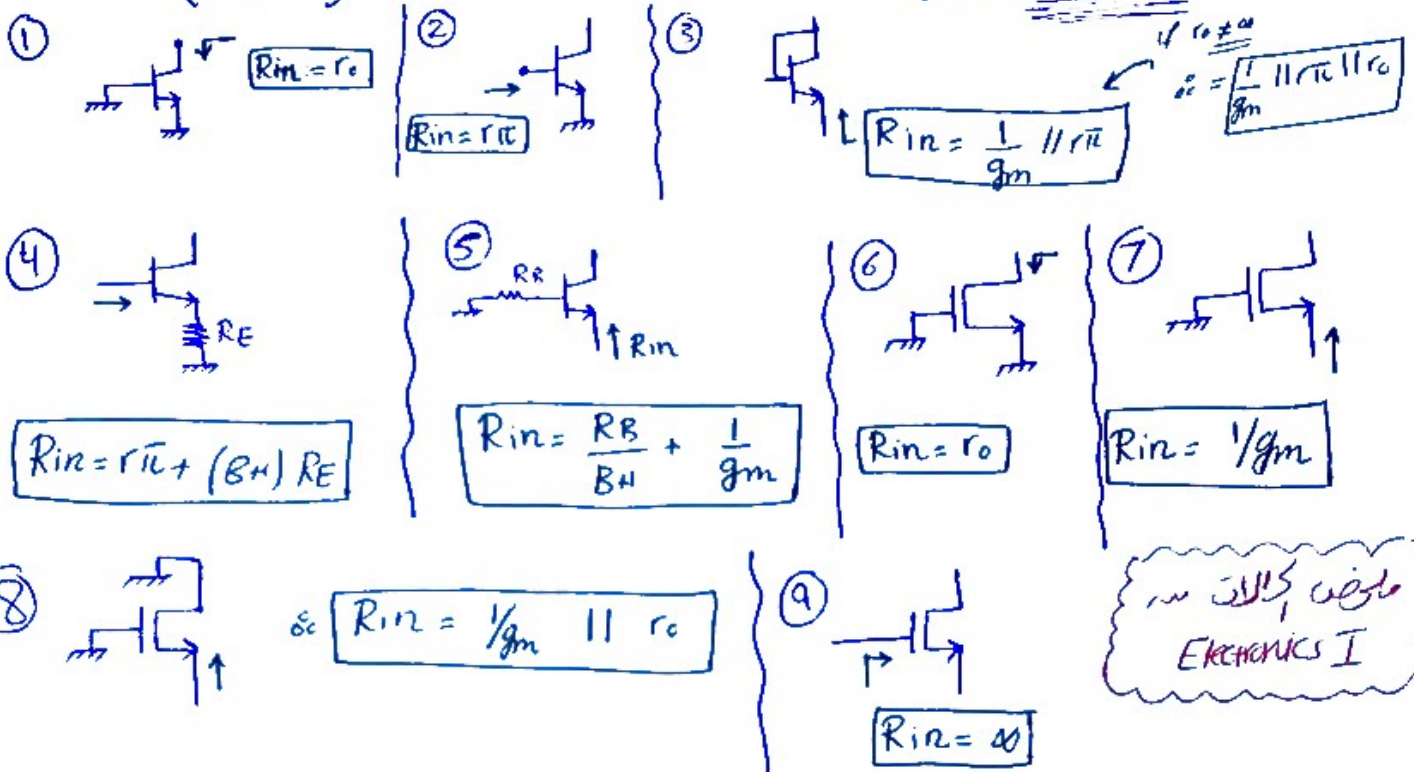
→ For MOSFET



(larger/fraction copies) نوع آخر

$$i_{copy} = \frac{(W/L)_{copy}}{(W/L)_{ref}} i_{ref}$$

* أشكال مسؤورة لـ لـ Cascade stage (Rout) حساب



← ملاحظة مهمة جداً: تلك الأشكال فقط لـ Cascade stage حيث أن لكل
استخدام small signal model هو الأساسي، بغالب هنا ...
تمام !!

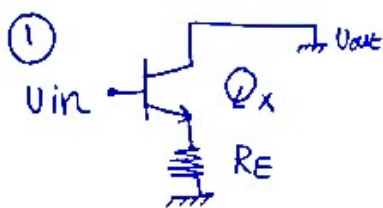
* AU

$$A_U = - G_m R_{out}$$

- يتم حساب Rout بالقانون المذكور سابقاً

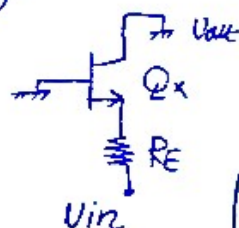
$$G_m = \frac{i_{out}}{v_{in}} \Big|_{v_{out} = 0}$$

- يتم حساب Gm من طرفي:



$$G_m = \frac{g_{m_x}}{1 + g_{m_x} R_E}$$

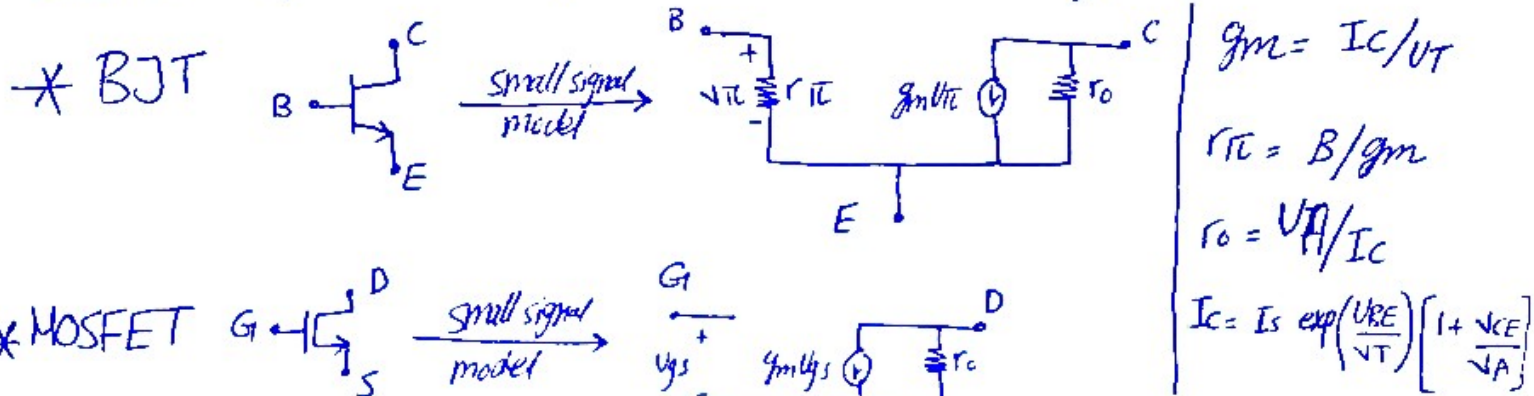
②



$$G_m = \frac{g_{m_x}}{1 - g_{m_x} R_E}$$

* أشكال مسؤورة في حساب Gm:

Ch9: (Cascode stages and current mirrors)



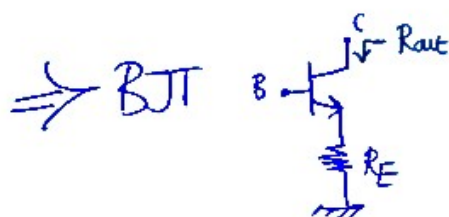
$$I_{D_{sat}} = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{th})^2 (1 + \lambda V_{DS})$$

$$r_o = \frac{1}{\lambda I_D}, \quad g_m = \begin{cases} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{th}) \\ 2 I_D / (V_{GS} - V_{th}) \\ \sqrt{2 I_D \mu_n C_{ox} \frac{W}{L}} \end{cases}$$

فقط للتذكير فقط small signal model سائرنا في Ch9 و Ch10 بشكل كبير

* R_{out}

(القانون العام في الساتر)



$$R_{out} = (1 + g_m r_o) (R_E \parallel r_{\pi}) + r_o$$



$$R_{out} = (1 + g_m r_o) R_S + r_o$$

عنه تلك هي اهم قوانينه (Ch9) ونحن * 50 ~ فهم الساتر

* Test your understanding: Find P_{o1} & P_{o2}

∞ ideal op-amp 1

∞ $i_x = i_y = 0$ & $U_x = U_y$

since $i_x = 0 \Rightarrow U_x = 10 \left(\frac{4}{4+4} \right) = \boxed{5V}$
by voltage divider

∞ $U_y = 5V$ hence, $i_x = \frac{12 - U_y}{4} = \frac{7}{4}A$

∞ $i_x = 1,75A$

since $i_y = 0 \Rightarrow \frac{U_y - U_{o1}}{40} = i_x$

∞ $U_{o1} = -(40 i_x) + U_y = -70 + 5$

∞ $U_{o1} = -65V$

∞ ideal op-amp 2

∞ $i_z = i_k = 0$ & $U_z = U_k$

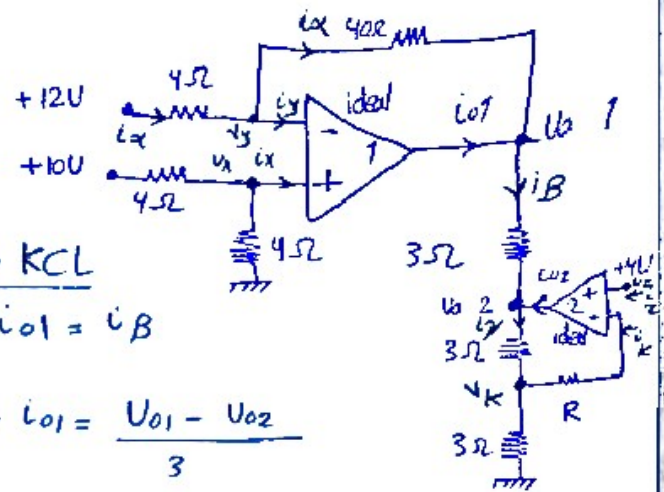
since $i_k = 0$ ∞ no current passes through R

hence $U_k = U_z = 4V$

from voltage divider $U_k = U_{o2} \frac{3}{3+3}$

∞ $U_{o2} = 2 U_k = 8V$

∞ $U_{o2} = 8V$



from KCL

$i_x + i_{o1} = i_B$

$1,75 + i_{o1} = \frac{U_{o1} - U_{o2}}{3}$

$i_{o1} = \frac{-65 - 8}{3} - 1,75 = -\frac{313}{12}$

∞ $i_{o1} = -\frac{313}{12} = -26,0833A$

from KCL

$i_B + i_{o2} = i_z$

$\frac{U_{o1} - U_{o2}}{3} + i_{o2} = \frac{U_{o2} - 0}{6}$ (GND)

$i_{o2} = \frac{77}{3} = 25,6666A$

∞ therefore

$\Rightarrow P_{o1} = i_{o1} U_{o1} = (-65) \cdot \left(-\frac{313}{12} \right)$

∞ $P_{o1} = \frac{20345}{12} = 1695,4166W$

$\Rightarrow P_{o2} = i_{o2} U_{o2} = (8) \cdot \left(\frac{77}{3} \right)$

$P_{o2} = \frac{616}{3} = 205,3333W$

* Test your understanding: Find R , i_o , P_o ?
if $V_{out} = \frac{600}{331} V$

Solution

∵ the op-amp is ideal

$$\& V_{in}^+ = V_{in}^- \& I_A = I_B = 0$$

$$\& V_{in}^- = V_{out} \& V_{in}^+ = 400 I_1$$

$$\& \frac{600}{331} = 400 I_1 \Rightarrow I_1 = 4,5317 \text{ mA}$$

$$\& I_B = 0 \& V_X = (20 + 400) I_1 = 1,9033 \text{ V}$$

now $I = I_1 + I_2$ from KCL

$$\text{but } I = \frac{V_{in} - V_X}{20} = \frac{2 - 1,9033}{20}$$

$$\& I = 4,8338 \text{ mA}$$

$$\text{hence, } I_2 = 302,1148 \mu A$$

∵ to find R

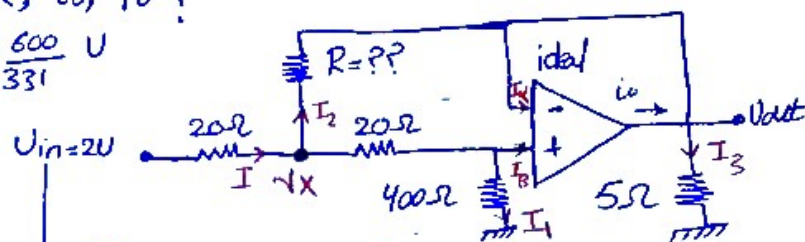
$$\frac{V_X - V_{out}}{R} = I_2$$

$$\& R = \frac{V_X - V_{out}}{I_2} = \frac{1,9033 - 600/331}{302,1148 \mu A}$$

$$R = 300 \Omega$$

* ملاحظة مهمة / الدقة دقيقة جداً لهذا أنه يجب أن نكتب في مقترع
مع كلمة يعني كحد 10 أرقام بعد الفاصلة
لذلك يمكن كتابة المقاومة تكون أقل / أكثر قليل

$$\text{tolerance} = \pm 10\% \quad \text{معنى / كذا
نسبة كذا
في حساباتك}$$



from KCL

$$i_o + I_2 = I_3$$

$$\& i_o = I_3 - I_2$$

$$= \frac{600/331}{5} - 302,1148 \mu A$$

$$\& i_o = \frac{1199}{3310} = 362,2356 \text{ mA}$$

now

$$P_o = i_o V_o$$

$$= (362,2356 \text{ mA}) \cdot \frac{600}{331}$$

$$\& P_o = 656,6205128 \text{ mW}$$

* Test your understanding:

→ Find R and w for all transistors, given:

$$I_{REF} = 20 \mu A, I_1 = 100 \mu A, I_2 = I_3 = 20 \mu A$$

$$I_4 = 50 \mu A, U_{DD} = 2.5 V, W_{ref} = 10 \mu m, L = 0.5 \mu m$$

$$M_n C_{ox} = 200 \mu A/V^2, M_p C_{ox} = 80 \mu A/V^2, U_{thN} = .4 V, U_{thp} = -.4 V, U_{ov2} = U_{ov3}$$

Assume L is fixed for all transistors!

Solution

$$I_1 = \frac{(w/L)_1}{(w/L)_{ref}} I_{ref}$$

$$100 \mu = \frac{w_1}{10 \mu} 20 \mu$$

$$\Rightarrow \boxed{w_1 = 50 \mu m}$$

$$I_2 = \frac{(w/L)_2}{(w/L)_{ref}} I_{ref}$$

$$20 \mu = \frac{w_2}{10 \mu} 20 \mu$$

$$\Rightarrow \boxed{w_2 = 10 \mu m}$$

From the circuit (given already)

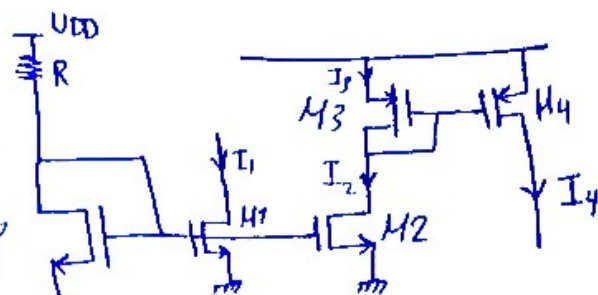
$$I_2 = I_3$$

$$\frac{1}{2} M_n C_{ox} \left(\frac{w}{L}\right)_2 U_{ov2}^2 = \frac{1}{2} M_p C_{ox} \left(\frac{w}{L}\right)_3 U_{ov3}^2$$

$$\Rightarrow U_{ov2} = U_{ov3}$$

$$\Rightarrow 200 w_2 = 80 w_3, \text{ but } w_2 = 10$$

$$\Rightarrow \boxed{w_3 = 25 \mu m}$$



$$I_4 = \frac{(w/L)_4}{(w/L)_3} I_3$$

$$50 \mu = \frac{w_4}{w_3} 20 \mu, \quad \underline{w_3 = 25}$$

$$\Rightarrow \boxed{w_4 = 62.5 \mu m}$$

$$\Rightarrow \boxed{R = \frac{U_{DD} - U_{gs,ref}}{I_{ref}}}$$

$$I_{ref} = \frac{1}{2} M_n C_{ox} \left(\frac{w}{L}\right)_{ref} (U_{gs,ref} - U_{thN})^2$$

$$U_{gs,ref} = U_{thN} + \sqrt{\frac{2 I_{ref}}{M_n C_{ox} (w/L)_{ref}}}$$

$$\boxed{U_{gs,ref} = .5 V}$$

$$\Rightarrow R = \frac{2.5 - .5}{20 \mu}$$

$$\boxed{R = 100 K \Omega}$$

OK, I F

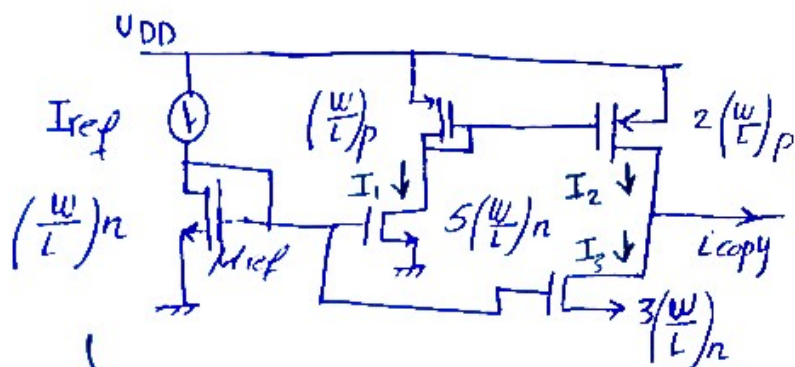
* Test your understanding:

find i copy!

$$I_1 = \frac{5}{1} I_{ref}$$

$$I_2 = 2 I_1 = 10 I_{ref}$$

$$I_3 = \frac{3}{1} I_{ref}$$



from KCL

$$i_{copy} = I_2 - I_3 = 7 I_{ref}$$

* Test your understanding:

$A_V = 15, I_D = 250 \mu A$
 $\lambda_N = 0.5 V^{-1}, \mu_n C_{ox} = 100 \mu A/V^2$
 $\lambda_P = 0.5 V^{-1}, \mu_p C_{ox} = 40 \mu A/V^2$

Solution

$$A_V = 15$$

$$\rightarrow A_V = -G_m R_{out}$$

$$\text{but } G_m = g_{m2}$$

$$R_{out} = r_{o1} \parallel r_{o2}$$

by inspection

$$\& |A_V| = |g_{m2} (r_{o1} \parallel r_{o2})|$$

$$\text{but } g_{m2} = \frac{2 I_D}{V_{ov}} \quad \text{--- (1)}$$

$$\& V_{ov} = \frac{2 I_D}{g_{m2}}$$

$$r_o = \frac{1}{\lambda I_D} \quad \text{--- (2)}$$

$$\& |A_V| = \frac{2 I_D}{V_{ov}} \left(\frac{1}{\lambda_N I_D} \parallel \frac{1}{\lambda_P I_D} \right)$$

معادله 1 و معادله 2 را در هم میزنیم

$$\& V_{ov} = \frac{2}{3} V$$

since $V_{ov1} = V_{ov2} = V_{ov}$

$$\& V_{ov1} = V_{ov2} = \frac{2}{3} V$$

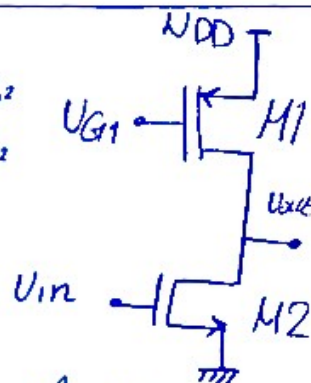
$$\& I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} V_{ov}^2$$

$$\& I_{D1} = I_{D2} \quad \left(\begin{array}{l} \text{from} \\ \text{the} \\ \text{circuit} \end{array} \right)$$

for M1

$$I_D = \frac{1}{2} \mu_p C_{ox} \left(\frac{W}{L} \right)_1 (V_{ov})^2$$

$$\& \left(\frac{W}{L} \right)_1 = 28,125$$

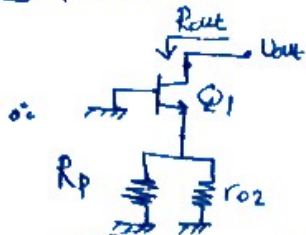
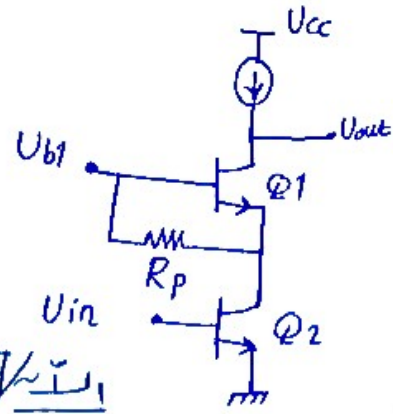
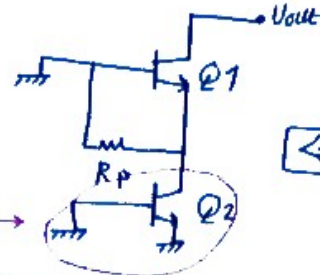
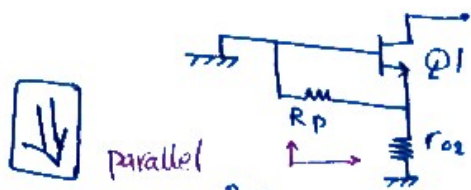


Similarly for M2

$$\left(\frac{W}{L} \right)_2 = 11,25$$

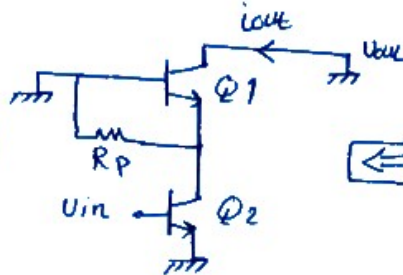
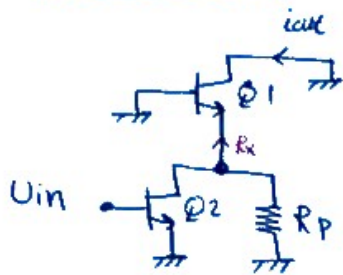
*Test your understanding: find A_v !

→ in R_{out} Calculations, V_{in} is shorted, so are U_{b1} & V_{cc}

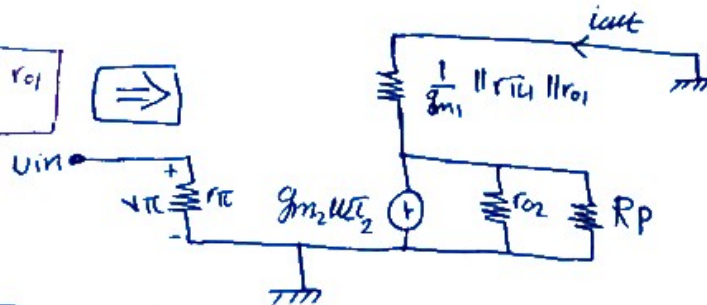


$$R_{out} = (1 + g_{m1} r_{o1}) (R_p \parallel r_{o2} \parallel r_{\pi 1}) + r_{o1}$$

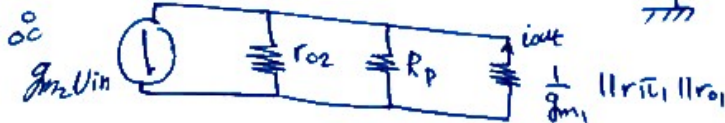
→ in G_m Calculations, V_{out} is shorted, so are U_{b1} & V_{cc}



but $R_x = \frac{1}{g_{m1}} \parallel r_{\pi 1} \parallel r_{o1}$



hence $V_{\pi 2} = V_{in}$



by current divider

$$i_{out} = g_{m2} V_{in} \frac{(r_{o2} \parallel R_p)}{(r_{o2} \parallel R_p) + \left(\frac{1}{g_{m1}} \parallel r_{\pi 1} \parallel r_{o1} \right)}$$

$$G_m = g_{m2} \frac{(r_{o2} \parallel R_p)}{(r_{o2} \parallel R_p) + \left(\frac{1}{g_{m1}} \parallel r_{\pi 1} \parallel r_{o1} \right)}$$

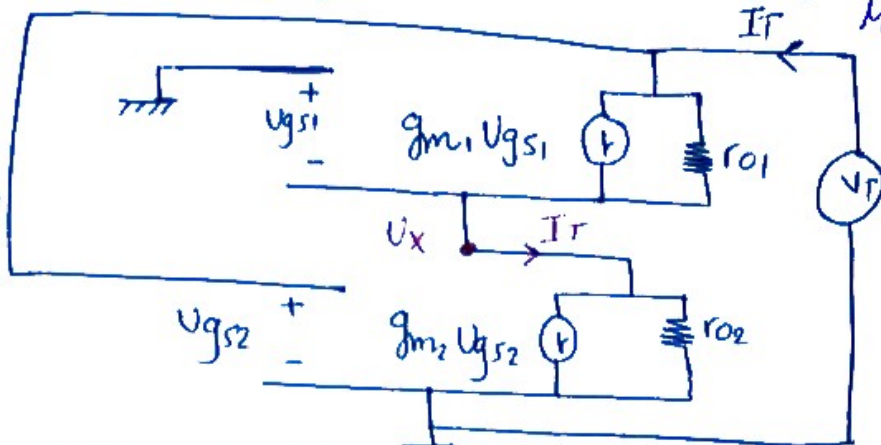
therefore, $A_v = -G_m R_{out} = - \left[(1 + g_{m1} r_{o1}) (R_p \parallel r_{o2} \parallel r_{\pi 1}) + r_{o1} \right] \left[\frac{g_{m2} (r_{o2} \parallel R_p)}{(r_{o2} \parallel R_p) + \left(\frac{1}{g_{m1}} \parallel r_{\pi 1} \parallel r_{o1} \right)} \right]$

* Test your understanding: Find R_{out} !

By drawing the small signal model for the circuit!

then,
by applying V_T

$$R_{out} = V_T / I_T$$



by KCL

$$\circ I_T = \frac{V_T - V_x}{r_{o1}} + g_{m1} V_{gs1} \quad (*)$$

but $V_x = (I_T - g_{m2} V_{gs2}) r_{o2}$... by subs in $(*)$

$$\circ I_T = \frac{V_T}{r_{o1}} - \frac{(I_T - g_{m2} V_{gs2}) r_{o2}}{r_{o1}} + g_{m1} V_{gs1}$$

but $V_{gs2} = V_T$, $V_{gs1} = V_{g1} - V_{s1} = 0 - V_x = -V_x$

$$\circ I_T = \frac{V_T}{r_{o1}} - \frac{I_T r_{o2}}{r_{o1}} + \frac{g_{m2} V_T r_{o2}}{r_{o1}} - g_{m1} V_x \quad (**)$$

since $V_x = (I_T - g_{m2} V_{gs2}) r_{o2}$, $V_{gs2} = V_T$

$\circ -V_x = (g_{m2} V_T - I_T) r_{o2}$ by subs in $(**)$

$$\circ I_T = \frac{V_T}{r_{o1}} - \frac{I_T r_{o2}}{r_{o1}} + \frac{g_{m2} V_T r_{o2}}{r_{o1}} + g_{m1} [(g_{m2} V_T - I_T) r_{o2}]$$

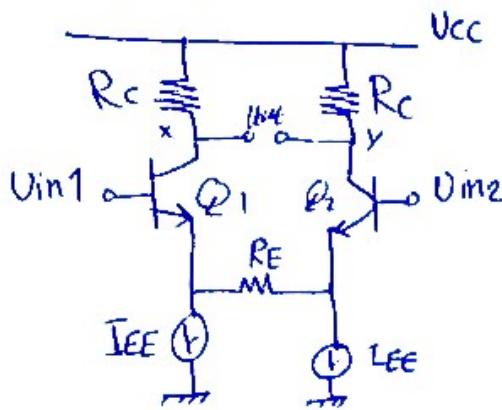
$$\circ I_T \left(1 + \frac{r_{o2}}{r_{o1}} + g_{m1} r_{o2} \right) = V_T \left(\frac{1}{r_{o1}} + g_{m2} \frac{r_{o2}}{r_{o1}} + g_{m1} g_{m2} r_{o2} \right)$$

$$\circ \frac{V_T}{I_T} = R_{out} = \frac{1 + \frac{r_{o2}}{r_{o1}} + g_{m1} r_{o2}}{\frac{1}{r_{o1}} + g_{m2} \frac{r_{o2}}{r_{o1}} + g_{m1} g_{m2} r_{o2}}$$

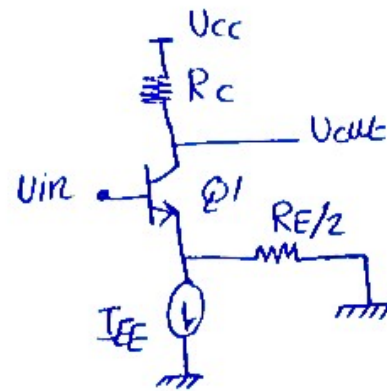
Ch 10 : (Differential Amplifiers)

* نفس مشابتر 9 قما . حفظ فتاح لتفريق قاعدة , Half circuit
والهدف هو حساب V_{out} للدارة

* BJT differential pair

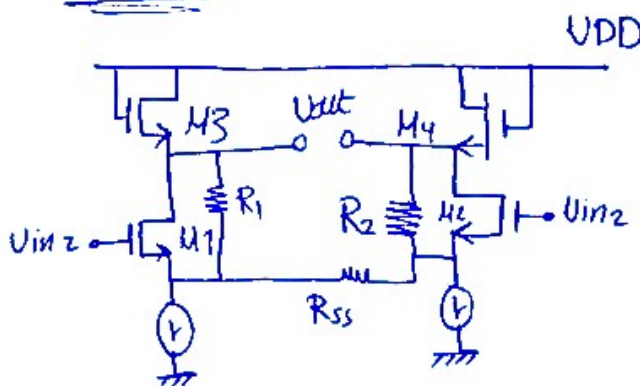


by
half circuit

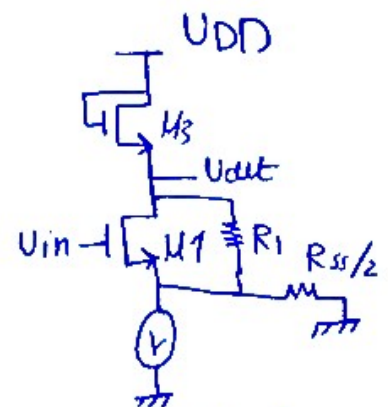


نفس لكل مشابتر 9

* MOS differential pair



by
half circuit



قما 5!!

نفس لكل مشابتر 9

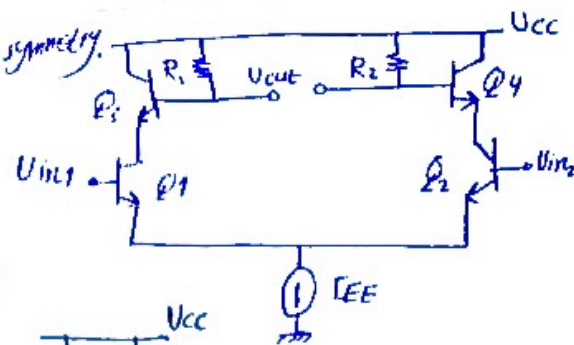
* نقطة جديدة وهي حساب A_{cm} (Common mode gain)

في حساب A_{cm} ، نوجد V_{out} ، V_{in} ، V_{out1} ، V_{in1} ، V_{out2} ، V_{in2} .
نقطة واحدة نسمى $V_{in,cm}$ ، لذلك V_{out1} ، V_{out2} نسميها $V_{out,cm}$

okay?

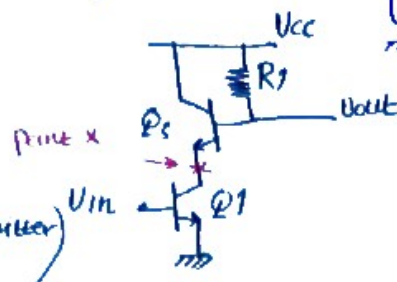
* Test your understanding: Assume perfect symmetry.
 $U_A \neq \infty$
 $\lim AV!$

Solution & perfect symmetry
 & by using half circuit

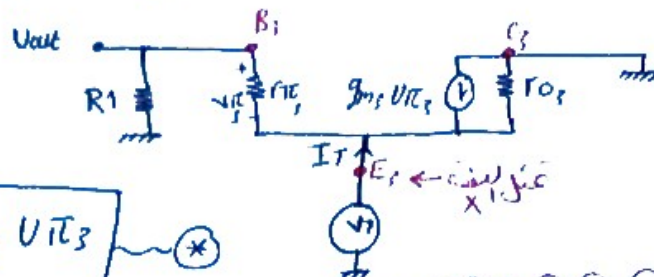


$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{V_{out}}{U_x} \cdot \frac{U_x}{V_{in}}$$

$$\frac{U_x}{V_{in}} = -g_{m1} (R_x \parallel r_{o1}) \quad (\text{common emitter stage})$$



but R_x ?
 by KCL



$$I_T = \frac{V_T}{r_{1s} + R_1} + \frac{V_T}{r_{os}} - g_{m1} V_{1s} \quad (*)$$

$$\rightarrow V_{1s} = V_T \frac{r_{1s}}{R_1 + r_{1s}} \quad \text{by subs. in } (*)$$

$$\therefore I_T = V_T \left(\frac{1}{r_{1s} + R_1} + \frac{1}{r_{os}} - \frac{g_{m1} r_{1s}}{R_1 + r_{1s}} \right)$$

$$\therefore R_x = \frac{V_T}{I_T} = \frac{1}{\frac{1}{r_{1s} + R_1} + \frac{1}{r_{os}} - \frac{g_{m1} r_{1s}}{R_1 + r_{1s}}}$$

$$\therefore \frac{U_x}{V_{in}} = -g_{m1} \cdot \left[(r_{o1}) \parallel \left(\frac{1}{\frac{1}{r_{1s} + R_1} + \frac{1}{r_{os}} - \frac{g_{m1} r_{1s}}{R_1 + r_{1s}}} \right) \right] \quad (1)$$

now

$$\rightarrow V_{out} = U_{R1} = V_T \frac{R_1}{r_{1s} + R_1} = V_T \times \frac{R_1}{r_{1s} + R_1}$$

$$\therefore \frac{V_{out}}{U_x} = \frac{R_1}{r_{1s} + R_1} \quad (2)$$

therefore

$$\frac{V_{out}}{V_{in}} = AV = \left[\frac{R_1}{r_{1s} + R_1} \right] \cdot \left[-g_{m1} \cdot \left((r_{o1}) \parallel \left(\frac{1}{\frac{1}{r_{1s} + R_1} + \frac{1}{r_{os}} - \frac{g_{m1} r_{1s}}{R_1 + r_{1s}}} \right) \right) \right]$$

small signal model
 القالب كذا في كل مرة

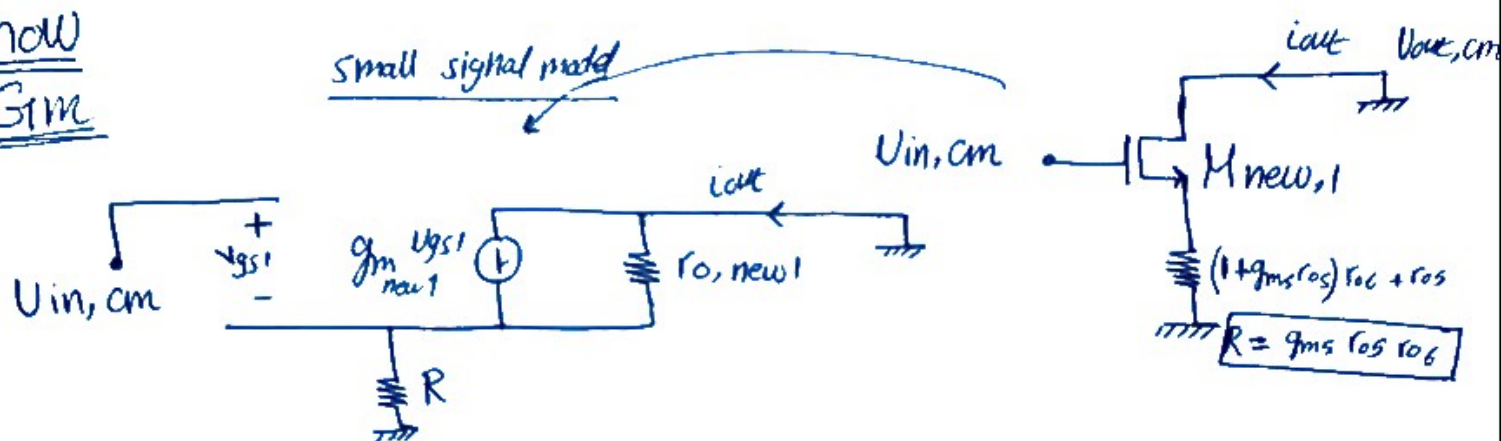
→ Assume that we have identical MOS

$$\begin{aligned} \infty R_{out} &= \left[(1 + g_{m1} r_{o1}) ((1 + g_{m2}) r_{o2} + r_{o1}) + \frac{r_{o2}}{2} \right] \parallel \frac{r_{o2}}{2} \\ &= \left[(g_{m1} r_{o1}) \cdot (g_{m2} r_{o2}^2) + \frac{r_{o2}}{2} \right] \parallel \frac{r_{o2}}{2} \end{aligned}$$

not identical
 $= (g_{m1} + g_{m2}) (r_{o1} \parallel r_{o2}) (g_{m2} r_{o2} r_{o1}) \parallel (r_{o2} \parallel r_{o1})$
 identical MOS
 $R_{out} \rightarrow \text{identical}$

$$R_{out} = \left[g_m^2 r_o^3 + \frac{r_o}{2} \right] \parallel \frac{r_o}{2} \quad \text{symmetry}$$

now
Gm



$$i_{out} = g_{m,new1} V_{gs1} + \frac{0 - V_{gs1}}{r_{o,new1}}$$

$$V_{gs1} = (V_{in,cm} - i_{out} R)$$

$$\infty i_{out} = g_{m,new1} \cdot V_{in,cm} - g_{m,new1} \cdot R \cdot i_{out} - \frac{i_{out} R}{r_{o,new1}}$$

$$\frac{i_{out}}{V_{in,cm}} = G_m = \frac{g_{m,new1}}{1 + \frac{R}{r_{o,new1}} + g_{m,new1} R}$$

$$\infty G_m = \frac{g_{m1} + g_{m2}}{1 + \frac{g_{m1} r_{o1} r_{o2}}{r_{o1} \parallel r_{o2}} + (g_{m1} + g_{m2}) g_{m1} r_{o1} r_{o2}}$$

$$\infty A_{v,cm} = - \left[\frac{g_{m1} + g_{m2}}{1 + \frac{g_{m1} r_{o1} r_{o2}}{r_{o1} \parallel r_{o2}} + (g_{m1} + g_{m2}) g_{m1} r_{o1} r_{o2}} \right] \left[(g_{m1} + g_{m2}) (r_{o1} \parallel r_{o2}) (g_{m1} r_{o1} r_{o2}) \parallel (r_{o1} \parallel r_{o2}) \right]$$

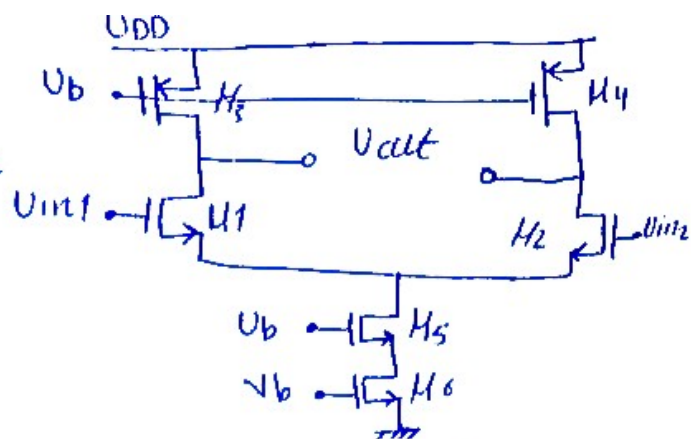
* Test your understanding:

Calculate the common mode gain A_{cm}

- assume, $g_{mro} \gg 1$, $\lambda > 0$

- Use $A_v = -G_m R_{out}$

Solution



$V_{in1} = V_{in2}$

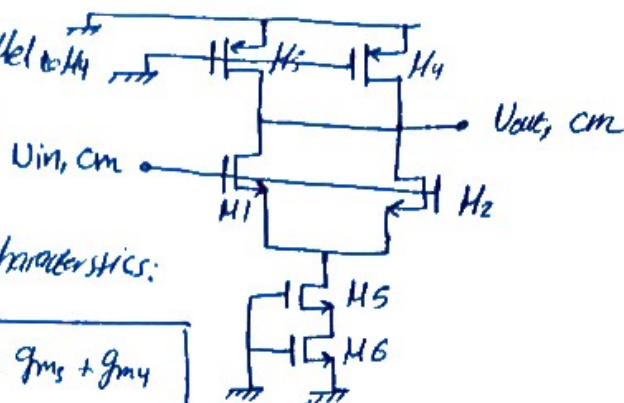
in common mode

→ M_1 is parallel to M_2 , & M_3 is parallel to M_4
each terminal of M_1 is connected with
so as M_3 terminals to M_4

& $M_{new} = M_1 || M_2$ has the following characteristics:
& $M_3 || M_4$

$$\begin{aligned} g_{m, new1} &= g_{m1} + g_{m2} \\ r_{o, new1} &= r_{o1} || r_{o2} \end{aligned}$$

$$\begin{aligned} g_{m, new2} &= g_{m3} + g_{m4} \\ r_{o, new2} &= r_{o3} || r_{o4} \end{aligned}$$

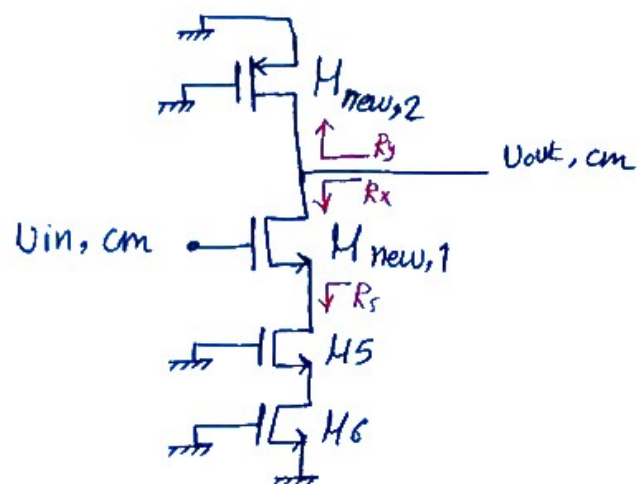


& the circuit is way too easier now to be analyzed

now $R_{out} = R_x || R_y$

$$R_y = r_{o, new2} = r_{o3} || r_{o4}$$

$$R_x = (1 + g_{m, new1} r_{o, new1}) R_s + r_{o, new1}$$



$$R_s = (1 + g_{m5} r_{o5}) r_{o6} + r_{o5}, \text{ by subs.}$$

$$R_x = \left(1 + (g_{m1} + g_{m2})(r_{o1} || r_{o2}) \right) \left[(1 + g_{m5} r_{o5}) r_{o6} + r_{o5} \right] + (r_{o1} || r_{o2})$$

$$R_{out} = \left[\left(1 + (g_{m1} + g_{m2})(r_{o1} || r_{o2}) \right) \left[(1 + g_{m5} r_{o5}) r_{o6} + r_{o5} \right] + (r_{o1} || r_{o2}) \right] || (r_{o3} || r_{o4})$$

* Test your understanding: $\lambda > 0$

Solution

∵ Perfect symmetry

& by half circuit

⇒ finding R_{out}

& by inspection:

$$R_x = \frac{1}{g_{m3}} \parallel r_{o3} \quad \left(R_y = 1 + g_{m1}(r_{o1} \parallel R_1) \cdot \frac{R_{SS}}{2} + (r_{o1} \parallel R_1) \right)$$

$$\Rightarrow R_{out} = \left[\frac{1}{g_{m3}} \parallel r_{o3} \right] \parallel \left(\left[1 + g_{m1}(r_{o1} \parallel R_1) \right] \cdot \frac{R_{SS}}{2} + (r_{o1} \parallel R_1) \right)$$

⇒ finding G_m

by KCL

$$i_{out} = \frac{0 - V_{S1}}{R_{SS}/2} + g_{m1} V_{GS1}$$

$$V_{S1} = i_{out} \cdot \frac{R_{SS}}{2}$$

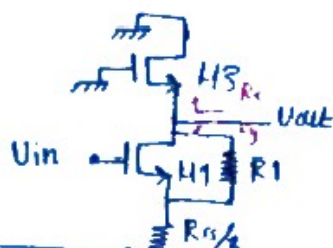
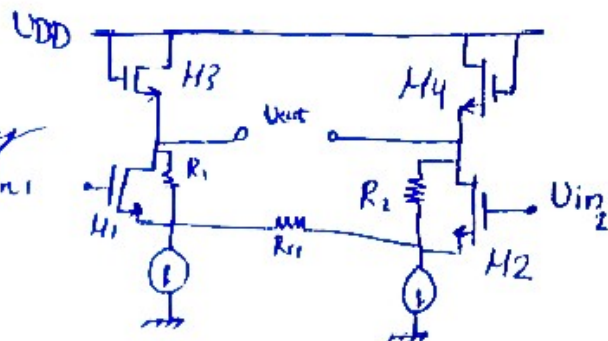
$$V_{GS1} = V_{in} - \frac{i_{out} R_{SS}}{2}$$

$$\therefore i_{out} = -i_{out} \frac{R_{SS}}{2(g_{m1} + \frac{1}{r_{o1} \parallel R_1})} + g_{m1} V_{in} - \frac{g_{m1} R_{SS}}{2} i_{out}$$

$$\therefore \frac{i_{out}}{V_{in}} = \frac{g_{m1}}{1 + \frac{R_{SS}}{2} \left(g_{m1} + \frac{1}{r_{o1} \parallel R_1} \right)} = G_m$$

now $A_V = -G_m R_{out}$

$$A_V = - \left[\frac{g_{m1}}{1 + \frac{R_{SS}}{2} \left(g_{m1} + \frac{1}{r_{o1} \parallel R_1} \right)} \right] \cdot \left(\left[\frac{1}{g_{m3}} \parallel r_{o3} \right] \parallel \left(\left[1 + g_{m1}(r_{o1} \parallel R_1) \right] \cdot \frac{R_{SS}}{2} + (r_{o1} \parallel R_1) \right) \right)$$

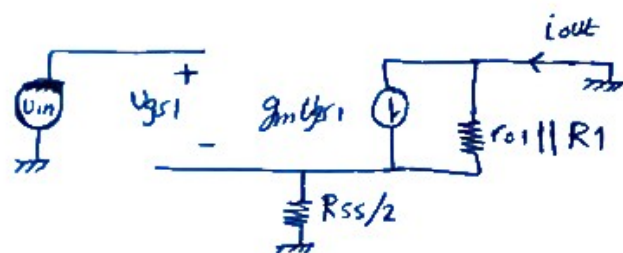


زیر
کلید

$$R_{out} = (1 + g_{m1}) R_S + r_o$$

$$(r_o = r_{o1} \parallel R_1) \text{ load}$$

$$R_S = \frac{R_{SS}}{2}$$



* Ch 11: (Frequency response)

- We'll study the effect due to the change in the input frequency
- We are interested to find the frequency at a point known as: "-3dB bandwidth"

$$\text{at "-3dB bandwidth"} \rightarrow \left| \frac{V_{out}}{V_{in}} \right| = \frac{\left| \frac{V_{out}}{V_{in}} \right|_{\text{at low frequency}}}{\sqrt{2}}$$

$$\rightarrow \left| \omega \right| = \frac{1}{\left(R_{out} \right)_{\text{at low frequency}} \cdot C_L}$$

at -3dB bandwidth

في حال وجود مكثف واحد

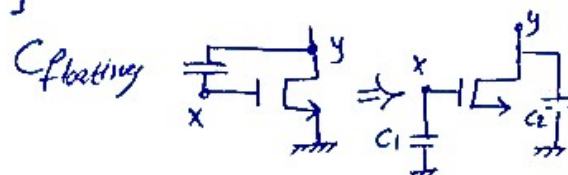
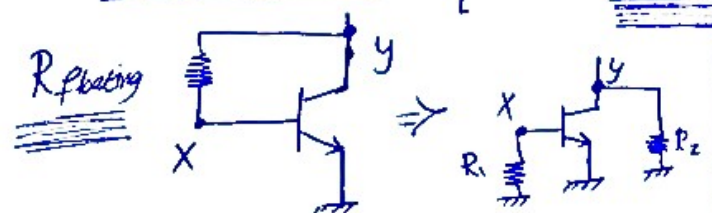
* عدد poles يعبر عن عدد الترددات ، ويتم حساب pole عن طريق الخطوات التالية :

- ① all other capacitances are shorted
- ② $V_{in} = 0$

$$\& \omega = \frac{1}{RC}, \quad R = \text{resistance seen from the terminal of } C$$

* في عملية رسم back plot ، يتخذ شكل التردد -20dB/dec . pole عند كل

* Miller theorem: [أحد أهم نظريات التباين]



$$R_1 = \frac{R_{\text{floating}}}{1 - A_{v_{\text{mid}}}}$$

$$R_2 = \frac{R_{\text{floating}}}{1 - \frac{1}{A_{v_{\text{mid}}}}}$$

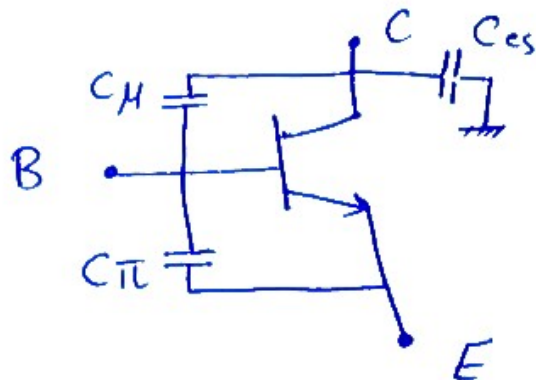
$$C_1 = C_{\text{floating}} \left(1 - A_{v_{\text{mid}}} \right)$$

$$C_2 = C_{\text{floating}} \left(1 - \frac{1}{A_{v_{\text{mid}}}} \right)$$

y, x gain $A_v \leftarrow A_{v_{\text{mid}}}$

* High frequency model of transistors:

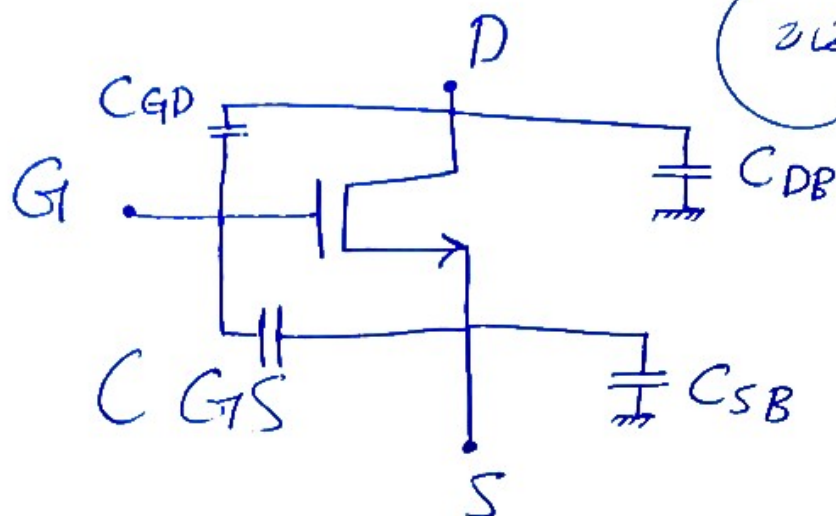
BJT:



نموذج الترددات العالية

npn و pnp

MOSFET:



نموذج الترددات العالية

PMOS و NMOS

high frequency

* ملحوظة: نموذج الترددات العالية / نموذج الترددات العالية

* مكافئة / coupling capacitors (مكافئة مع الترددات العالية) فقط

* midband region

* high frequency region / low frequency region

OK! Miller's theorem

* cutoff frequency

for BJT $\rightarrow W_T = g_m / C_{\pi}$

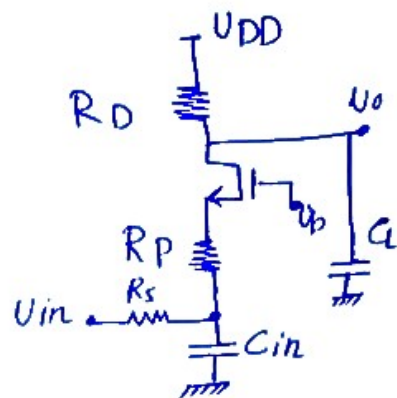
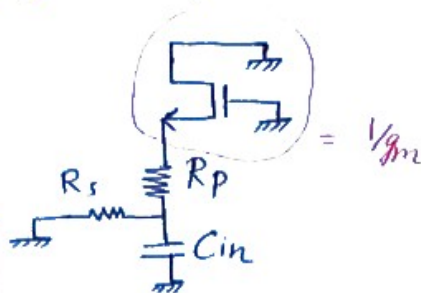
MOSFET $\rightarrow W_T = g_m / C_{gs}$

* Test your understanding:

if $\lambda = 0$, find the input and the output poles!

for C_{in}

$$\omega_{p, in} = \frac{1}{R_s \parallel (R_p + \frac{1}{g_m})}$$



$$\omega_{p, in} = \frac{1}{[R_s \parallel (R_p + \frac{1}{g_m})] \cdot C_L}$$

for C_L (output capacitor)

$$R_{C, out} = R_D$$

$$\omega_{p, out} = \frac{1}{R_D \cdot C_L}$$

C_L is seen from V_{in}

$$\omega_p = \frac{1}{R \parallel C_L}$$

as seen from C_L

Handwritten signature

* Test your understanding:

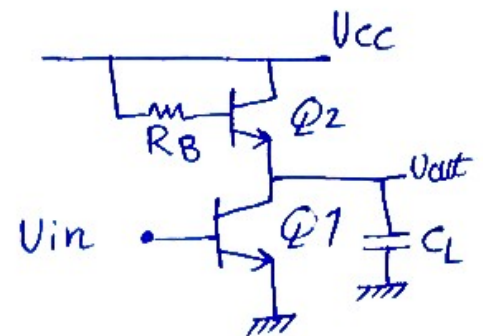
Determine the -3dB bandwidth of the circuits shown:

$$\lambda > 0, \quad U_A = \infty$$

(a)
$$\omega_{-3dB} = \frac{1}{C_L \cdot R_{out}} \quad \text{at low frequency}$$

$$R_{out} = \frac{1}{g_m} + \frac{R_B}{\beta + 1}$$

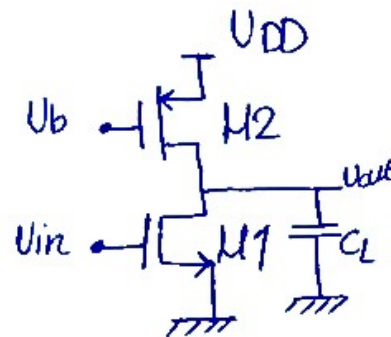
&
$$\omega_{-3dB} = \frac{1}{\left[\left(\frac{R_B}{\beta + 1} \right) + \left(\frac{1}{g_m} \right) \right] \cdot C_L}$$



(b)
$$\omega_{-3dB} = \frac{1}{C_L \cdot R_{out}} \quad \text{at low frequency}$$

$$R_{out} = r_{o1} \parallel r_{o2}$$

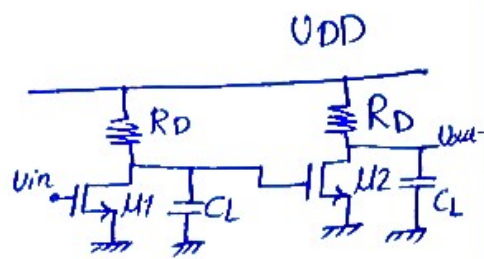
&
$$\omega_{-3dB} = \frac{1}{(r_{o1} \parallel r_{o2}) \cdot C_L}$$



* Test your understanding:

Find the bode plot for the circuit that illustrates a cascade of two identical CS stages with $\lambda = 0$

Solution ∵ identical CS stages ∵ they have the same pole



$$\omega_{p1} = \omega_{p2} = \omega_p = \frac{1}{R_D C_L}$$

at ω_p , a -40 dB/dec will occur because we have two poles at the same frequency

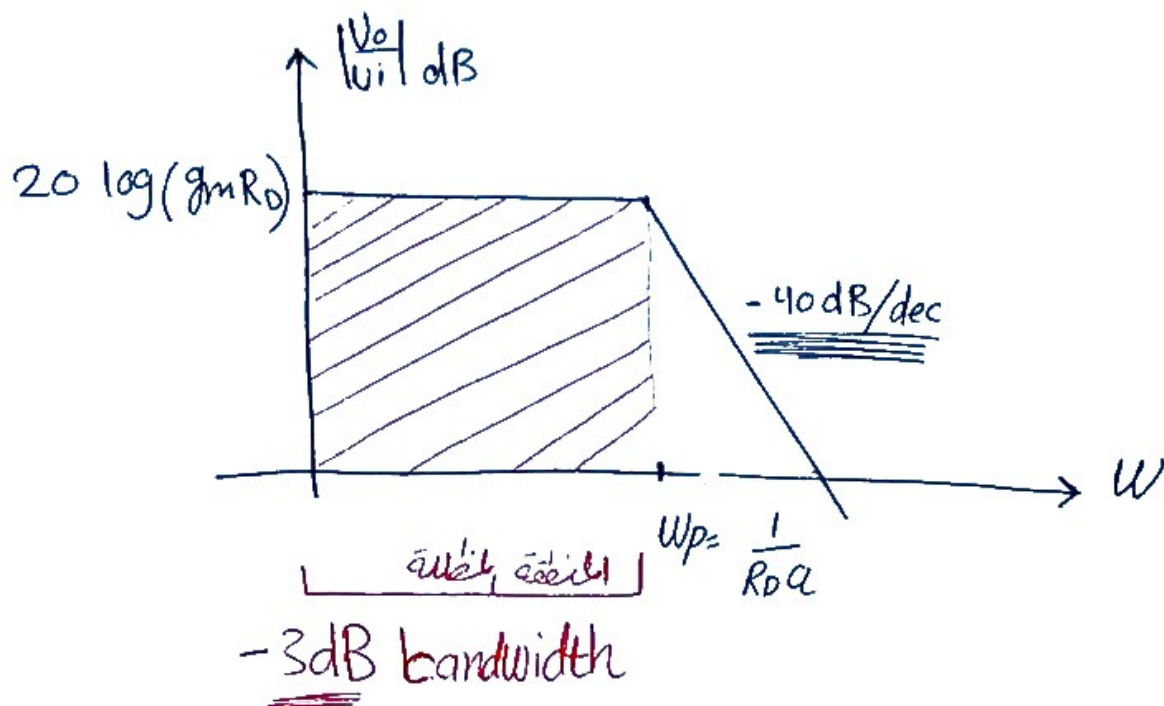
now

$$\text{dc gain} = 20 \log |g_m R_D|$$

$$\begin{aligned} \left| \frac{V_o}{V_i} \right| &= \left| \frac{V_o}{V_x} \right| \cdot \left| \frac{V_x}{V_i} \right| \\ &= 20 \log \left| \frac{V_o}{V_x} \right| + 20 \log \left| \frac{V_x}{V_i} \right| \\ &= 40 \end{aligned}$$

الضرب في 2 يعني

∵ the bode plot:



* Test your understanding:

Find the voltage gain of the circuit shown:

Solution $\because r_o$ is a floating resistance, & by using Miller's theorem

$$r_{o1} = r_o (1 - A_{u_{\text{Miller}}})^{-1}, \quad r_{o2} = r_o (1 - \frac{1}{A_{u_{\text{Miller}}}})^{-1}$$

$$A_{u_{\text{Miller}}} = g_m R_c$$

assume x is the input, y is the output

$$\therefore r_{o1} = \frac{r_o}{1 - g_m R_c}$$

$$\& \quad r_{o2} = \frac{r_o}{1 - \frac{1}{g_m R_c}}$$

$\therefore$ the circuit's voltage gain could be found using the same topology used in Ch9

$$\underline{R_{out}} = R_c \parallel r_{o2} = R_c \parallel \left(\frac{r_o}{1 - \frac{1}{g_m R_c}} \right)$$

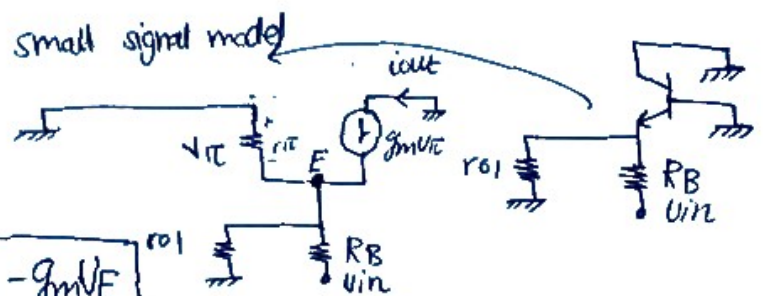
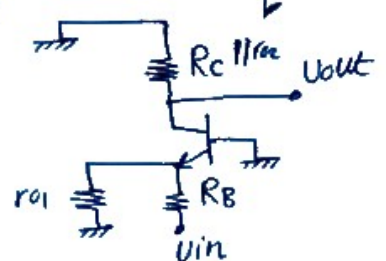
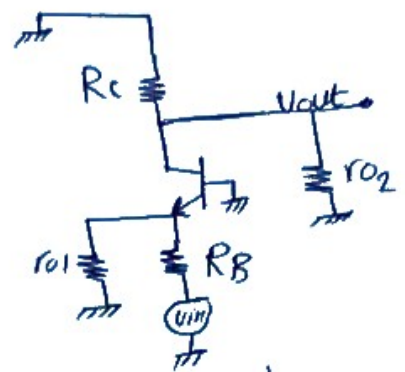
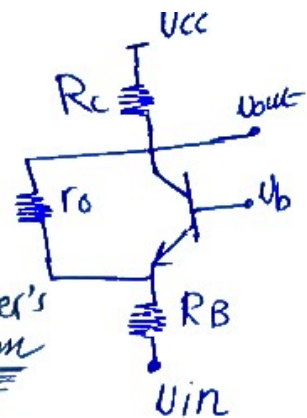
$$G_m = \frac{i_{out}}{U_{in}} \Big|_{U_{out}=0}$$

$$\rightarrow i_{out} = g_m V_{TC} \quad \left. \begin{array}{l} \\ V_{TC} = -V_E \end{array} \right\}$$

$$\therefore i_{out} = -g_m V_E$$

by KCL around $E \rightarrow \frac{V_E}{r_{TC}} + \frac{V_E}{r_{o1}} + \frac{V_E - U_{in}}{R_B} = i_{out} = -g_m V_E$

but $\& \quad V_E = \frac{U_{in}}{\left(\frac{1}{r_{TC}} + \frac{1}{r_{o1}} + \frac{1}{R_B} + g_m \right)} \cdot \frac{1}{R_B}$



$$\infty \quad V_E = \frac{v_{in}}{\left(\frac{1}{r_{\pi}} + \frac{1}{r_{o1}} + \frac{1}{R_B} + g_m\right)} \cdot \frac{1}{R_B}$$

$$\infty \quad i_{out} = -g_m \left(\frac{v_{in}}{\left(\frac{1}{r_{\pi}} + \frac{1}{r_{o1}} + \frac{1}{R_B} + g_m\right)} \cdot \frac{1}{R_B} \right)$$

$$\infty \quad G_m = \frac{-g_m/R_B}{\frac{1}{r_{\pi}} + \frac{1}{r_{o1}} + \frac{1}{R_B} + g_m}$$

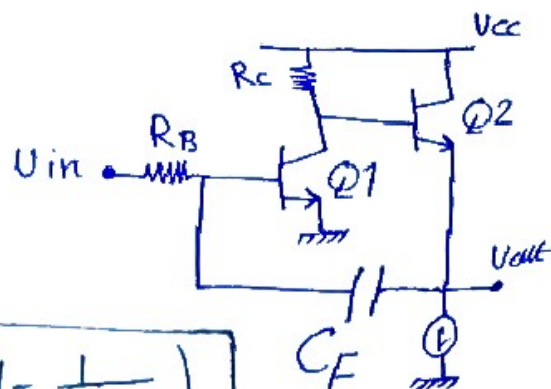
$$\infty \quad A_V = -G_m R_{out}$$

$$\infty \quad A_V = \frac{g_m/R_B}{\frac{1}{r_{\pi}} + \frac{1}{r_{o1}} + \frac{1}{R_B} + g_m} \cdot \left(R_c \parallel \left[\frac{r_o}{\left(1 - \frac{1}{g_m R_c}\right)} \right] \right)$$

* Test your understanding :-

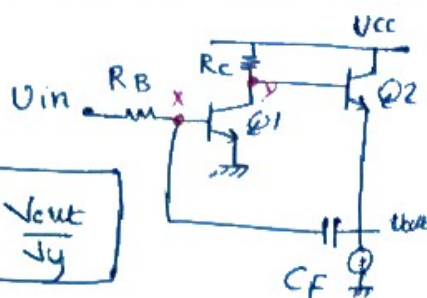
determine the input & output poles!! $U_A = \alpha$
 → by using Miller's theorem

$$C_1 = C_F (1 - A_{U \text{ miller}}), \quad C_2 = C_F \left(1 - \frac{1}{A_{U \text{ miller}}}\right)$$

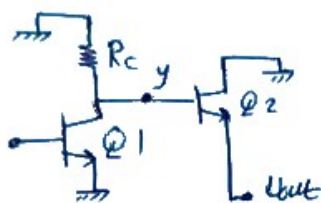


$A_{U \text{ miller}}$

$$\frac{V_{out}}{U_x} = \frac{U_y}{U_x} \cdot \frac{V_{out}}{U_y}$$



$$\frac{U_y}{U_x} = -g_{m1} R_C$$



$\frac{V_{out}}{U_y} \Rightarrow$ emitter follower stage

$$\frac{V_{out}}{U_y} \approx 1 \quad (\text{small signal model})$$

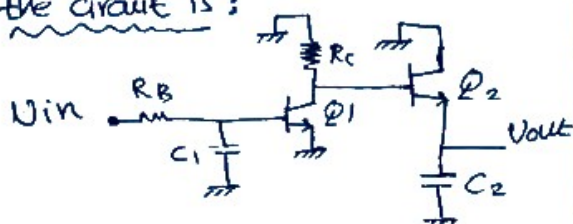
$$A_{U \text{ miller}} = -g_{m1} R_C$$

hence

$$C_1 = C_F (1 + g_{m1} R_C) \quad \text{input } C$$

$$C_2 = C_F \left(1 + \frac{1}{g_{m1} R_C}\right) \quad \text{output } C$$

& the circuit is:



We need to find R for each C

& for C_1

$$R_1 = R_B \parallel r_{\pi 1}$$

$$\omega_{p, \text{input}} = \frac{1}{(R_B \parallel r_{\pi 1}) \cdot C_F (1 + g_{m1} R_C)}$$

for C_2

$$R_2 = \frac{1}{g_{m2}} + \frac{R_C}{\beta + 1}$$

$$\omega_{p, \text{output}} = \frac{1}{\left(\frac{1}{g_{m2}} + \frac{R_C}{\beta + 1}\right) \cdot C_F \left(1 + \frac{1}{g_{m1} R_C}\right)}$$

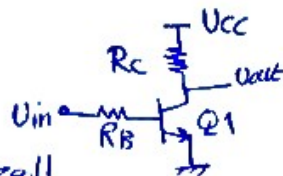
EASY, BOY!

* Test your understanding:

input pole = 500 MHz
output pole = 2 GHz
 $C_{\pi} = 20 \text{ pF}$, $C_M = 5 \text{ pF}$, $C_{cs} = 10 \text{ pF}$

Design

find R_B & R_C in which the dc voltage gain is maximized!



→ dc voltage gain

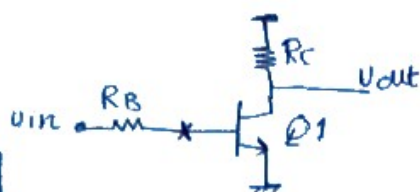
$$\frac{V_{out}}{V_{in}} = \frac{V_{out}}{V_x} \cdot \frac{V_x}{V_{in}}$$

$$\frac{V_{out}}{V_x} = -g_m R_C$$

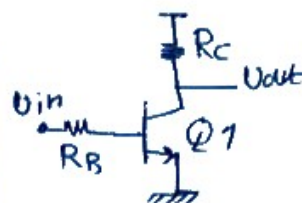
$$\frac{V_x}{V_{in}} = \frac{r_{\pi}}{r_{\pi} + R_B}$$

hence

$$\frac{V_{out}}{V_{in}} = -g_m R_C \cdot \frac{r_{\pi}}{r_{\pi} + R_B}$$



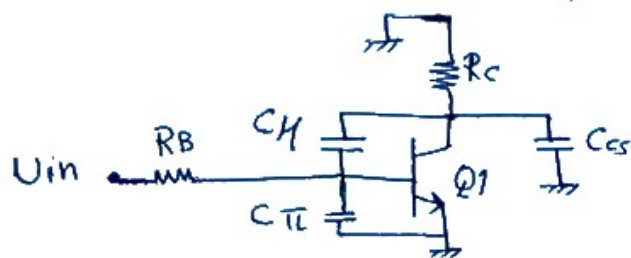
$$\frac{V_{out}}{V_{in}} = \frac{-R_C}{\frac{1}{g_m} + \frac{R_B}{\beta + 1}}$$



to maximize A_{vdc}

→ R_C must be at max. possible value
→ R_B = min.

now by finding the model of the circuit in high frequency!



C_M is a floating capacitor, by using Miller's theorem!

$$C_{M,in} = C_M (1 - A_v), \quad C_{M,out} = C_M (1 - \frac{1}{A_v})$$

$$A_v = -g_m R_C$$

$$g_m = I_C / V_T = 1 \text{ mA} / 25 \text{ mV} = 38.4615 \text{ mS}$$

$$C_{in} = C_{\pi} + C_{M,in} (1 + g_m R_C)$$

$$C_{out} = C_{cs} + C_{M,out} (1 + \frac{1}{g_m R_C})$$

$$R_{in} = R_B \parallel r_{\pi}, \text{ but since } R_B \text{ is min.} \Rightarrow R_{in} = R_B$$

$$R_{out} = R_C$$

$$\omega_{input} = 2\pi f_{input\ pole} = 2\pi (500 \text{ MHz}) = \frac{1}{R_B \cdot [C_{\pi} + C_M (1 + g_m R_C)]}$$

$$\omega_{output} = 2\pi f_{out\ pole} = 2\pi (2 \text{ GHz}) = \frac{1}{R_C [C_{cs} + C_M (1 + \frac{1}{g_m R_C})]}$$

by solving * for R_C using $f_{x-570ES}$ PLUS

$$R_C = 5296.498 \text{ k}\Omega$$

by subs and solving for R_B similarly

$$R_B = 305.0238619 \text{ k}\Omega$$

! ... we need R_C !

$$A_{u \text{ miller}} = -G_m R_{out}$$

where point x is considered the input point
& y = output

R_{out} (as seen from node y)

$$R_{out} = 1/g_{m2}$$

G_m (by shorting node y)

$$\therefore G_m = g_{m1}$$

from KCL $I_{C1} = I_{C2} + I_{C3}$

$$I_{C3} = .75 I_{C1}$$

hence, $I_{C2} = .25 I_{C1}$

since $g_m = I_C / V_T$

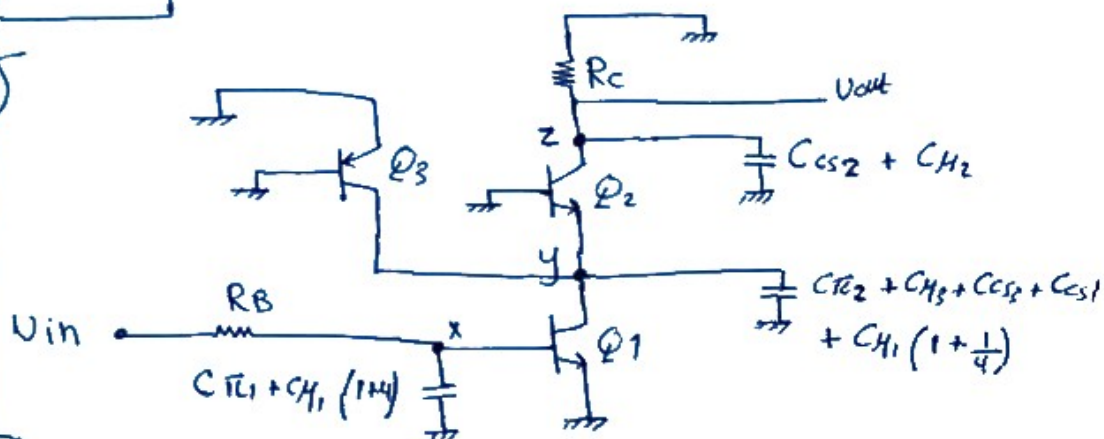
$$\therefore g_{m2} \sqrt{I} = .25 g_{m1} \sqrt{I}$$

$$\therefore g_{m2} = .25 g_{m1} \text{ by subs. in}$$

therefore, $A_{u \text{ miller}} = -4$

the most simplified version of the circuit

$\Rightarrow$ We have three poles



$$C_x = C_{\pi 1} + 5 C_{H1}, \quad R_x = R_B \parallel r_{\pi 1}$$

$$C_y = C_{\pi 2} + C_{H2} + C_{cs2} + C_{cs1} + \frac{5}{4} C_{H1}, \quad R_y = \frac{1}{g_{m2}} \parallel r_{\pi 2}$$

$$C_z = C_{cs2} + C_{H2}, \quad R_z = R_c$$

therefore

$$W_x = \frac{1}{(R_B \parallel r_{\pi 1}) (C_{\pi 1} + 5 C_{H1})}$$

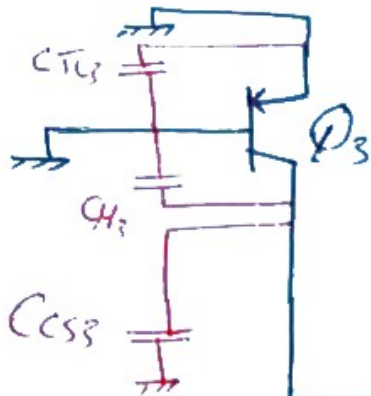
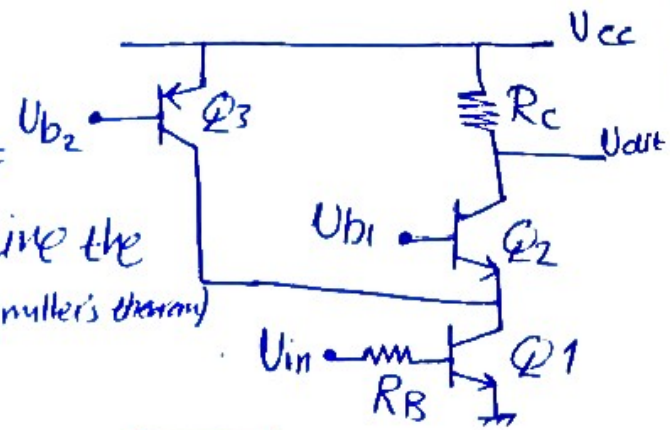
$$W_y = \frac{1}{\left(\frac{1}{g_{m2}} \parallel r_{\pi 2} \right) \cdot \left(C_{cs1} + \frac{5}{4} C_{H1} + C_{\pi 2} + C_{H2} + C_{cs2} \right)}$$

$$W_z = \frac{1}{R_c (C_{cs2} + C_{H2})}$$

الان شاء الله، سؤال (طول به سطر 9)

* Test your understanding:

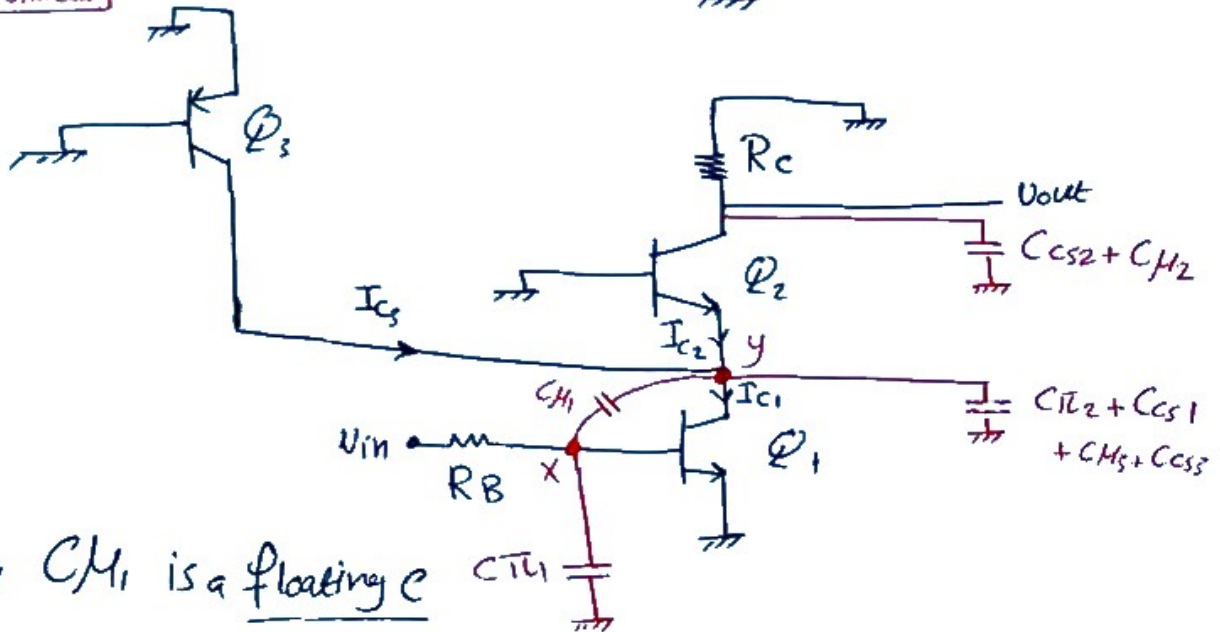
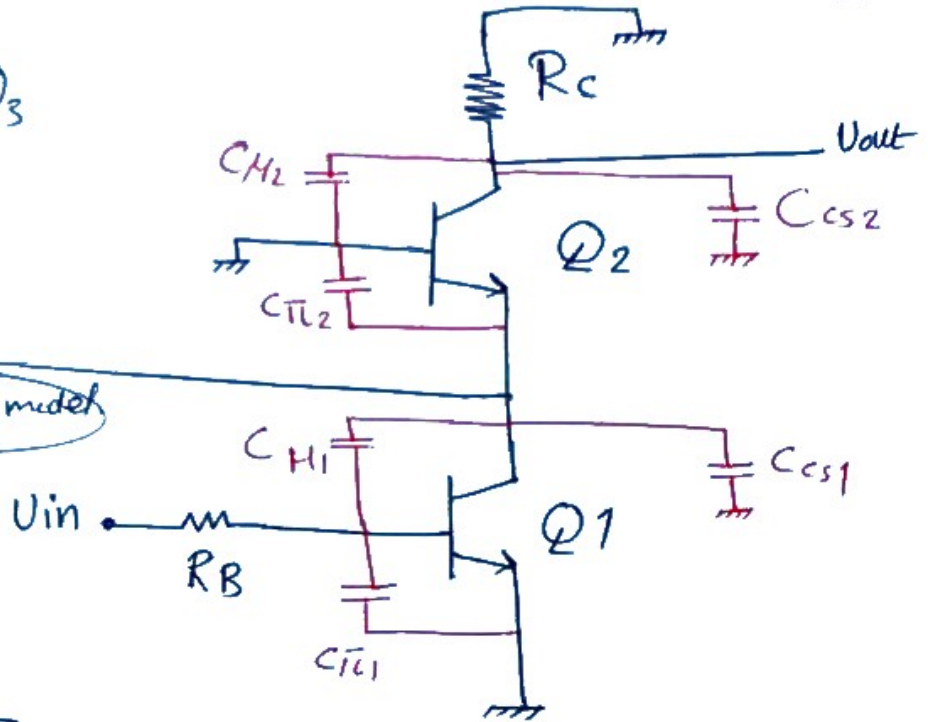
Q_3 provides 75% of the bias current of Q_1 , assume $\beta_A = \infty$, determine the poles of the circuit! (you may use miller's theory)



① adding the high-frequency model in consideration

② Simplify the circuit

Note C_{IL3} is shorted



therefore, C_{M1} is a floating c

$$C_x = C_{M1} (1 - A_v)$$

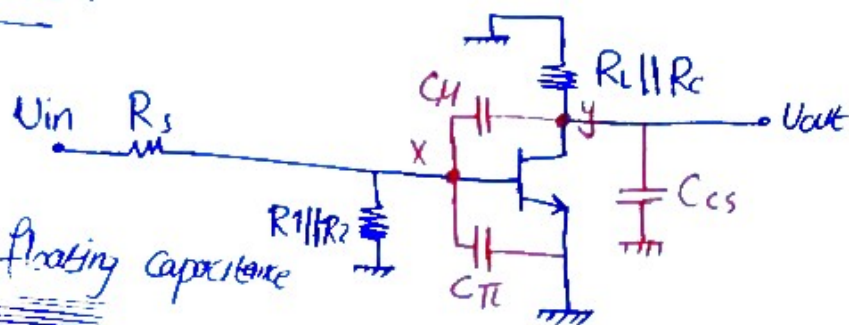
$$C_y = C_{M1} \left(1 - \frac{1}{A_v} \right)$$

but, we need to find (x, y) (nuller) !!

to be continued...

③ at high frequency, $(C_s, C_c \& C_E)$ are shorted
 (C_{π}, C_M, C_{cs}) appear

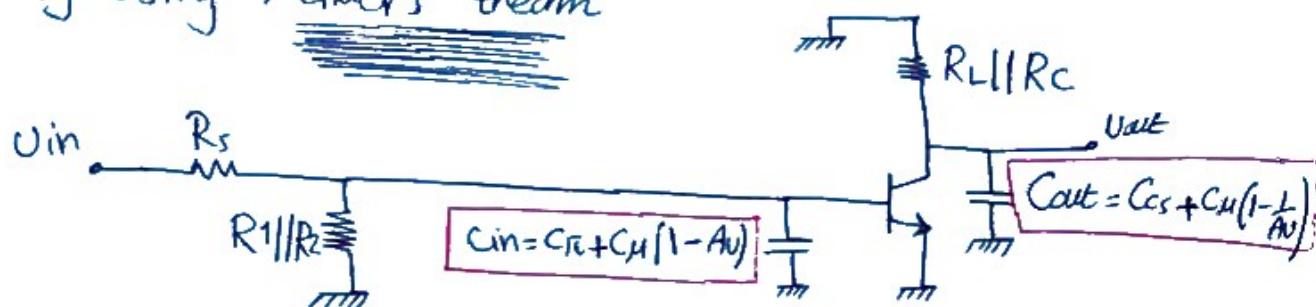
$\therefore$ the circuit is:



We only have one floating capacitance

$\rightarrow C_M$

$\therefore$ by using Miller's theorem



$$A_U(\text{miller}) = -G_m \cdot R_{out} \quad \text{for}$$



$$\therefore \text{CE stage} \quad \therefore A_U = -g_m (R_C || R_L)$$

$$= -(63.45 \text{ m}) (1419.35)$$

$$\therefore \boxed{A_U = -90.058}$$

$$\therefore \boxed{C_{in} = 406.23 \text{ PF}}$$

$$\boxed{C_{out} = 12.955 \text{ PF}}$$

now, we need to find the poles

$\therefore$ For C_{in}

$$R = R_s || R_1 || R_2 || r_{\pi}$$

$$\therefore \boxed{R = 568.34 \Omega}$$

$$\therefore \omega_{in} = 4.33 \text{ Mrad/sec}$$

$$\therefore \boxed{f_{in} = 689.346 \text{ KHz}}$$

For C_{out}

$$R = R_L || R_C$$

$$\boxed{R = 1419.35 \Omega}$$

$$\therefore \omega_{out} = 54.216 \text{ Mrad/sec}$$

$$\therefore \boxed{f_{out} = 8.6288 \text{ MHz}}$$

② at midband, all capacitances are neglected

$$\therefore \underbrace{(C_M, C_{CS}, C_{\pi})}_{\text{opened}}, \underbrace{(C_S, C_C \& C_E)}_{\text{shorted}}$$

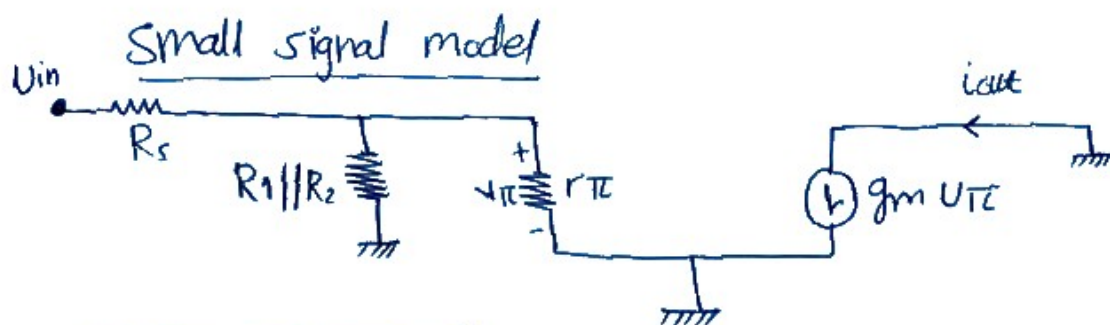
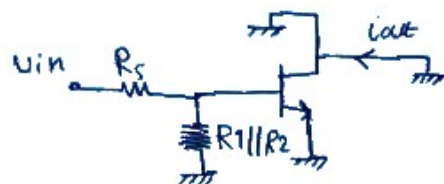
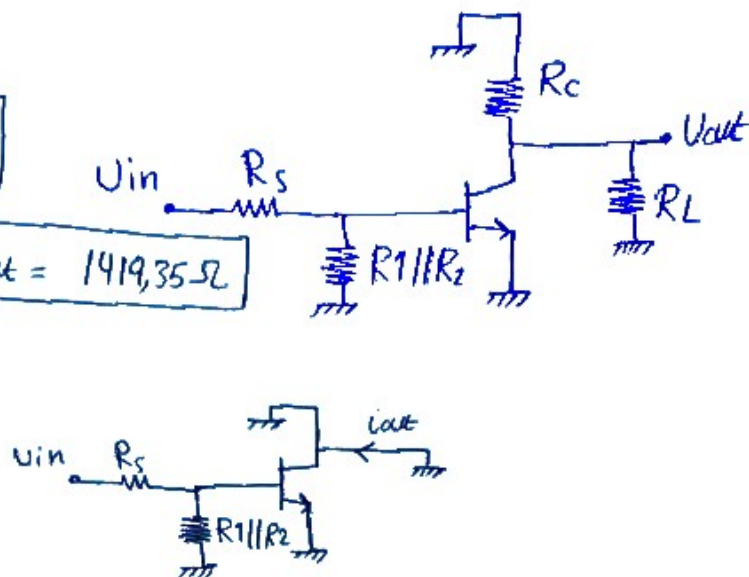
← أبواب مغلقة

the circuit is:

$$\therefore A_U = -G_m R_{out}$$

$$\rightarrow R_{out} = R_C \parallel R_L \Rightarrow R_{out} = 1419,35 \Omega$$

$$\rightarrow G_m = \left. \frac{I_{out}}{U_{in}} \right|_{U_{out} = 0}$$



$$I_{out} = g_m U_{\pi} \quad (*)$$

$$U_{\pi} = U_{in} \frac{r_{\pi} \parallel R_1 \parallel R_2}{R_s + r_{\pi} \parallel R_1 \parallel R_2}$$

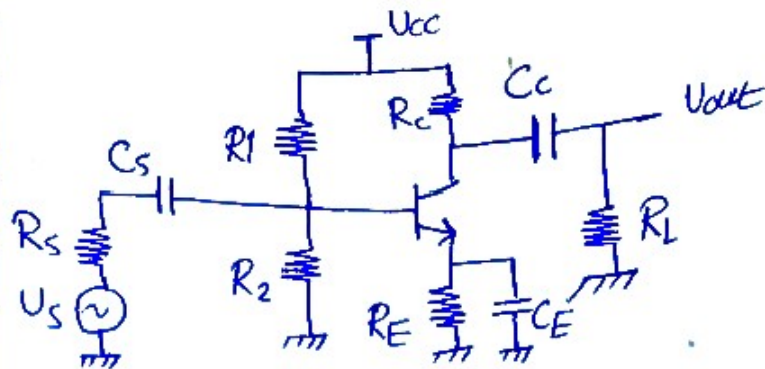
by subs in (*)

$$\therefore G_m = g_m \cdot \frac{r_{\pi} \parallel R_1 \parallel R_2}{R_s + (r_{\pi} \parallel R_1 \parallel R_2)}$$

$$\therefore G_m = 36,06 \text{ mS}$$

therefore, $A_U = -51,183$
at midband

$$\begin{aligned}
 R_1 &= 40\text{K}\Omega & C_S &= 10\mu\text{F} \\
 R_2 &= 10\text{K}\Omega & C_C &= 1\mu\text{F} \\
 R_C &= 4\text{K}\Omega & C_E &= 20\mu\text{F} \\
 R_E &= 2\text{K}\Omega & B &= 100 \\
 R_L &= 2,2\text{K}\Omega & V_A &= \infty \\
 R_S &= 1\text{K}\Omega & g_m &= 63,45\text{m}\Omega^{-1}
 \end{aligned}$$



→ Use Miller's theorem if $(C_M = 4\text{PF}, C_{CS} = 9\text{PF}, C_{CL} = 42\text{PF})$ to:

- ① Find the poles at low-frequency region.
- ② Find the midband gain at midband.
- ③ Find the poles at high-frequency region.
- ④ Sketch the frequency response for the low & high frequency regions & at the sketch, determine the band width

Solution

① at low frequency, $[C_M, C_{CS} \& C_{CL}]$ don't appear

& only the capacitances $[C_S, C_C \& C_E]$ have an effect

for C_S , U_{CC} & U_{in} are shorted
so as all other C ~~are ignored~~

∴ the circuit is:

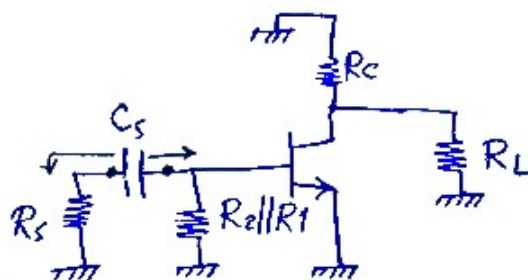
$$R = R_S + R_1 \parallel R_2 \parallel r_{\pi}$$

since $r_{\pi} = B/g_m$

$$\therefore r_{\pi} = 1576\Omega$$

→ we have R_1, R_2 & R_S

$$\therefore R = 2316,65\Omega$$

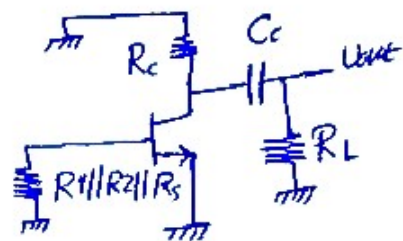


$$\therefore \omega_{C_S} = \frac{1}{RC_S} = 43,165 \text{ rad/sec}$$

$$\therefore f_{C_S} = 6,87 \text{ Hz}$$

For C_C

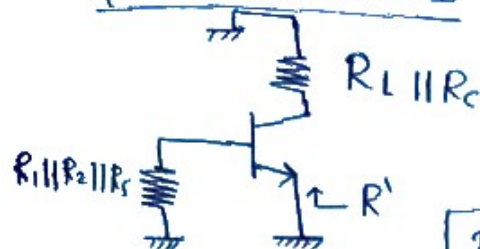
$$R = R_C + R_L \quad \left\{ \begin{array}{l} \text{the circuit is} \\ \omega_{C_C} = 161,29 \text{ rad/sec} \\ f_{C_C} = 25,67 \text{ Hz} \end{array} \right.$$



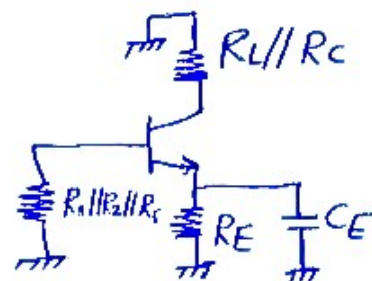
For C_E

from electronics I

the circuit is:



$$R' = \frac{R_B}{B+1} + \frac{1}{g_m}$$



$$R = R' \parallel R_E = \frac{8000/4}{100+1} + \frac{1}{63,45 \text{ m}} = 24,56 \Omega$$

$$R = 24,56 \Omega$$

$$\omega_{C_E} = 2035,72 \text{ rad/sec} \Rightarrow f_{C_E} = 323,995 \text{ Hz}$$

$$f_{C_S} = 6,87 \text{ Hz} , \quad f_{C_C} = 25,67 \text{ Hz} , \quad f_{C_E} = 323,995 \text{ Hz}$$

thus, the dominant pole is $= \max(f_{C_S}, f_{C_C}, f_{C_E}) = f_{C_E}$

$$\text{dominant pole} = 323,995 \approx 324 \text{ Hz}$$

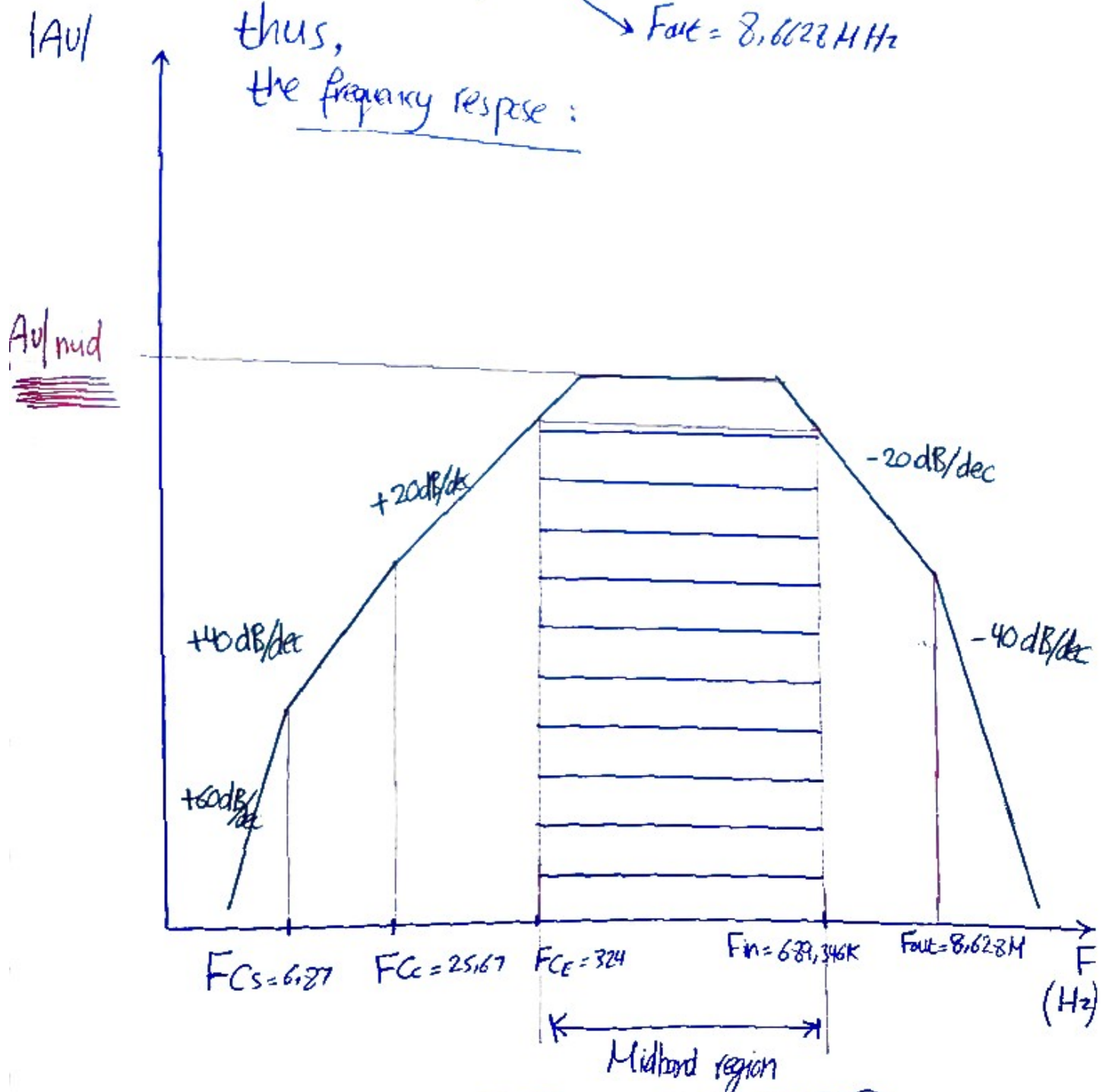
(low-cut-off frequency) pole / القطب / القطب المنخفض **

→ Hence, at $F_L = 324 \text{ Hz}$ (3-dB frequency)

& Summary

- ① low-frequency region poles
 - $F_{Cs} = 6.87 \text{ Hz}$
 - $F_{Cc} = 25.67 \text{ Hz}$
 - $F_{CE} = 323.495 \text{ Hz}$ (cutoff frequency)
- ② Midband's gain = -51,1833
- ③ high-frequency region poles
 - $F_{in} = 689.346 \text{ KHz}$
 - $F_{out} = 8.6628 \text{ MHz}$

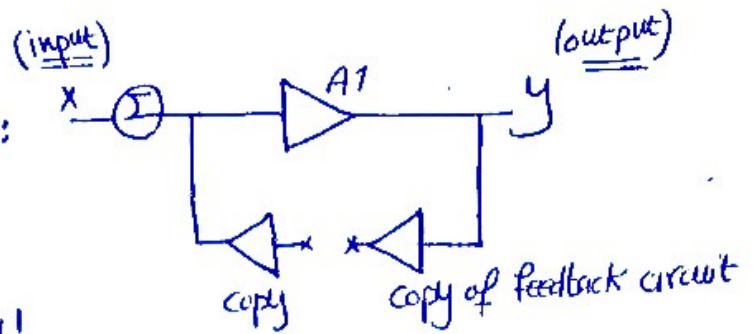
thus,
the frequency response:



& Bandwidth = $F_{in} - F_{CE} = 689.022 \text{ KHz}$

Ch 12: (Feedback)

→ Consider the following circuit:



Use the table below for each topology!

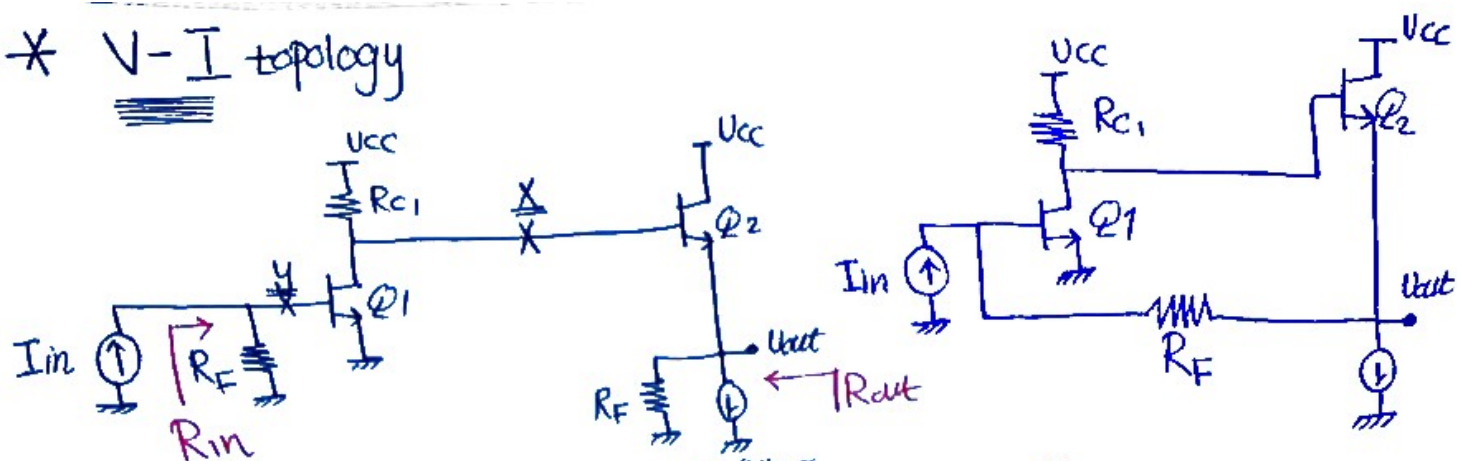
Topology	A1	K	R
$V-V$ $A = \frac{V_{out}}{V_i}$ <u>Feedback</u> <u>Input</u>	 $K = \frac{V_2}{V_1}$	$R_{if} = R_{in}(1+KA1)$ $R_{of} = \frac{R_{out}}{1+KA1}$	
$V-I$ $A = \frac{V_{out}}{I_{in}}$	 $K = \frac{I_2}{V_1}$	$R_{if} = \frac{R_{in}}{1+KA1}$ $R_{of} = \frac{R_{out}}{1+KA1}$	
$I-V$ $A = \frac{I_{out}}{V_{in}}$	 $K = \frac{V_2}{I_1}$	$R_{if} = R_{in}(1+KA1)$ $R_{of} = R_{out}(1+KA1)$	
$I-I$ $A = \frac{I_{out}}{I_{in}}$	 $K = \frac{I_2}{I_1}$	$R_{if} = \frac{R_i}{1+KA1}$ $R_{of} = R_{out}(1+KA1)$	

⇒ $A_F = \text{closed loop gain} = \frac{A1}{1+KA1}$

لأى نوع من تلك الأنواع

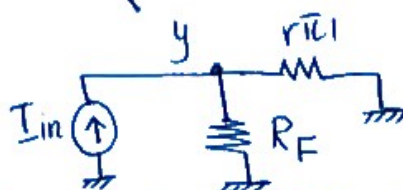
خطوات الحل / ١) تحديد نوع topology ← ٢) تحديد A-circuit
 ٣) تحديد open loop gain A1
 ٤) تحديد R_{in}, R_{out}
 ٥) تحديد K
 ٦) تطبيق القوانين
 ٧) تحديد K-circuit

* V-I topology



$$\frac{V_{out}}{I_{in}} = \frac{V_{out}}{V_x} \cdot \frac{V_x}{V_y} \cdot \frac{V_y}{I_{in}} = \left(\frac{R_F}{\frac{1}{g_{m2}} + R_F} \right) \cdot \left[-g_{m1}(R_{C1} || r_{\pi 2}) \right] \cdot \frac{V_y}{I_{in}}$$

to determine $\frac{V_y}{I_{in}}$



$$\frac{V_y}{I_{in}} \approx r_{\pi 1} || R_F$$

$$\approx \frac{V_{out}}{I_{in}} = \left[\frac{R_F}{\frac{1}{g_{m2}} + R_F} \right] \cdot \left[-g_{m1}(R_{C1} || r_{\pi 2}) \right] \cdot \left[r_{\pi 1} || R_F \right] = A_1$$

$$\Rightarrow \boxed{R_{in} = R_F || r_{\pi 1}} \quad \boxed{R_{out} = R_F || \left(\frac{1}{g_{m2}} + \frac{R_{C1}}{\beta + 1} \right)}$$

for K



$$\boxed{K = \frac{I_2}{V_1} = \frac{I_2}{-I_2 R_F} = \frac{-1}{R_F}}$$

$$A_F = \frac{A_1}{1 + K A_1}$$

$$R_{if} = \frac{R_{in}}{1 + K A_1}$$

$$R_{of} = \frac{R_{out}}{1 + K A_1}$$

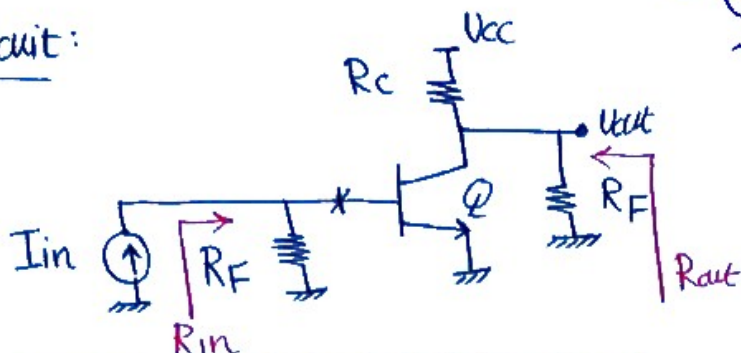
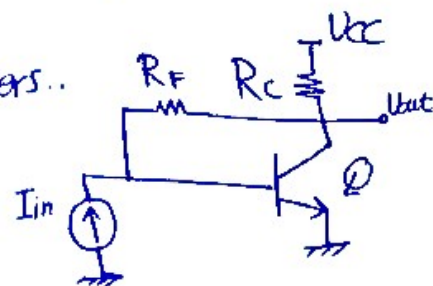
الآن بالقول في المعادلات

* Test your understanding:

Assume $V_A \neq \infty$
Find the closed loop parameters..

V-I topology

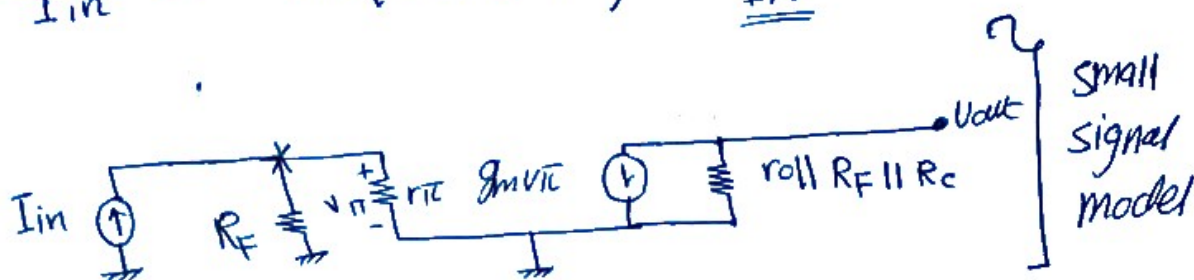
→ The A-circuit:



$$R_{in} = R_F \parallel r_{\pi}$$

$$R_{out} = R_C \parallel r_o \parallel R_F$$

$$\frac{V_{out}}{I_{in}} = \frac{V_{out}}{U_X} \cdot \frac{U_X}{I_{in}} = -g_m (R_C \parallel R_F \parallel r_o) \cdot \frac{U_X}{I_{in}}$$



$$\& \frac{U_X}{I_{in}} = (R_F \parallel r_{\pi})$$

$$\& A_1 = -g_m \cdot (R_C \parallel R_F \parallel r_o) \cdot (R_F \parallel r_{\pi})$$

therefore

⇒ we need K



$$K = \frac{I_2}{V_1} = -\frac{1}{R_F}$$

$$A_F = \frac{A_1}{1 + K A_1}$$

$$R_{if} = \frac{R_{in}}{1 + K A_1}$$

$$R_{of} = \frac{R_{out}}{1 + K A_1}$$

the closed loop parameters

سوال ۴۵

* Test your understanding :

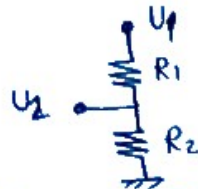
U-U topology
& the A circuit

$$A_1 = A_V = \frac{V_{out}}{V_{in}} = (R_1 + R_2) \parallel R_D \cdot g_m$$

$$R_{in} = 1/g_m$$

$$R_{out} = R_D \parallel (R_1 + R_2)$$

→ K

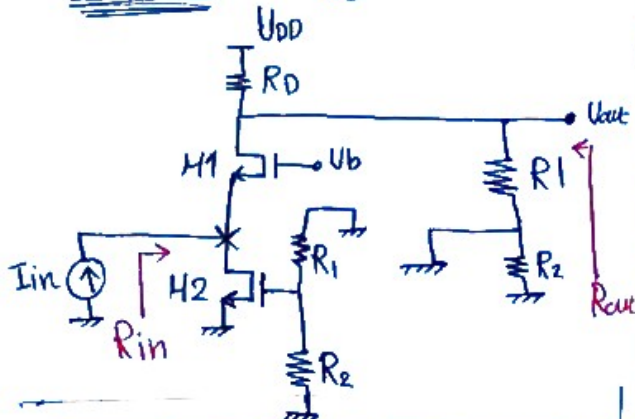


$$K = \frac{V_2}{V_1} = \frac{R_2}{R_1 + R_2}$$

$$\Rightarrow A_F = \frac{A_1}{1 + K A_1}, \quad R_{if} = R_{in} (1 + K A_1), \quad R_{of} = \frac{R_{out}}{1 + K A_1}$$

تقریب
مبارز

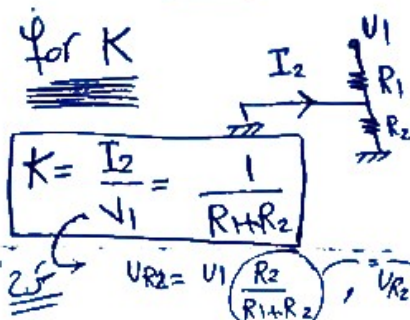
U-I topology



$$R_{in} = \frac{1}{g_{m1}}$$

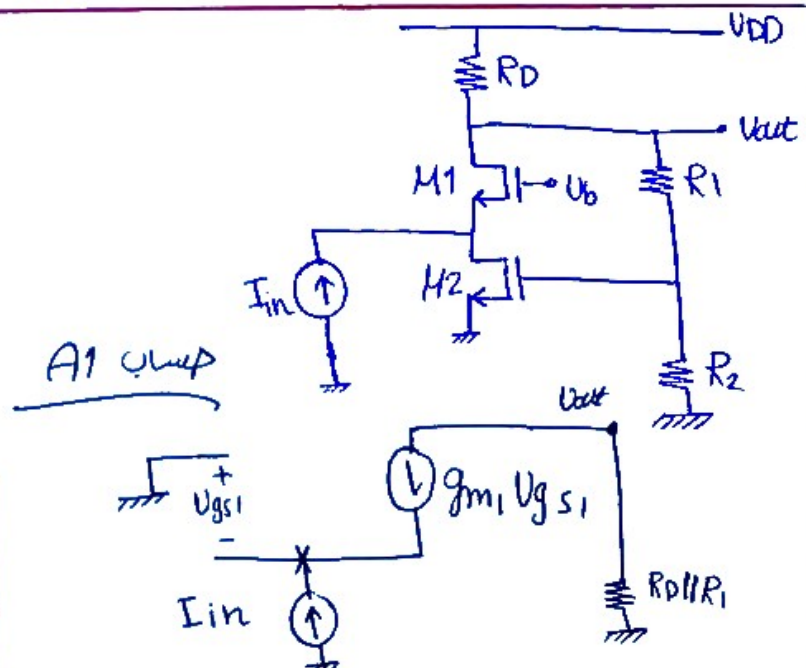
$$R_{out} = R_D \parallel R_1$$

for K



$$K = \frac{V_2}{V_1} = \frac{R_2}{R_1 + R_2}$$

$$V_{R2} = V_1 \cdot \frac{R_2}{R_1 + R_2}, \quad V_{R2} = I_2 R_2$$



since ~~the circuit is~~
 $V_{out} = (R_D \parallel R_1) \cdot I_{in}$

$$\therefore \frac{V_{out}}{I_{in}} = R_D \parallel R_1$$

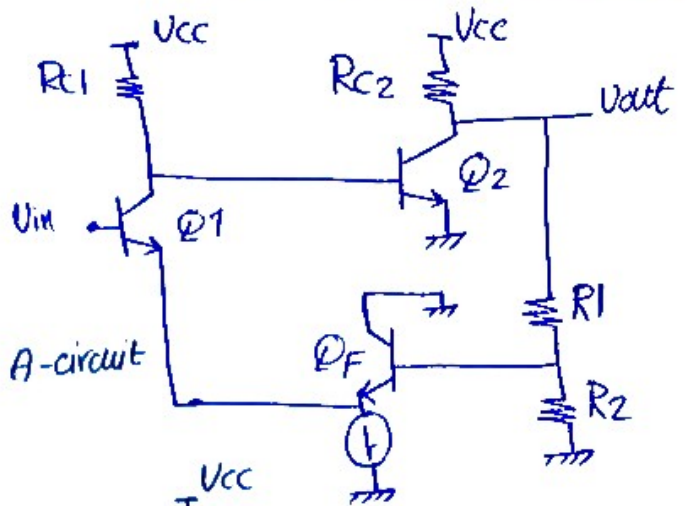
این یک تقویت کننده
جریان به ولتاژ است

Assume Q_F as a part of forward circuit A1

Q_F belongs to A1 circuit

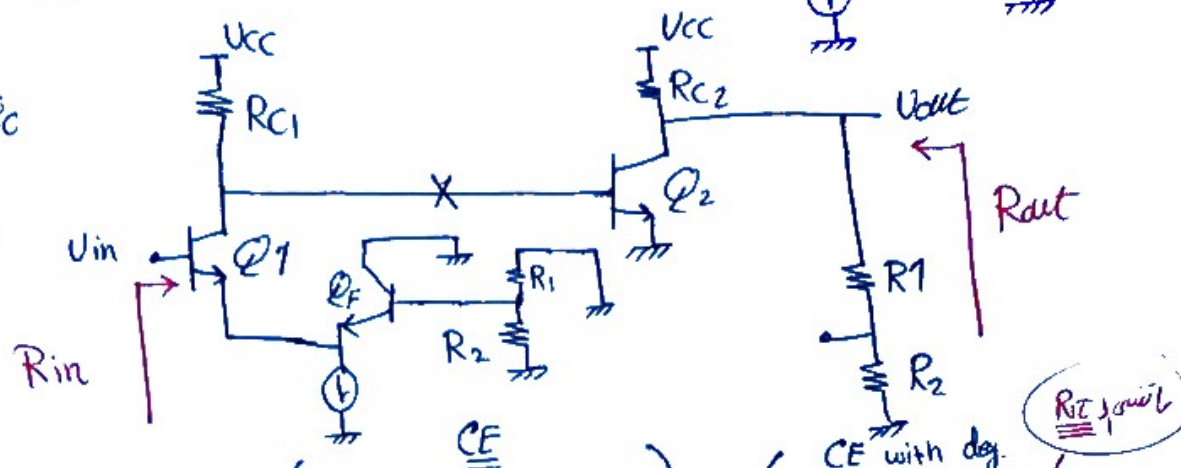
Find A_F , R_{if} , R_{of} ...

U-U topology, by obtaining the A-circuit



جواب

→ A circuit



$$\frac{V_{out}}{V_{in}} = \frac{V_{out}}{V_X} \cdot \frac{V_X}{V_{in}} = \left(-g_{m2} [(R_1 + R_2) \parallel R_C] \right) \cdot \left(\frac{-R_C \parallel r_{\pi 2}}{\frac{1}{g_{m1}} + \frac{1}{g_{mF}} + \frac{R_1 \parallel R_2}{\beta + 1}} \right)$$

$$\frac{V_{out}}{V_{in}} = A_V = \frac{g_{m2} [R_C \parallel (R_1 + R_2)] [R_C \parallel r_{\pi 2}]}{\frac{1}{g_{m1}} + \frac{1}{g_{mF}} + \frac{R_1 \parallel R_2}{\beta + 1}}$$

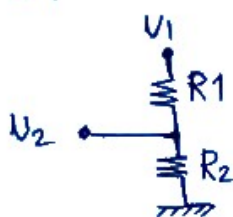
$$R_{in} = \frac{1}{g_{m1}} + \frac{R_B}{\beta + 1}$$

$$R_{out} = R_{C2} \parallel (R_1 + R_2)$$

$$R_{in} = r_{\pi 1} + (\beta + 1) \left[\frac{1}{g_{mF}} + \frac{(R_1 \parallel R_2)}{\beta + 1} \right]$$

now K?

K-circuit



$$K = \frac{V_2}{V_1} = \frac{R_2}{R_1 + R_2}$$

$V_1 \approx V_{input}$
 $V_2 \approx V_{feedback}$

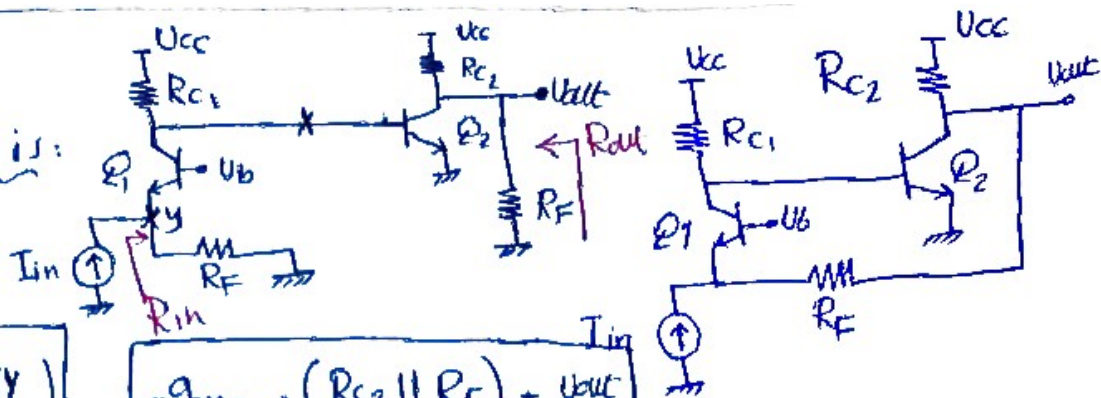
$$A_F = \frac{A_1}{1 + K A_1}$$

$$R_{if} = R_{in} (1 + A_F K)$$

$$R_{of} = \frac{R_{out}}{1 + K A_1}$$

... V_1

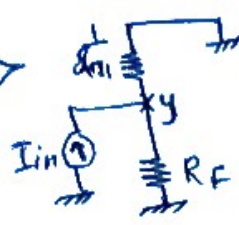
U-I topology
the circuit of A1 is:



$$\frac{V_{out}}{I_{in}} = \left(\frac{V_{out}}{V_x} \right) \left(\frac{V_x}{V_y} \right) \left(\frac{V_y}{I_{in}} \right)$$

$$-g_{m2} \cdot (R_{C2} \parallel R_F) = \frac{V_{out}}{V_x}$$

$$\Rightarrow \frac{V_x}{V_y} = g_{m1} (R_{C1} \parallel r_{\pi 2})$$

for $\frac{V_y}{I_{in}} \Rightarrow$  $\infty \frac{V_y}{I_{in}} = \left(\frac{1}{g_{m1}} \parallel R_F \right)$

$$= \frac{\frac{1}{g_{m1}} \cdot R_F}{\frac{1}{g_{m1}} + R_F}$$

$$\& \frac{V_{out}}{I_{in}} = \left[g_{m2} (R_{C2} \parallel R_F) \right] \cdot \left[g_{m1} (R_{C1} \parallel r_{\pi 2}) \right] \cdot \left[\frac{\frac{1}{g_{m1}} \cdot R_F}{\frac{1}{g_{m1}} + R_F} \right]$$

$$\& A_1 = \left[g_{m2} (R_{C2} \parallel R_F) \right] \left[R_{C1} \parallel r_{\pi 2} \right] \left[\frac{R_F}{\frac{1}{g_{m1}} + R_F} \right]$$

نفس جابو برتقورده

$$R_{in} = \frac{1}{g_{m1}} \parallel R_F \quad R_{out} = R_{C2} \parallel R_F$$

for K 

$$K = \frac{I_2}{v_1} = \frac{I_2}{-I_2 R_F} = \frac{-1}{R_F}$$

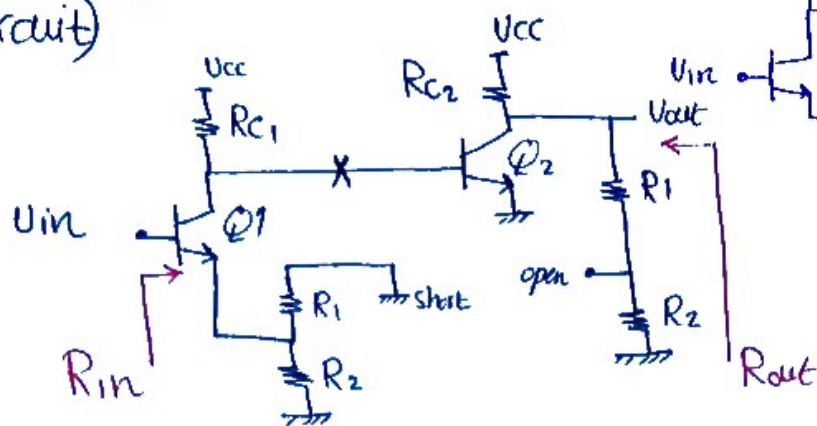
$$A_F = \frac{A_1}{1 + K A_1}$$

$$R_{if} = \frac{R_{in}}{1 + K A_1}, R_{of} = \frac{R_{out}}{1 + K A_1}$$

الآن بالتقريب بشكل مباشر في لقوانين

مَعْدَل

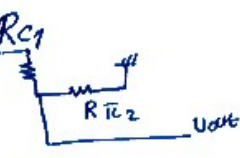
⇒ Find the closed loop parameters
 → U-U topology
 the (A-circuit)



کپی نہ کرنا
 کتب خانہ

$$\therefore \frac{V_{out}}{V_{in}} = \frac{V_{out}}{V_x} \cdot \frac{V_x}{V_{in}}$$

$$= \left(-g_{m2} \cdot [R_{c2} \parallel (R_1 + R_2)] \right) \cdot \left(\frac{-R_{c1} \parallel r_{\pi 2}}{\frac{1}{g_{m1}} + (R_1 \parallel R_2)} \right)$$



$$\therefore \frac{V_{out}}{V_{in}} = +g_{m2} [R_{c2} \parallel (R_1 + R_2)] \cdot \frac{R_{c1} \parallel r_{\pi 2}}{\frac{1}{g_{m1}} + (R_1 \parallel R_2)}$$

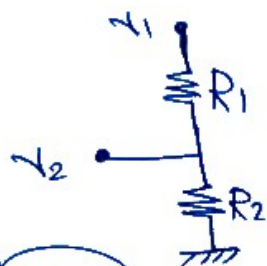
the open
 loop gain

$$R_{in} = [r_{\pi 1} + (B+1)(R_1 \parallel R_2)]$$

$$R_{out} = R_{c2} \parallel (R_1 + R_2)$$

For K

feedback $\frac{V}{V}$
 input $\frac{V}{V}$



$$K = \frac{V_2}{V_1} = \frac{R_2}{R_1 + R_2}$$

∞ A_1, R_{in}, R_{out} ✓

∞ K ✓

منظور فی بقائے

$$A_F = \frac{A_1}{1 + K A_1}$$

$$R_{if} = R_{in} (1 + K A_1), \quad R_{of} = \frac{R_{out}}{1 + K A_1}$$