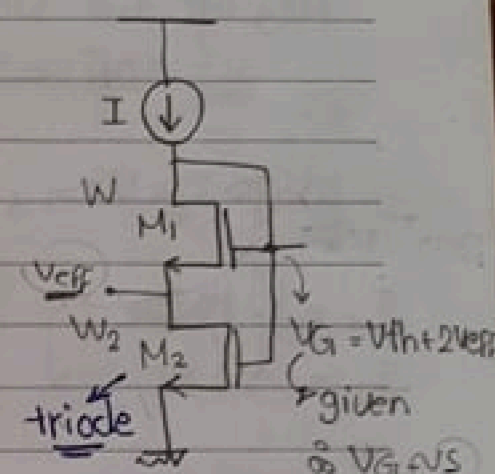
Sheet 1 _ Analog

— Sec 1.
— Eng. Bassem

(1) show that $W_2 = \frac{1}{4} W$ to generate the requierd bias voltage.



$I_{M_1} = I_{M_2}$

SAT ↲ ↳ Triode

$\frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L}\right) (V_{th} + V_{eff} - V_{th})^2$

$= \mu_n C_{ox} \frac{W_2}{L} (V_{th} + 2V_{eff} - V_{th}) V_{eff}$

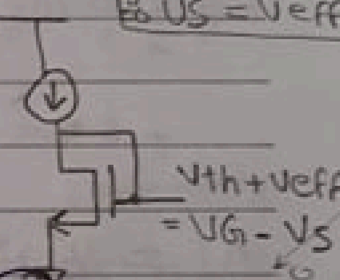
in triode we ignore the square

Given: ∴ $V_G - V_S = V_{th} + V_{eff}$

$\boxed{∴ V_S = V_{eff}}$

$\frac{1}{2} W V_{eff}^2 = W_2 * 2 V_{eff}^2$

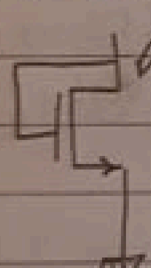
$\boxed{W_2 = \frac{1}{4} W}$

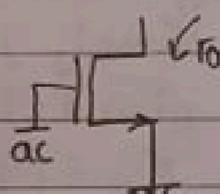


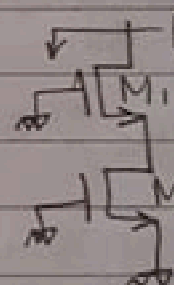
for M_2 : $V_{DS} = V_{eff}$. $V_{GS} - V_{th} = 2V_{eff}$

∴ $V_{GS} - V_{th} > V_{DS}$ ∴ M_2 triode

(2) remember :



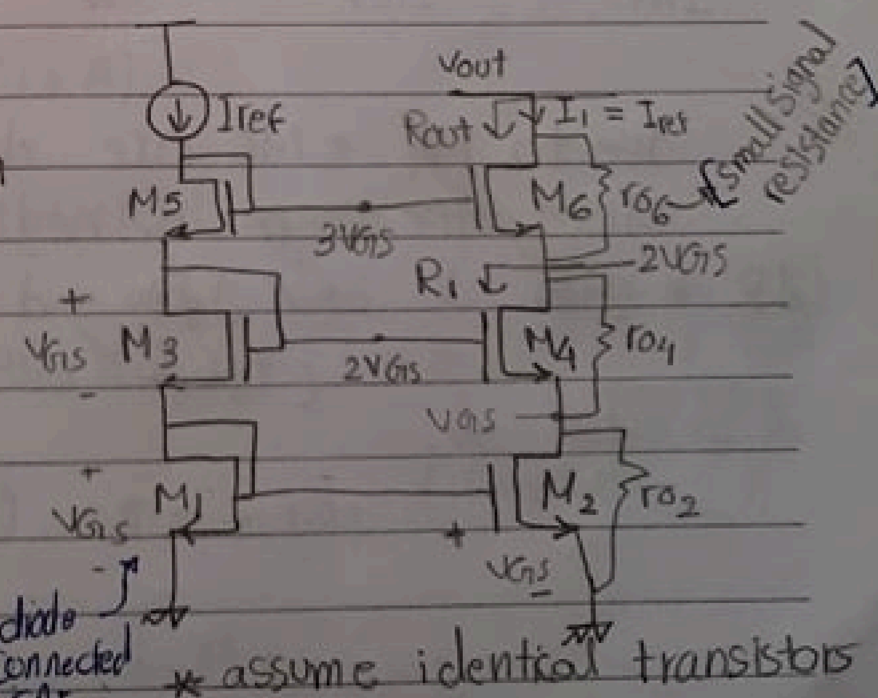




$R_{out} = r_{o2} * g_{m1} r_{o1} + r_{o2} + r_{o1}$

(A) $R_1 = r_{o2} * g_{m4} r_{o4} + r_{o2} + r_{o4}$

$R_{out} = R_1 * g_{m6} r_{o6} + r_{o2} + r_{o4}$



(B) For M_6 : $V_{DS} \overset{?}{>} V_{GS} - V_{th}$

$V_{out} > 3V_{GS} - V_{th}$

↳ $V_{eff} + V_{th}$

$V_{out} > 3V_{eff} + 2V_{th}$

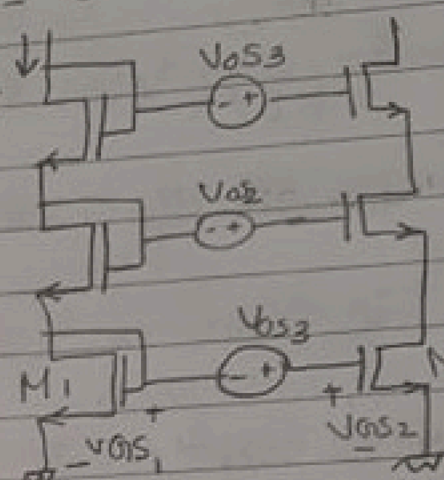
$V_{comp} = 3V_{eff} + 2V_{th}$

[أقل Voltage تخلي كل الترانزستورات شغالة في الـ sat]

* assume identical transistors *

(c) Assuming random mismatches between "matched" transistors find $\frac{\Delta I_1}{I_{ref}}$

للتنبيه ← يبقى تأكيد دول أكتر اتنين trans. اللي بيعملوا mirroring ال current لل M_2, M_1 critical ولوحصل فيهم offset.



$V_{GS2} = V_{GS1} + V_{OS1}$

$I_1 = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L}\right) (V_{GS} - V_{th})^2$

$I_2 = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L}\right) (V_{GS} + V_{OS} - V_{th})^2$

$\Delta I = I_2 - I_1$

$= \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L}\right) \left[\cancel{(V_{GS} - V_{th})^2} + V_{OS}^2 \right.$

$\left. + 2 V_{OS} (V_{GS} - V_{th}) - \cancel{(V_{GS} - V_{th})^2} \right]$ $\quad \approx V_{OS} \lll$

$\Delta I \approx \underbrace{\cancel{\tfrac{1}{2}} \mu_n C_{ox} \left(\frac{W}{L}\right)}_{g_m} \times \cancel{2} V_{OS} (V_{GS} - V_{th})$, $g_m = \frac{2 I_{ref}}{V_{eff}}$

$g_m = \frac{\partial I_{DS}}{\partial V_{GS}}$

$\Delta I \approx g_m V_{OS1}$

$\frac{\Delta I}{I_{ref}} = \frac{g_m V_{OS1}}{I_{ref}} = \frac{2 V_{OS1}}{V_{eff}}$

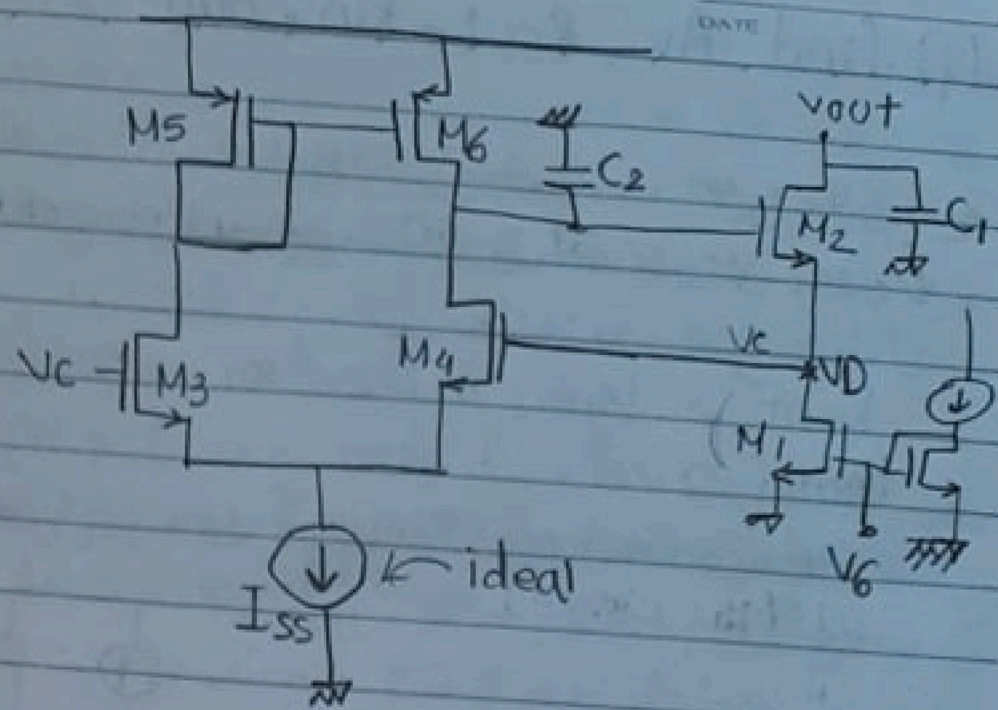
(ال source مش متوصل على ال ground)

due to M4 & M6 are degenerative so the offset in them is neglable → [بما أن M4 متوصلة على ال ro2 لل gnd مش متوصلة لل gnd على طول فكدة ال gain الى طالع نتيجة ال vos2 مش كبيرة أوي فنهملها)

(3)

From the feedback theory :

كل ما ال gain بيزيد كل ما ال VD تبقى بتساوي ال V_C



(A) $V_{comp} = V_{eff} + V_C$

(B) $V_C|_{min} = V_{eff\,1}$

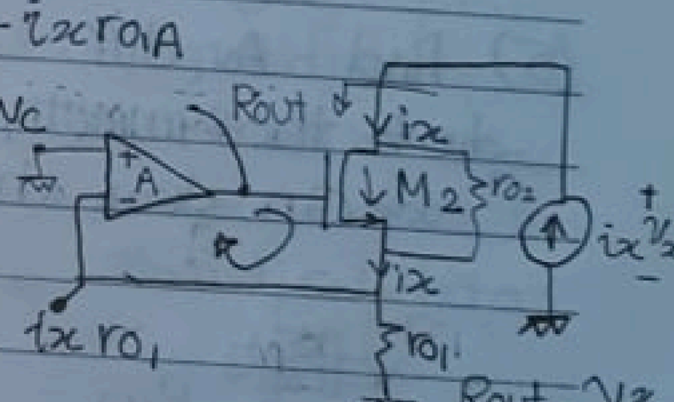
بس هنا كدا زودنا خودنا أنه ال Vc لازم تزيد ال $V_t + V_{gs3}$
on current source

gain stage bec. the differential amplifier is just giving again

& $V_{comp,optimum} = V_{eff1} + V_{eff2}$

(C) ★ أداء هنا حاجات ة [Connected in series] يبقى

الأسهل أني أحط current source ع out node الـ Vc وأشوف الـ voltage اللي هتقع عليها وأجيب الـ Rout.



$Rout = \frac{v_x}{i_x}$

$i_2 = -g_{m2}\, i_x\, r_{o1} (1 + A) = g_{m2} V_{gs}$

$i|_{r_{o2}} = i_x [1 + g_{m2} r_{o1} (1 + A)]$

$v_x = i_x r_{o2} [1 + g_{m2} r_{o1} (1 + A)] + i_x r_{o1}$

$Rout = \frac{v_x}{i_x} = r_{o2} [1 + g_{m2} r_{o1} (1 + A)] + r_{o1}$

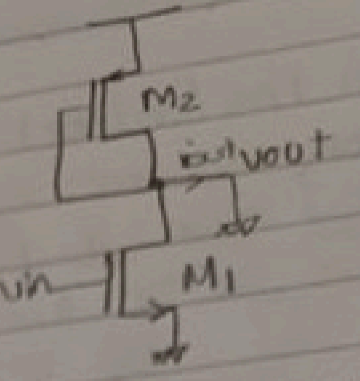
$= r_{o1}\, g_{m2} r_{o2} (1 + A) + r_{o2} + r_{o1}$

ال Rout زادت بسبب ال amplifier اللي عامله -ve [feedback.

(D) $A = g_{m3} (r_{o3} // r_{o5}) \rightarrow$ of M_3

$A(s) = g_{m3} (r_{o3} // r_{o5} // 1/sC \ldots$ [illegible]

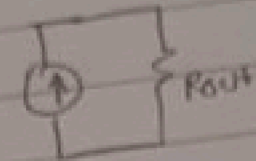
(4) find Av. Rout. Rin. Gm



- Rin = ∞ (المفروض كنت احط الsource واشوف
[الcurrent الموجود تكته و اقسمه على بعض]

- Rout = $1/g_{m2} // r_{o2} // r_{o1}$

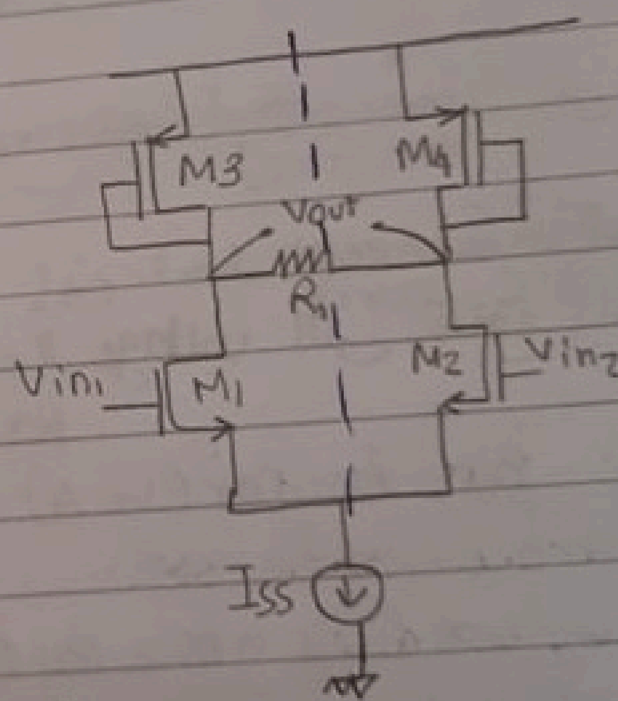
- Gm) قدرة الcct. على انها تحول الinput voltage لـ output current
[transconductance of the circuit]

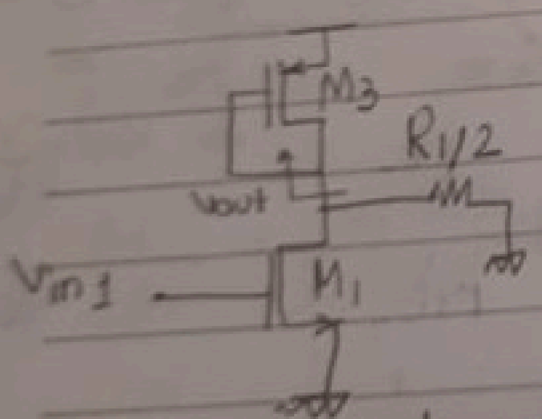


$$G_m = \frac{i_{out}}{v_{in}} = \frac{-g_{m1} v_{in}}{v_{in}} = -g_{m1}$$

$$A_v = G_m * R_{out} = -g_{m1} * (1/g_{m2} // r_{o1} // r_{o2})$$

(5) Find A_v, diff.
due to the symmetry in the cct.
we can draw a half cct.





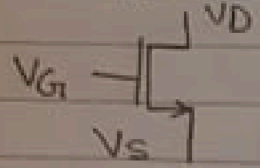
$$A_v = -g_{m1} \left(\frac{1}{g_{m3}} // r_{o3} // \frac{R_1}{2} // r_{o1} \right)$$

Analog electronics

Sec. 2
Eng. Basem

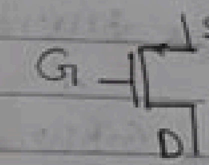
→ Saturation conditions:

NMOS

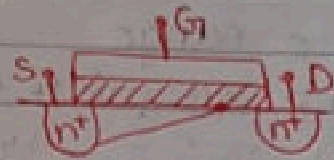


$V_{DS} > V_{GS} - V_{th}$
$V_{GD} < V_{Th}$

PMOS



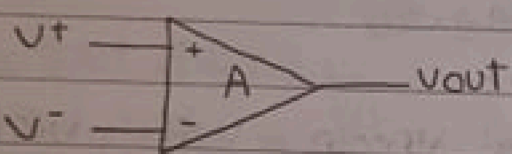
$V_{D,max} = V_G + |V_{th}|$
$V_{G,min} = V_D + |V_{th}|$



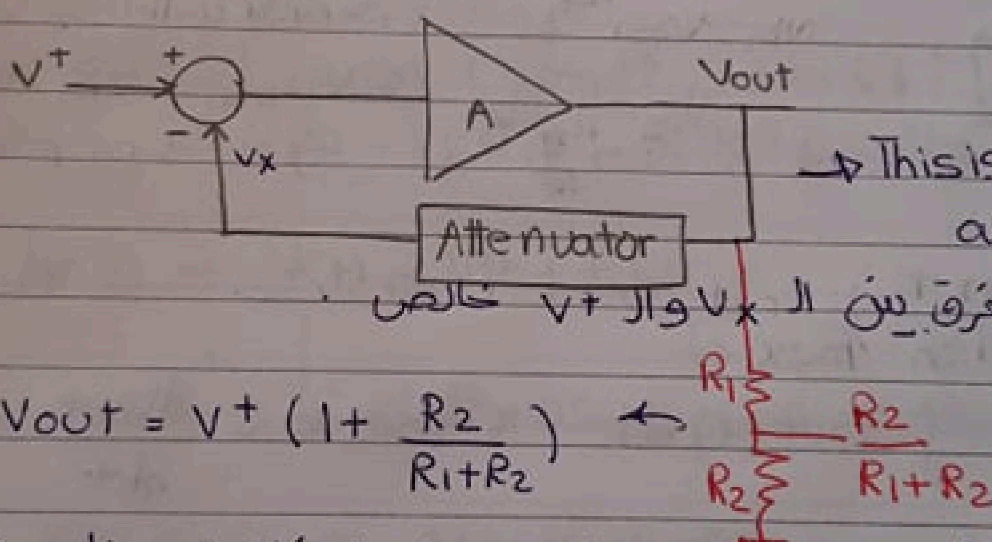
$V_{Dmin} = V_G - V_{th}$
$V_{G\,max} = V_D + V_{th}$

يبقى هنا ال sat معناها عدم قدرة ال channel على أنها تكمل لحد الآخر وتعمل pinchoff.

* op-amps:



هو بيطرح 2i/ps من بعض وبعدين بيهم gain عالي وبتظهر أهميته فال feedback loop)



→ This is a high-precision amplifier

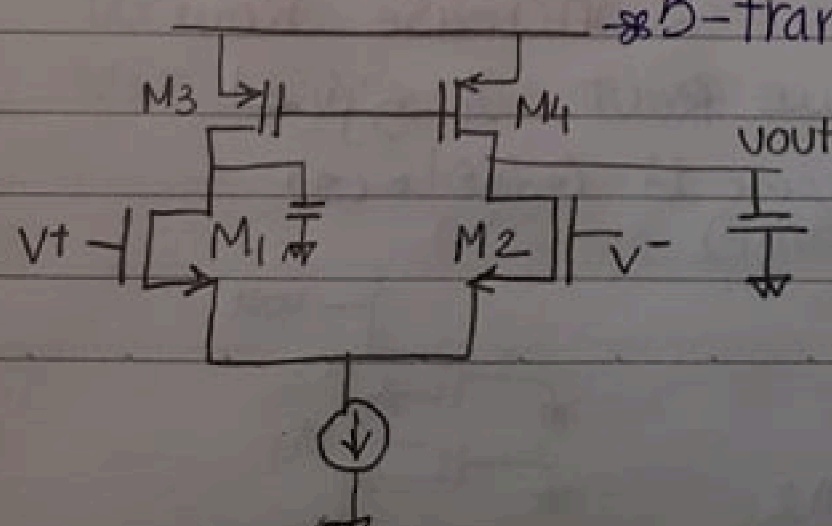
(لأنه بيقلل الفرق بين ال Vx وال V+ خالص.

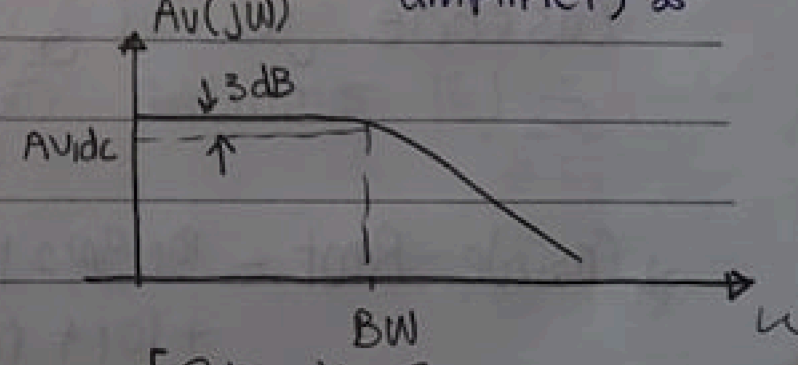
$$V_{out} = V^+ \left(1 + \frac{R_2}{R_1+R_2}\right)$$

← فهنا لو عاوزة أ apply ← amplifier أحط فال feedback attenuator

← أقرب دايرة ليه لل op-amplifier هي ال diffrential pair

* 5-transistor OTA (opretional transconductance amplifier) *





$[P_{ok} = 1/RC]$

at small signal analysis

* $A_{v,dc} = -g_m (r_{o2} // r_{o4})$ → I_{SS} open circuit.

* $BW = \frac{1}{C_L (r_{o2} // r_{o4})}$

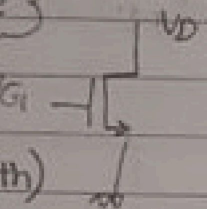
* $GBW = \frac{g_m}{C_L}$ (closed loop B.w ∝ GBW)
 ← بيحدد ال Speed تبع الدايرة.

large signal

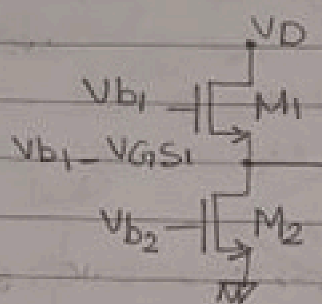
* input common mode range
 $V_{cm,min} = V_{comp, I_{SS}} + V_{eff1} + V_{th}$
 $V_{cm,max} = V_{DD} - V_{SG3} + V_{th1} = V_{DD} - (V_{eff3} + |V_{th}|_3) + V_{th1}$
 ↳ أنا خايفة إن M_1 يخرج ما ل SAT فكدة بيجيب $V_{cm,max}$

* output swing :
 $V_{out,max} = V_{DD} - V_{eff4}$ (خايف لا M_4 يخرج ما ل sat)
 $V_{out,min} = V_{cm} - V_{th1}$ (خايف M_2 ,, ,, ,,)
 ↳ (اللي بيضمنلي إن I_{SS} شغال)

Note



$(V_{D,min} = V_G - V_{th})$



∴ ~~$V_{Dmin} = V_{eff2} + V_{eff1}$~~
 only valid if $V_{D2} = V_{eff2}$
∴ $V_{Dmin} = V_{b1} - V_{th1}$

* Slew rate :

$$SR = \left.\frac{dv_{out}}{dt}\right)_{max}$$

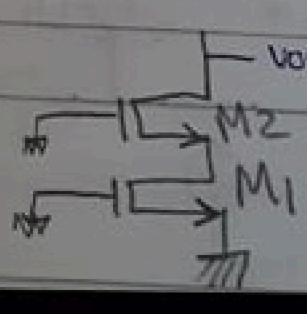
$$V_{out} = \frac{1}{C} \int i_{out}(t)\, dt \quad , \quad i_{out} = C \frac{dv_{out}}{dt}$$

$$\left.\frac{dv_{out}}{dt}\right)_{max} = \frac{I_{out,max}}{C} = \frac{I_{SS}}{C_L}$$

← أنا عاوزة أزود ال gain تبع الدايرة اللي فاتت لكي بستغل
∴ gain = Gm Rout ∴ increase Rout

لـ بنزود ال Rout عن طريق أننا نعمل Cascode
زي ما هنشوف ف Telescopic op-amp) في المحاضرة الجاية.

* Cascode $R_{out} = r_{o1} g_{m2} r_{o2} + r_{o1} + r_{o2}$
 $\simeq r_{o1} r_{o2} g_{m2}$



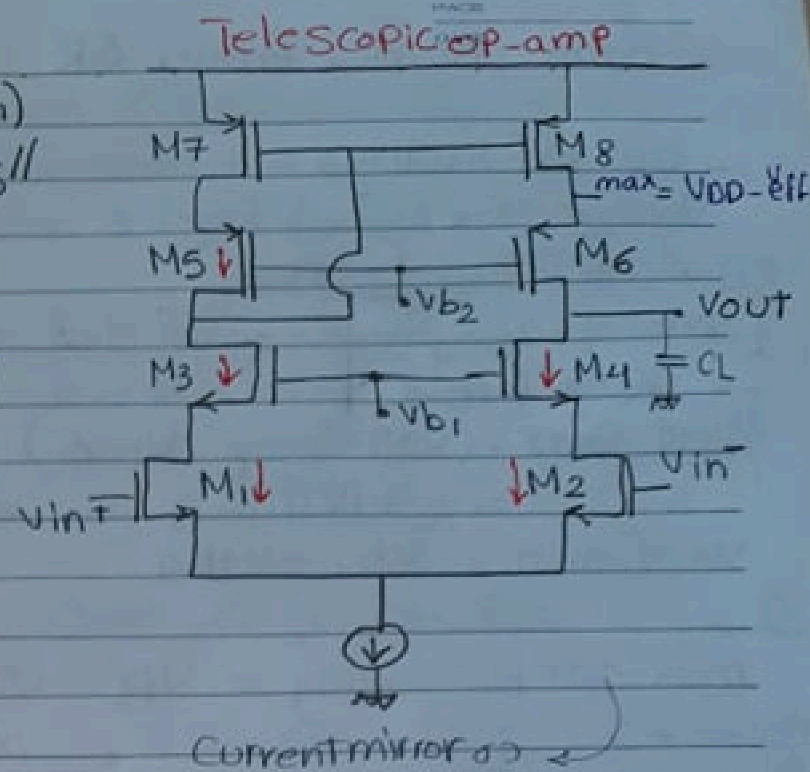
- Sheet 2 :
- problem 1 :-

(1) $A_{v,dc} = -g_{m1,2}\left(r_{o8} r_{o6} g_{m6} \,//\, r_{o2} r_{o4} g_{m4}\right)$ ($-g_{m1}(R_{up} // R_{down})$)

∴ all r_o & g_m are equal

∴ $A_{v,dc} \simeq -g_{m1} \frac{(g_m r_o)^2}{2}$

gain الـ 1 على 2



(2) $GBW = \frac{g_{m1}}{C_L}$

$BW = \frac{1}{R_{out} C_L}$

(3) Slew rate $= \frac{I_{SS}}{C_L}$

(4) output swing :

$V_{out,max} = V_{b2} + |V_{th6}|$

$V_{out,min} = V_{b1} - V_{th4}$

for max output swing ($V_{b2} \uparrow\uparrow$, $V_{b1} \downarrow\downarrow$)

$V_{b2}|_{max} = V_{DD} - V_{eff7} - (V_{eff6} + V_{th6})$

$V_{b1}|_{min} = \boxed{V_{CM}} - V_{th1} + \underbrace{V_{GS3}}_{\to (V_{eff3} + V_{th3})}$

→ at the assumption of $V_{cm} = V_{comp,I_{SS}} + V_{eff} + V_{th1}$

∴ max. o/p swing $= V_{max} - V_{min} = V_{DD} - (4V_{eff} + \text{Comp.})$

(5) Input CMR :

$V_{cm,min} = V_{comp,I_{SS}} + V_{eff1} + V_{th1}$

$V_{cm,max} = V_D + V_{th} = (V_{b1} - V_{GS3}) + V_{th1}$

أصلاً الـ SR $\neq \frac{I_{SS}}{C_L}$ هنشوف الورقة الجاية.

- Same $A_{v,dc}$ * GBW * SR

- output swing:

$V_{out,max} = V_{G} + |V_{th6}|$

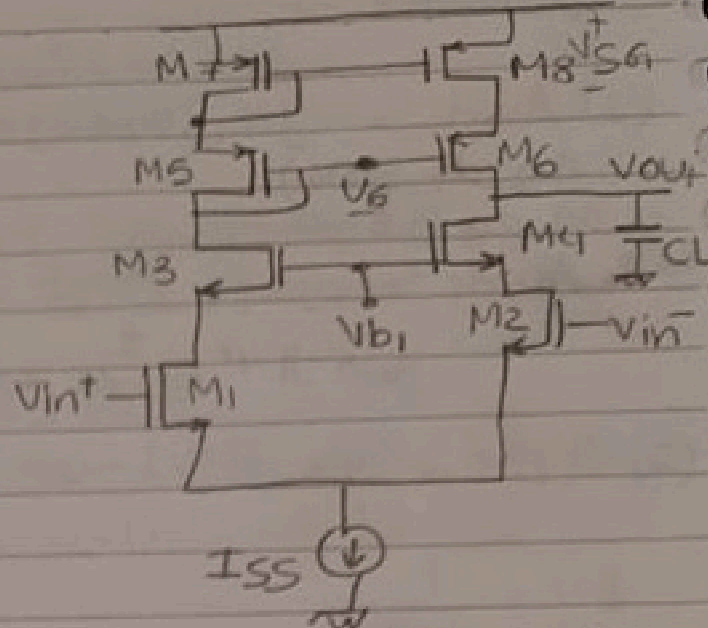
[M8 او الـM6 تانية] ←

[يخرجوا مالـ Sat

→ $V_6 + |V_{th}|_6$

$V_{out,max} = (V_{DD} - V_{SG7} - V_{SG5}) + |V_{th}|_6$

$V_{out,min} = V_{b1} - V_{th4}$



max output swing $= V_{DD} - (3V_{eff} + V_{SG} + V_{comp,ISS})$

$V_{b\,min} = V_{eff3} + V_{th3} + V_{eff1} + V_{comp}\ I_{SS}$

$V_{6\,max} = V_{DD} - V_{SG7} - V_{eff6}$

∴ $V_{out,max})_{max} - V_{out,min})_{min} = V_{DD} - V_{SG7} - V_{eff} + V_{th6}$

$- (V_{eff} + \cancel{V_{th3}} + V_{eff} + V_{comp,ISS}) + \cancel{V_{th}}4$

$= V_{DD} - (3V_{eff} + V_{SG7} + V_{comp,ISS}) + V_{th6}$