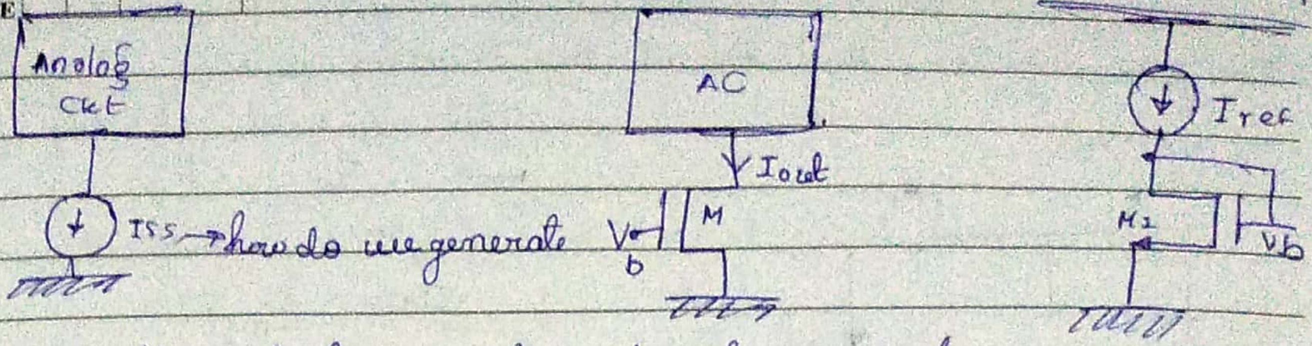
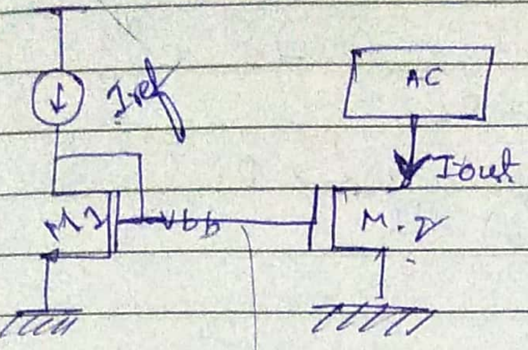
CHAPTER - 4

15th Oct'19



so we ↑ the potential each node act as capacitor

BASIC CURRENT MIRROR CIRCUIT



$$I_{ref} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 \left(V_{gs_1} - V_{th_1}\right)^2$$

$$I_{out} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_2 \left(V_{gs_2} - V_{th_2}\right)^2$$

$$\frac{I_{out}}{I_{ref}} = \frac{(W/L)_2}{(W/L)_1}$$

$$I_{out} = \frac{\left(\frac{W}{L}\right)_2}{(W/L)_1} \cdot I_{ref}$$

* Advantage: We can bias 'n' number of ckts by using only one reference (Band gap ref)
* All done, assuming there is no channel length modulation

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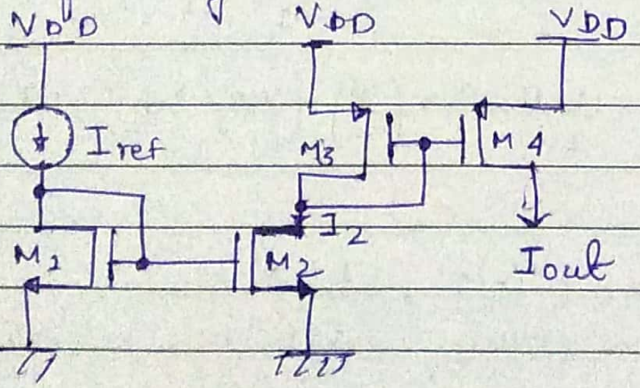
Q1 For following Ckt calculate Output current in



$$I_2 = \frac{(W/L)_2}{(W/L)_1} \times I_{ref}$$

CURRENT STEERING CKT

$$I_{out} = \frac{(W/L)_4}{(W/L)_3} \times I_2 = \frac{(W/L)_4}{(W/L)_3} \times \frac{(W/L)_2}{(W/L)_1} \times I_{ref}$$

→ here we steered current from one branch to another branch

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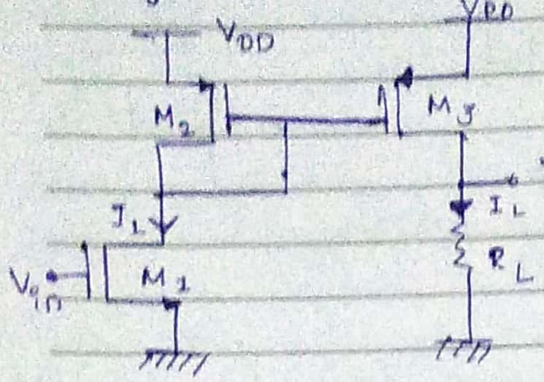
Q:2. For following ckt, Find small signal voltage gain



Find current flowing through $v_{out} = R_L$

Coz it's a small signal

$$I_1 = g_{m_1} v_{in}$$

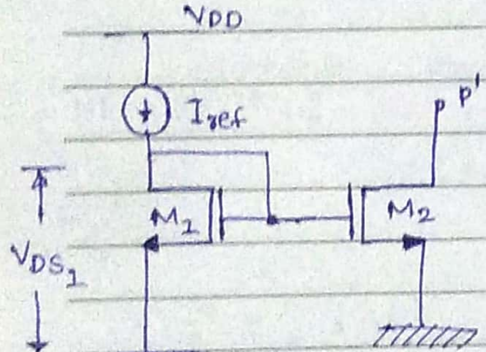
$$I_{out} = \frac{(W/L)_3}{(W/L)_2} \cdot g_{m_1} v_{in}$$

$$V_0 = I_{out} \times R_L$$

$$= \frac{(W/L)_3}{(W/L)_2} \cdot g_{m_1} v_{in} \times R_L$$

$$A_v = \frac{V_0}{v_{in}} = \frac{(W/L)_3}{(W/L)_2} g_{m_1} R_L \quad //$$

INCLUDING CHANNEL LENGTH MODULATION:



$V_{DS_1} = V_{gs_1} = V_{gs_2} \neq V_{DS_2}$

∴ coz it depends on another whatever will come on top

$$I_{ref} = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L}\right)_1 (V_{gs_1} - V_{th_1})^2 (1 + \lambda V_{DS_1})$$

$$I_{out} = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L}\right)_2 (V_{gs_2} - V_{th_2})^2 (1 + \lambda V_{DS_2})$$

$$\frac{I_{out}}{I_{ref}} = \frac{(W/L)_2}{(W/L)_1} \cdot \frac{(1 + \lambda V_{DS_2})}{(1 + \lambda V_{DS_1})} .$$

How can we match the potentials of both the transistors?

Cascode stage used to ↑ the output impedance, place one more common gate on the common source

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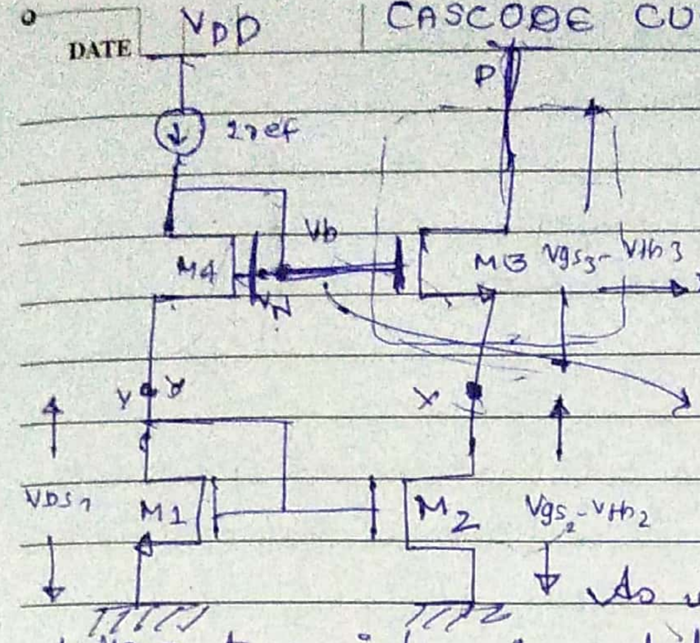
CASCODE CURRENT MIRROR CKT



$V_b = V_{gs_3} + V_x$

★ Sheilding property

only if $V_{gs4} = V_{gs_3}$; $V_{gs_2} = V_{gs_1}$

$\left(\frac{W}{L}\right)_4 = \left(\frac{W}{L}\right)_3$ $\left(\frac{W}{L}\right)_2 = \left(\frac{W}{L}\right)_1$

As we ↑ the P, it will not affect the bottom transistor is protected

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To make $V_x = V_y$

$V_b = V_{gs_3} + V_x$

To generate V_b, we connected 1 more diode load

We need to make $V_N = V_{gs_3} + V_x$

$V_N = V_{gs4} + V_x$

If we make that condition satisfied my $V_N = V_b$

*Imp trade off → $V_{gs1} = V_{gs_2}$ is the assumed condition

If we maintain them in saturation region my $V_{gs_2} \neq V_{gs1}$ coz one more V_{th} factor become extra there.

We cant get $I_{out} \neq I_{ref}$

* To overcome this we need to add one more V_{th} at M_2 but our V_p will ↑ by V_{th} its a large amount

APPLICATION :- (Current Mirror)

1> For biasing

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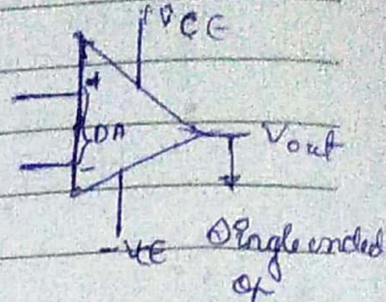
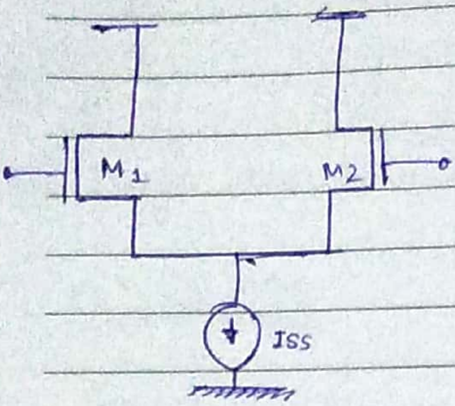
ACTIVE CURRENT MIRROR

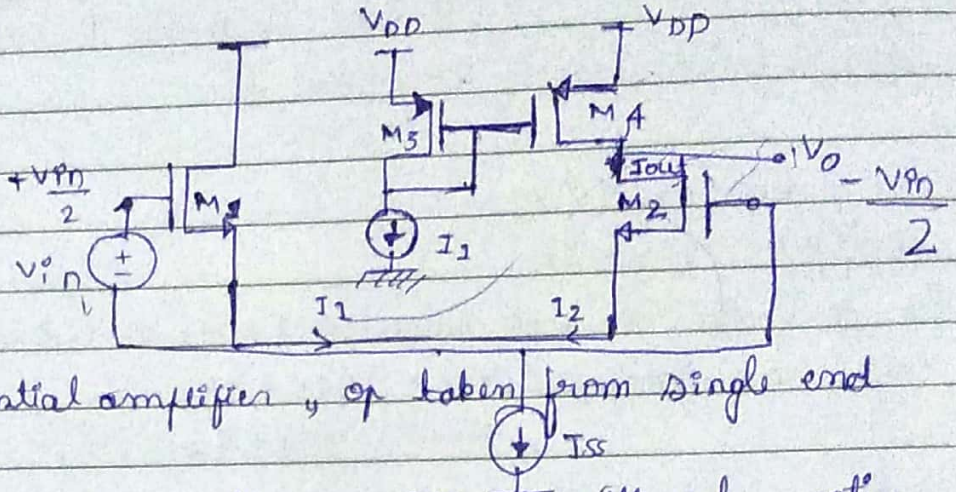
Basic current mirror → act like Active load.



* Input of an Op-amp is Differential amplifier
* Op-amp can (741IC) give only one output, or double ended output.



Taking output at one end. place active load, we can also do that with p-mos



Unbalanced differential amplifier, o/p taken from single end

Q: Why do we need to replace active resistive with only entire basic current mirror act as active lod

Q: How do we find the gain of this ckt?

⇒

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

WKT $A_v = G_M R_{out} \longrightarrow (1)$ ↳ (of ckt)

$$G_m = \frac{I_{out}}{V_{in}}$$

$$I_1 = g_{m_1} \cdot \frac{V_{in}}{2}$$

$I_{out} = I_1$ [If we match $(W/L)_4 = (W/L)_3$]

$$G_m = \frac{I_1}{V_{in}} = \frac{g_{m_1} \cancel{V_{in}}}{2 \cancel{V_{in}}} = \frac{g_{m_1}}{2}$$

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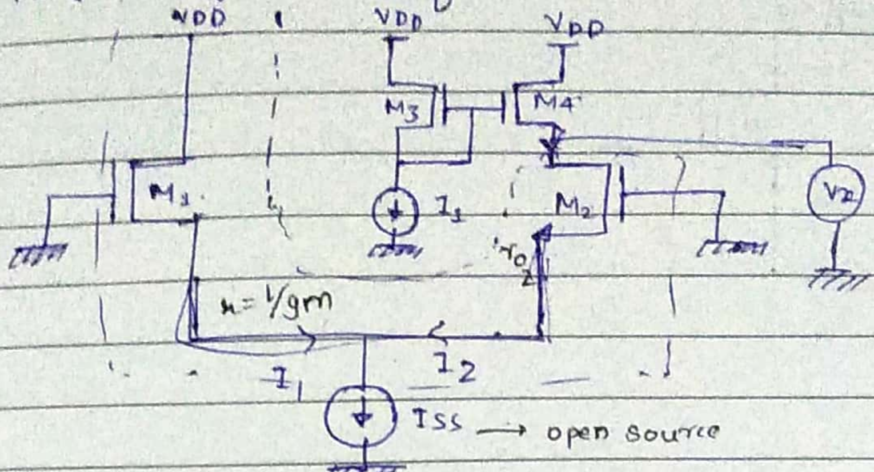
To find Rout.

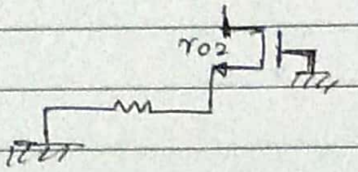
1> Short the input

2> apply voltage source, findout I_x



resistance offered by the below part

r_{o2} is series with $\frac{1}{g_m}$



→ Common Source Degeneration

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

$$= (1 + g_m r_{o2}) \frac{1}{g_{m1}} + r_{o2}$$ ($1/g_{m1}$ is so small) (same W/L = same g_m)

$$\approx 2r_{o2}$$

Total res = $2r_{o2} \| r_{o4}$

$$A_v = \frac{g_{m1}}{2}(2r_{o2} \| r_{o4})$$

* Current mirror used to amplify the signal & to bias the ckt.

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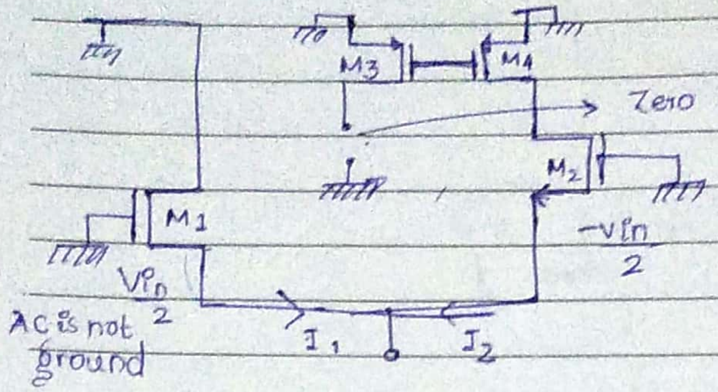
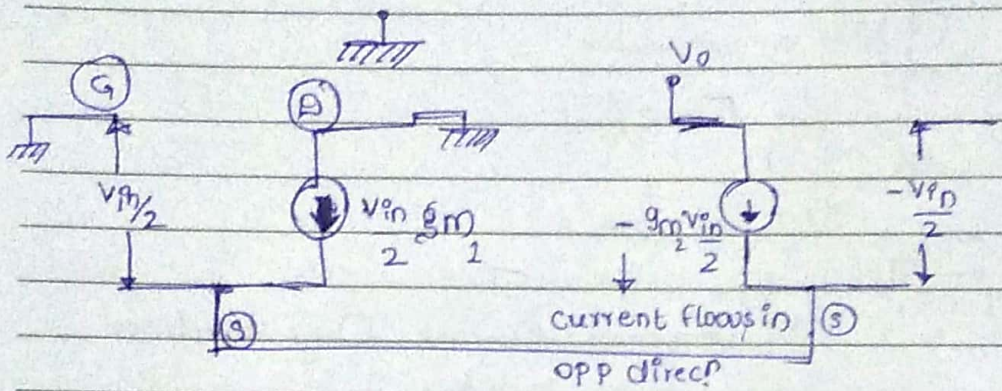
SMALL SIGNAL EQUIVALENT OF ACTIVE CURRENT MIRROR

Make all the dc sources to zero

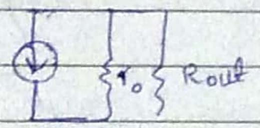


→ Zero current, hence in the current mirror ckt it's an open ckt

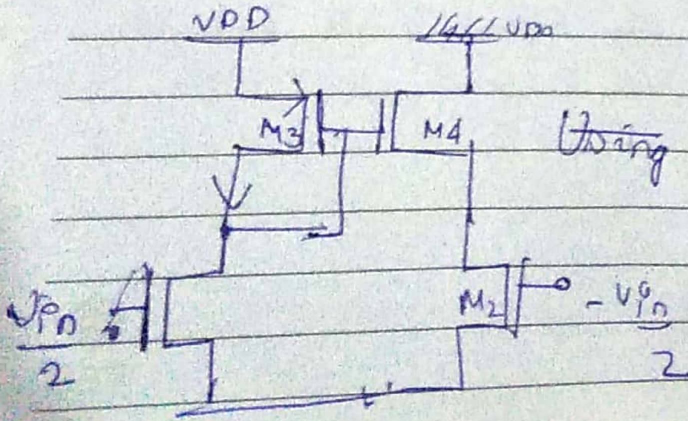


$I_{out} = +g_{m1}\frac{V_{in}}{2}$

* M_1, gate & drain are grounded, common diode connected $= \frac{1}{g_{m1}}$



* So it is final circuit proper or some issues are there?
Drawback :- Gain is half.



Using ~~[illegible]~~ abi
Using current M_1 to we can bias and M_2

* observed that ~~[illegible]~~ current of M_2 by M_1

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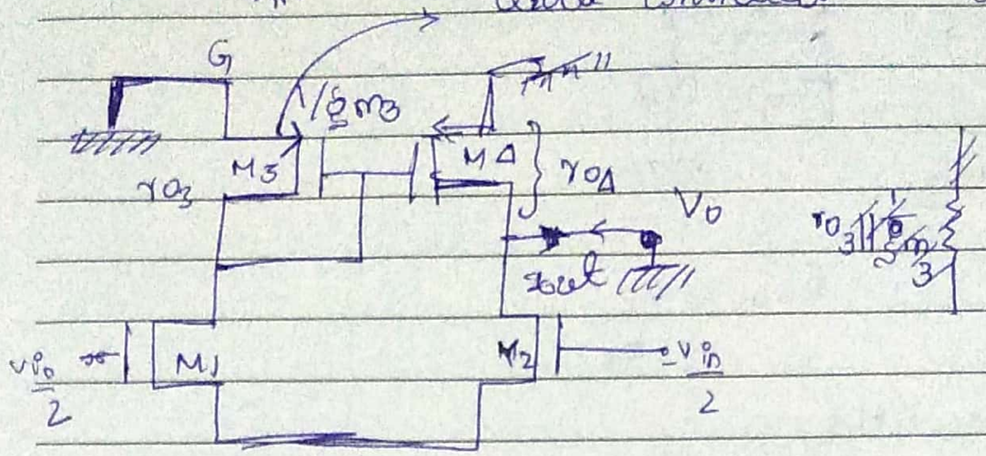
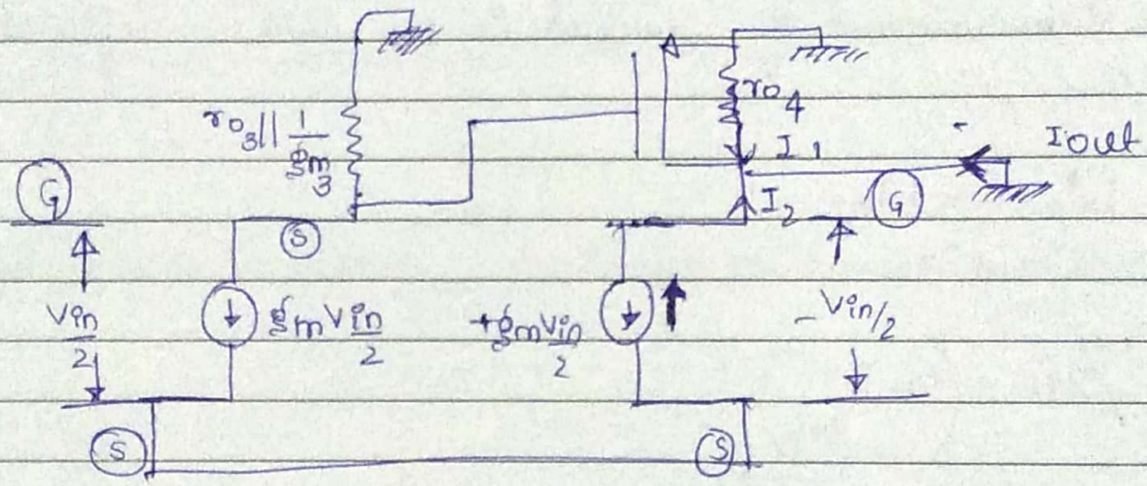
Small signal analysis ★

$A_v = G_m R_{out}$

$G_m = \frac{I_{out}}{v_{in}}$

diode connected $\quad R_3 = ?$





$I_{out} + I_1 + I_2 = 0$

$I_{out} = -(I_1 + I_2)$

$= -\left(g_m \frac{v_{in}}{2} + g_m \frac{v_{in}}{2}\right)$

$I_{out} = -g_m v_{in}$

$\frac{I_{out}}{v_{in}} = -g_m =$

R_{out} in

$-g_m = \frac{I_{out}}{V_{in}}$ [current is flowing in opp direction)

$G_m = -g_m$

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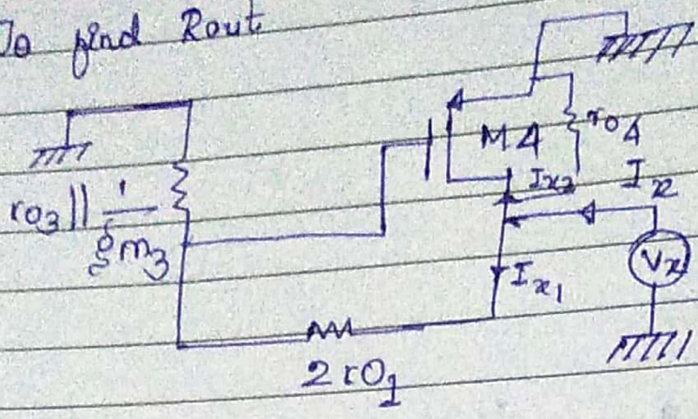
To find Rout



$I_x = I_{x1} + I_{x2}$ $\qquad$ $R_{out} = \frac{V_x}{I_x}$

$I_{x1} \rightarrow$ flows through M_1, M_2 & M_3

**We should take account of current in M_1 which is reflected at the M4.

$$I_x = I_{x1}' + I_{x2} + I_{x1}$$
$$= 2I_{x1} + I_{x2}$$

$$I_{x1} = V_x / 2r_{o1} + \left(r_{o3} \| \frac{1}{g_{m3}}\right)$$

very very small compared to $2r_{o1}$

$$I_{x2} = \frac{V_x - 0}{r_{o4}}$$

$$I_x = 2\left[\frac{V_x}{2r_{o1} + \frac{r_{o3}}{g_{m3}\left(r_{o3} + \frac{1}{g_{m3}}\right)}}\right] + \frac{V_x}{r_{o4}}$$

$$= \frac{V_x}{r_{o1}} + \frac{V_x}{r_{o4}}$$

$$= V_x\left[\frac{1}{r_{o1}} + \frac{1}{r_{o4}}\right]$$

$$I_x = V_x\left[r_{o1} \| r_{o4}\right]$$

$$R_{out} = \frac{V_x}{I_x} = r_{o1} \| r_{o4} = r_{o2} \| r_{o4}$$

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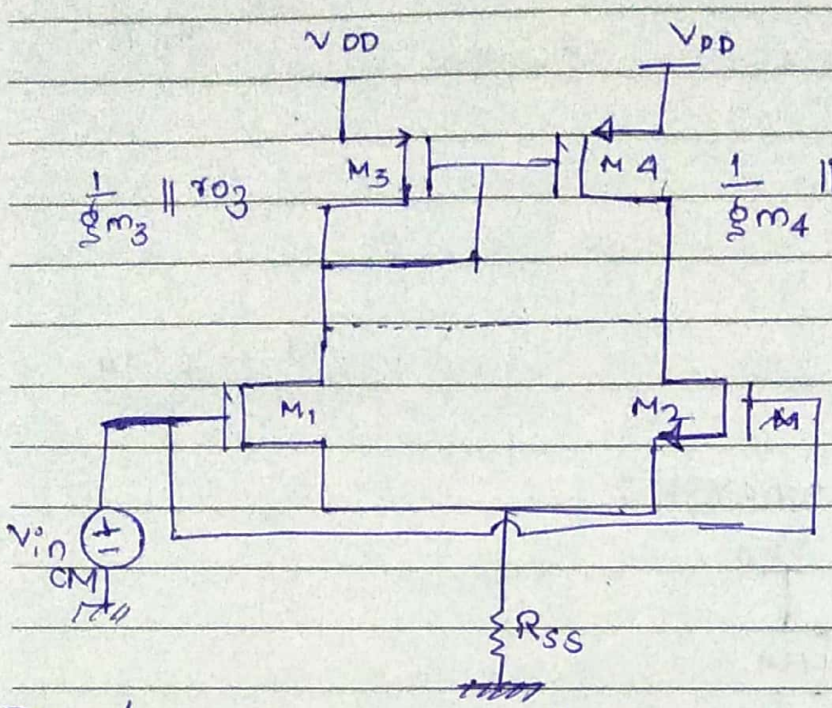
$A_v = G_m R_{out} = -g_m (r_{o2} \parallel r_{o4})$

~~A~~COMMON MODE RESPONSE OF ACTIVE CURRENT MIRROR LOAD.

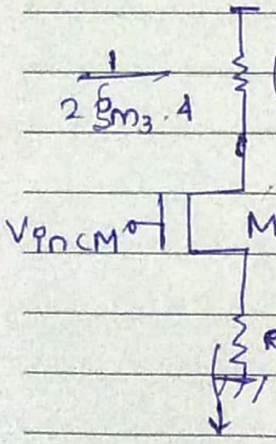
[~~NOT HERE-4~~ ~~SYLLABUS~~]

$A_v = ?$



$\frac{1}{g_{m3}} \parallel r_{o3}$ $\qquad$ $\frac{1}{g_{m4}} \parallel r_{o4}$

Gate, Source is common, drain also common as we shorted



$\frac{1}{2 g_{m3,4}}$

$\left(\frac{1}{g_{m3}} \parallel r_{o3}\right) \parallel \left(\frac{1}{g_{m4}} \parallel r_{o4}\right)$

$\longrightarrow$ approx $\frac{1}{g_{m3}}$ $\qquad$ $\longrightarrow$ approx $\frac{1}{g_{m4}}$

parallel of both $= \frac{1}{2}$

$\frac{1}{2 g_{m1,2}} + R_{SS}$

$A_v = \frac{\text{resistance at load}}{\text{" " source}}$

$$= \frac{-1/2 g_{m3,4}}{\frac{1}{2 g_{m1,2}} + R_{SS}} = \frac{-\cancel{2} g_{m1,2}}{(1 + 2 g_{m1,2} R_{SS}) \cancel{2} g_{m3,4}}$$

$$\boxed{= \frac{-g_{m1,2}}{(1 + 2 g_{m1,2}) R_{SS}\, g_{m3,4}}} = \frac{\partial V_{out}}{\partial V_{in\,CM}}$$

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Common Mode Rejection Ratio) = $\frac{A(\text{differen mode})}{A(\text{common mode})}$

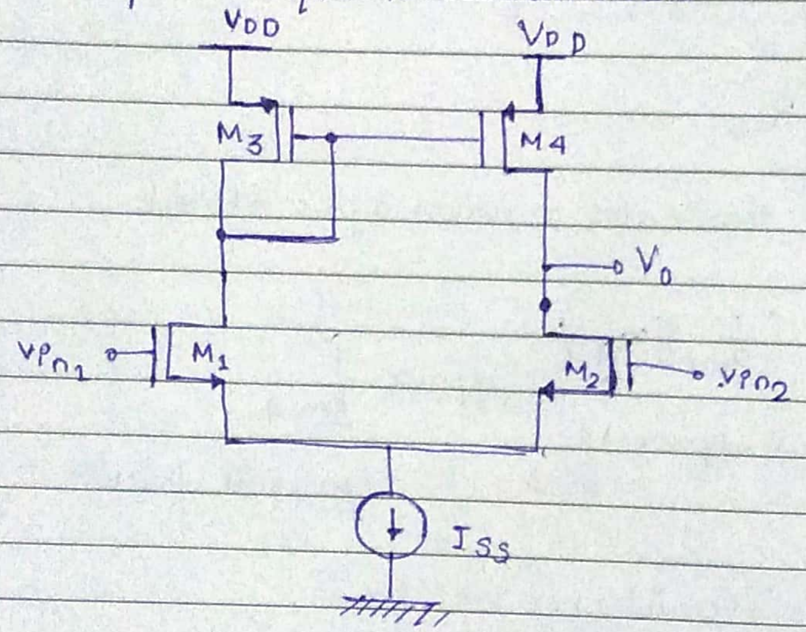
$$= \frac{g_{m_{1,2}}(r_{o2} \| r_{o4})}{\frac{g_{m1,2}}{1+2g_{m_{1,2}}R_{SS},\, g_{m3,4}}} = \underbrace{(1+2g_{m1,2}R_{SS})}_{g_m R_{SS}} \underbrace{g_{m3,4}\, v\,(r_{o2} \| r_{o4})}_{g_m r_o}$$

$$= (g_m r_o)(g_m r_o)$$

$$= (g_m r_o)^2 \;//$$

23rd Oct'19

LARGE SIGNAL ANALYSIS:



Case 1: When $V_{in_1} = +ve$ & $V_{in_2} = 0$

$M_1 = on$

$M_3 = on$ $\qquad V_0 = V_{in_1} - V_{in_2}$

$M_4 = on$

$M_2 = off$

* If all transistors on, the current is not flowing in M_2 act as open circuit, the current flowing through M_4 is stored in capacitor each & every node act as a capacitor

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hence $V_0 = V_{DD}$

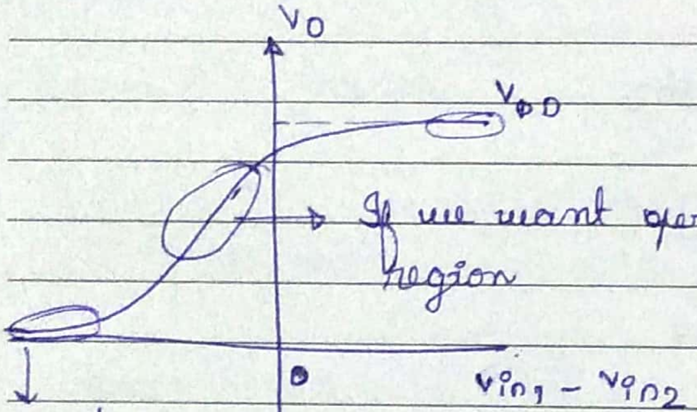
Case 2: When $V_{in_2} = +ve$ & $V_{in_1} = 0$

$M_4 = M_1 = $ off $= M_3 = V_{DD}$ gate & source at ~~source~~ same potential $V_{GS} = 0$
$M_2 =$ ON

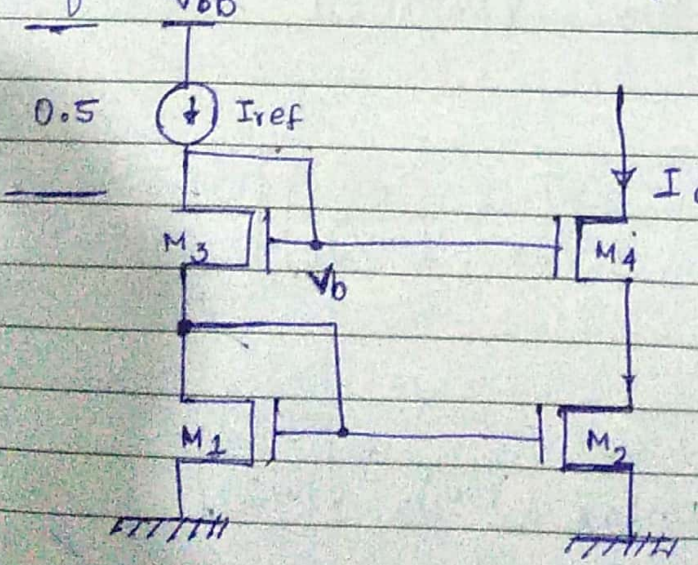
∴ The charge stored in capacitor will completely discharged $= 0$

Case 3: If we kept $V_{in_1} = +ve$ & slightly increasing the value of V_{in_2}, so it will start move towards Zero.

* As we applied larger differential input gain / slope will be Zero



Q.1 For following ckt find max value of I_{ref} ∋ the current source (I_{ref}) should sustain a voltage drop of 0.5 V across it



$$\cancel{I_{ref}} = \left(\frac{(W/L)_3}{(W/L)_4}\right) \times \cancel{I_{out}}$$

$$\cancel{I_{out}} = \left(\frac{(W/L)_2}{(W/L)_1}\right) \times$$

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$$V_b = V_{GS_3} + V_{GS_1}$$

$$I_{ref} = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L}\right)_3 \left(V_{GS_3} - V_{th_3}\right)^2$$

$$I_{ref} = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L}\right)_1 \left(V_{GS_1} - V_{th_1}\right)^2$$

$$2 I_{ref} = \mu_n C_{ox} \left(\frac{W}{L}\right)_3 \left(V_{GS_3} - V_{th_3}\right)^2$$

$$\left(\frac{L}{W}\right)_3 \frac{2 I_{ref}}{\mu_n C_{ox}} = \left(V_{GS_3} - V_{th_3}\right)^2$$

$$= \sqrt{\frac{2 I_{ref} L_3}{\mu_n C_{ox} W_3}} = V_{GS_3} - V_{th_3}$$

$$V_{GS_3} = V_{th_3} + \sqrt{\frac{2 I_{ref} L_3}{\mu_n C_{ox} W_3}}$$

$$V_{GS_1} = V_{th_1} + \sqrt{\frac{2 I_{ref}}{\mu_n C_{ox} \left(\frac{W}{L}\right)_1}}$$

$$V_b = V_{th_3} + V_{th_1} + \sqrt{\frac{2 I_{ref}}{\mu_n C_{ox} \left(\frac{W}{L}\right)_3}} + \sqrt{\frac{2 I_{ref}}{\mu_n C_{ox} \left(\frac{W}{L}\right)_1}}$$

$$V_{DD} - V_b = 0.5$$

$$V_{DD} - \left[V_{th_3} + V_{th_1} + \sqrt{\frac{2 I_{ref}}{\mu_n C_{ox}}} \left(\sqrt{\frac{1}{(W/L)_3}} + \sqrt{\frac{1}{(W/L)_1}} \right) \right] = 0.5$$

$$\cancel{0.5 - V_{DD} + V_{th_3}}$$

$$V_{DD} - 0.5 - V_{th_3} - V_{th_1} = \sqrt{\frac{2 I_{ref}}{\mu_n C_{ox}}} \left(\sqrt{\frac{1}{(W/L)_3}} + \sqrt{\frac{1}{(W/L)_1}} \right)$$

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$$(V_{DD}-0.5-V_{th3}-V_{th1})^2 = \frac{2 I_{ref}}{\mu_n C_{ox}}\left(\frac{1}{\sqrt{W/L_3}}+\frac{1}{\sqrt{W/L_1}}\right)^2$$

$$I_{ref} = \frac{(V_{DD}-0.5-V_{th3}-V_{th1})^2\,\mu_n C_{ox}}{2\left(\left[\sqrt{\left(\frac{L}{W}\right)_3}+\sqrt{\left(\frac{L}{W}\right)_1}\right]^2\right)}$$ //

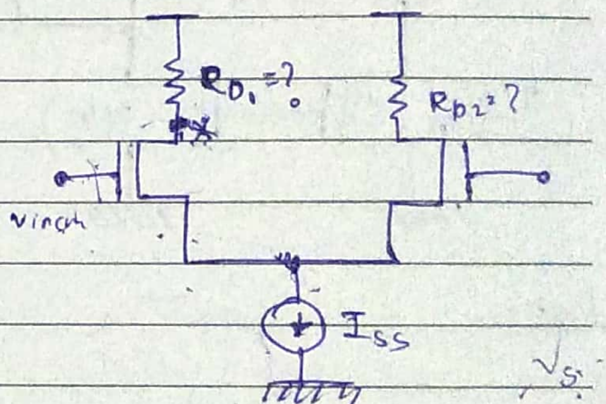
Q:2 Design differential amplifier circuit with resistive load for the following specifications, calculate the gain for the designed ckt

Power = 1 mW $\qquad V_{th} = 0.4 \qquad V_{inCM} = 1V$

$V_{gs} - V_{th} = 100mV$ $\qquad \mu_n C_{ox} = 100\,\mu A/V^2$

(overdrive) $\qquad V_{DD} = 1.8$

$I_{SS} = \cancel{5.5}\ 0.56mA$



$$g_m = \frac{2 I_D}{V_{gs}-V_{th}} = 5.5\,m\mho$$

$$g_m = \sqrt{2 I_D \mu_n C_{ox}\left(\frac{W}{L}\right)}$$

$$5.5\times10^{-3} = \sqrt{2\times0.277\times100\times10^{-6}\times\left(\frac{W}{L}\right)}$$

$$= 3.025\times10^{-5} = 5.54\times10^{-8}\left(\frac{W}{L}\right) \Rightarrow \left(\frac{W}{L}\right) = 546$$

$$x = V_{DD} - \frac{R_D I_{SS}}{2}$$

$$V_{gs}-V_{th} = 1.8 - R_D\left(\frac{0.555}{2}\right)$$

$$A_v = -g_m R_D$$

$$100\times10^{-3} = 1.8 - 0.2775 R_D \qquad = \cancel{0.03}\ 33.693 //$$

$$1.7 = 0.2775 R_D$$

$$R_D = 6.126\ k\Omega$$

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$$V_{DD} - \frac{R_D I_{SS}}{2} = V_{incm} - V_{th}$$

$$1.8 - R_D\left(\frac{0.55 \times 10^{-3}}{2}\right) = 0.6$$

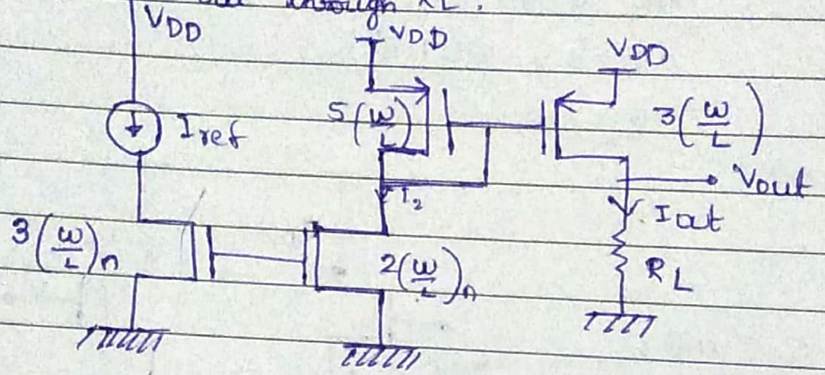
$= \cancel{10} = R_D = 4.36\,k\Omega$

$A_v = -g_m R_D$

$= -23.98$

24th Oct' 19

Q:2) Find I_{out} through R_L?



Soln:

$$I_2 = \frac{2\left(\frac{W}{L}\right)}{3\left(\frac{W}{L}\right)} \times I_{ref}$$

$$I_{out} = \frac{3\left(\frac{W}{L}\right)}{5\left(\frac{W}{L}\right)} \times I_2 = \frac{3\cancel{\left(\frac{W}{L}\right)}}{5\cancel{\left(\frac{W}{L}\right)}} \times \frac{2\cancel{\left(\frac{W}{L}\right)}}{3\cancel{\left(\frac{W}{L}\right)}} \times I_{ref}$$

$$= \frac{2}{5} I_{ref}$$

Design

Q:3 For following ckt shown below for the max power of 3mW?

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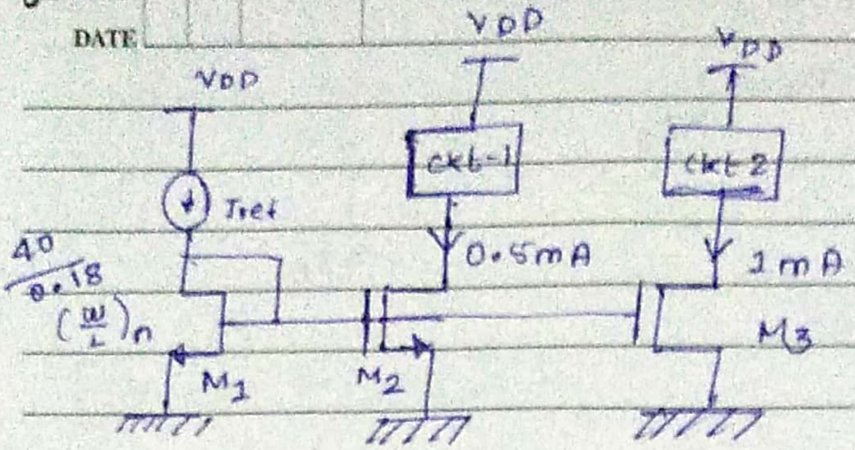


$V_{DD} = 1.8V$

$P = 3 \times 10^{-3}$

$P = V I$

$I_T = 1.66 \text{ mA}$ //

$1.667 = 1 + 0.5 + I_{ref}$

$I_{ref} = 0.17$

$1 \times \cancel{10^{-3}} = \frac{(W/L)_3}{653.59} \times 0.5 \times \cancel{10^{-3}}$

$= \frac{1}{0.5} \times 653.59 = 1307.1$

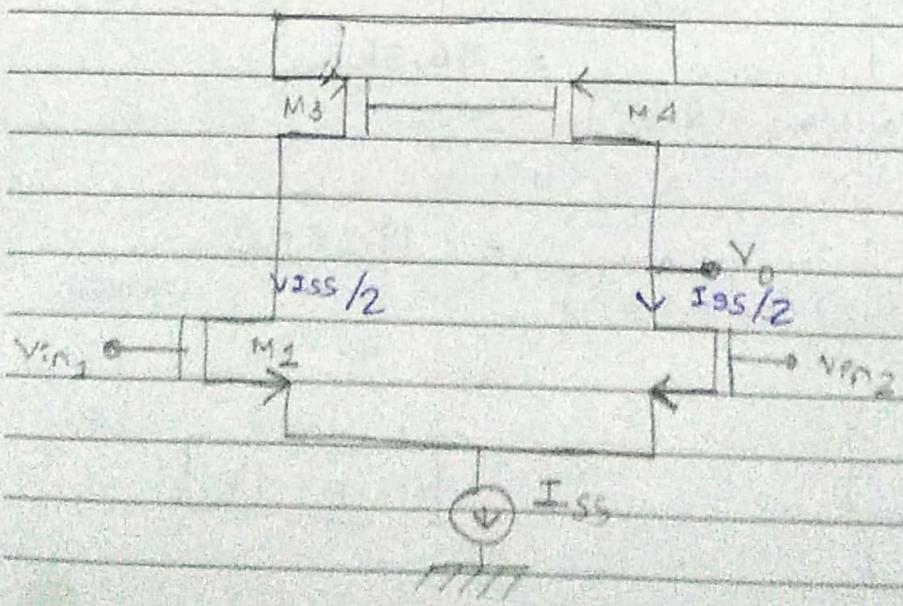
$0.5 \times \cancel{10^{-3}} = \frac{(\frac{W}{L})_2}{(\frac{W}{L})_n} \times 1.66 \times \cancel{10^{-3}}$

$(\frac{W}{L})_2 = \frac{0.5}{0.17} (\frac{W}{L})_n$

$= 2.94 (\frac{W}{L})_n$

$= 653.59$

Q: Design for the following ckt for following specifications,



$V_{th_n} = 0.5$

$V_{DD} = 1.8$

$V_{th_p} = -0.4$

$A_v = 20$

$P = 1mW$

$\lambda_n = 0.1 V^{-1}$

$\lambda_p = 0.2 V^{-1}$

$I_{SS} = 0.55 \text{ mA}$

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$A_v = 20$ $\qquad R_D = \frac{1}{\lambda I_D}$

~~$g_m = \sqrt{2 \mu_n C_{ox} \left(\frac{W}{L}\right) I_D}$~~ $\qquad r = \frac{1}{\lambda I_{D_1}}$

$A_v = g_m \left[r_{o1} \| r_{o2} \right]$

$= g_m \left[\frac{r_1 \cdot r_2}{r_1 + r_2} \right]$

$= g_m \left[\frac{\frac{1}{\lambda I_{D1}} \cdot \frac{1}{\lambda I_{D2}}}{\frac{1}{\lambda I_{D_1}} + \frac{1}{\lambda I_{D2}}} \right] = \qquad A_v = g_m \left(\frac{1}{\lambda_1 I_D + \lambda_2 I_D} \right)$

$20 = \frac{g_m}{I_D} \left[\frac{1}{0.3} \right]$ $\qquad A_v = \frac{2 \cancel{I_D}}{\cancel{I_D} (V_{gs} - \underset{0.5}{V_{th}}) (0.3)} = \frac{2}{(V_{gs} - 0.5)(0.3)}$

$20 = \frac{2}{V_{gs}(0.3) - 0.15}$

$= 20 V_{gs}(0.3) - 20(0.15) = 2$ $\qquad \Rightarrow 6 V_{gs} - 3 = 2$

$6 V_{gs} = 2 + 3 = 5$

$I_1 = I_2 = 0.27 \, mA$ $\qquad V_{gs} = 0.833$

$r_{o2} = \frac{1}{\lambda_n I_D} = \frac{1}{(0.1)(0.275 \times 10^{-3})} = 36.3 k\Omega$

$r_{o4} = \frac{1}{\lambda_p I_D} = \frac{1}{(0.2)(0.275 \times 10^{-3})} = 18.18 \, k\Omega$

$A_v = g_m \left[\frac{656.304}{54.48} \right]$

$20 = g_m (12.046)$ $\qquad \boxed{V_{incm} = 1V}$

$g_m = 1.66$

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$$g_m = \frac{2I_D}{V_{gs} - V_{th}} = 1.66 = \frac{2(0.275 \times 10^{-3})}{V_{gs} - V_{th}}$$

$= V_{gs} - V_{th} = 0.33V$

$V_{gs} = 0.83V$

$\boxed{\mu_n C_{ox} = 100\,\mu A/V^2}$

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

$$\frac{0.55 \times 10^{-3}}{100 \times 10^{-6}(0.33)^2} = \frac{W}{L}$$

$$\left(\frac{W}{L}\right)_{1,2} = 50.5$$

$\boxed{\mu_P = 200\,\mu A/V^2}$

$V_x = V_{inCM} - V_{th} = 1 - 0.5 = 0.5$

$V_{g_3} = V_x = 0.5$

$|-V_{DD} + V_{g3}| = V_{gs}$

$V_{gs} = 1.3$

$|V_{gs}| - |V_{th,P}| = 1.3 - 0.4 = 0.9$

$$I_D \quad \left(\frac{W}{L}\right)_{3,4} = \frac{0.555 \times 10^{-3}}{200 \times 10^{-6} \times (0.9)^2} = 3.43 \;//$$

Now

A_v = same, ϕ = same

change basic current mirror by resistive load.

PES UNIVERSITY

26th Oct

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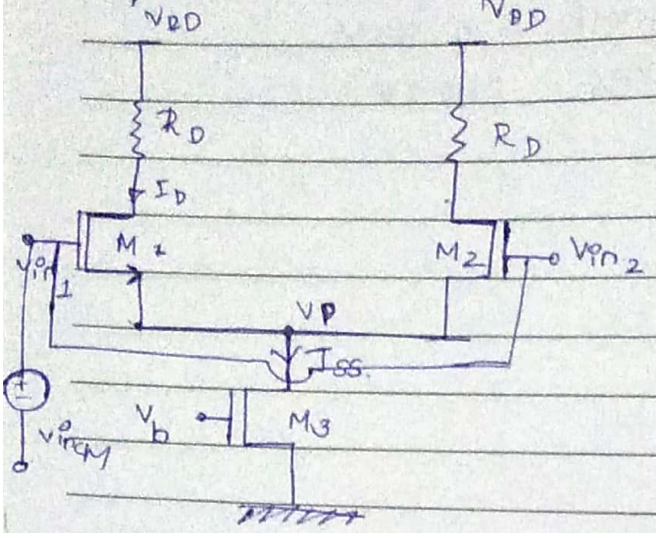
(1) For following ckt, calculate the common mode gain assuming channel length modulation for M_1 & $M_2 = 0$ & for $M_3^{(\lambda)} \neq 0$. Compute gain expression



$\lambda_{M_1} = 0$ - $\lambda_{M_3} \neq 0$

$\lambda_{M_2} = 0$

* take r_3 into account, r_1 & r_2 can neglected
* Overdrive voltage is of M_1 & M_2

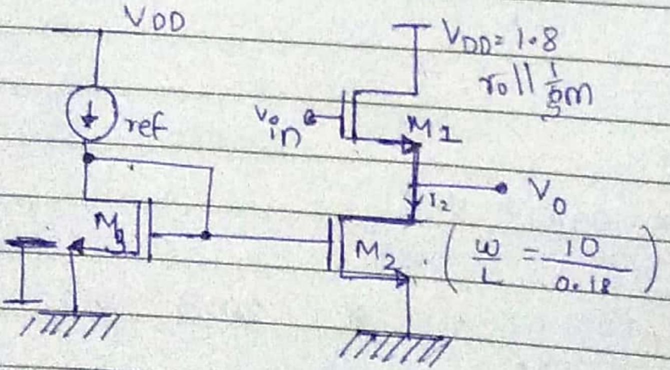
$$A_{CM} = \frac{-R_D I_{SS}}{(V_{gs} - V_{th}) + \frac{2}{\lambda}}$$

$$I_D = \frac{I_{ss}}{2}$$

$$V_{in_1} = -\frac{g_m R_D}{1}(V_{inCM} - \cancel{V_P})_2$$

$$V_{in_2} = -\frac{g_m R_D}{2}(\cancel{V_{inCM}} - \cancel{V_P})$$

(2)



$\lambda = 0.1V^{-1}$

$V_{th} = 0.5V$

$\Delta V = 0.85$

$\mu_n C_{ox} = 100\mu A^2/V^2$

$V_{GS_3} = 1V$

$$I_2 = \frac{\left(\frac{W}{L_2}\right)}{(W/L)_1} \times I_{ref} = \frac{\frac{10}{0.18}}{x} \times I_{ref} = \frac{55.5}{(W/L)_3} \times I_{ref}$$

Common drain amplifier → Source follower

Rs is replaced by Current mirror

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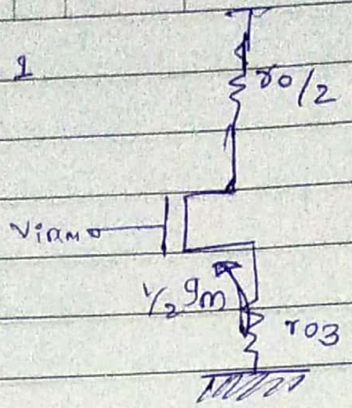
Sol^n : 1



$$= \frac{\frac{r_o}{2}}{r_{o3} + \frac{1}{2g_m}}$$

$$r_{o3} = \frac{1}{\lambda I_D}$$

$$g_m = \frac{2 I_D}{V_{gs} - V_{th}}$$

$$= \frac{r_o/2}{\frac{1}{\lambda I_D} + \frac{1}{2g_m}} = \frac{r_o}{2\left[\left(\frac{1}{\lambda I_D}\right) + \frac{1}{2g_m}\right]}$$

$$= \frac{r_o}{2\left[\frac{2g_m + \lambda I_D}{2g_m \lambda I_D}\right]} = \frac{r_o}{\cancel{2}(2g_m + \lambda I_D)} \times \cancel{2} g_m \lambda I_D \cdot \frac{r_o \times \frac{2 I_D}{V_{gs}-V_{th}} \cdot \lambda I_D}{2 \times \frac{2 I_D}{V_{gs}-V_{th}} + \lambda I_D}$$

Sol^n : 2

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

$$= \frac{1}{2} \times 100 \times 10^{-6} \times \left(\frac{10}{0.18}\right) (1 - 0.5)^2$$

$$= 0.694 mA.$$

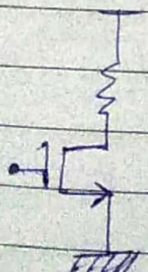
$$\cancel{0.694 \times 10^{-3} = \frac{55.5}{(W/L)_3} \times I_{ref}}$$

$$r_{o2} = \frac{1}{\lambda I_D} = \frac{1}{0.1 \times 0.694 \times 10^{-3}} = 14.4 K\Omega.$$

~~g_{m2}~~

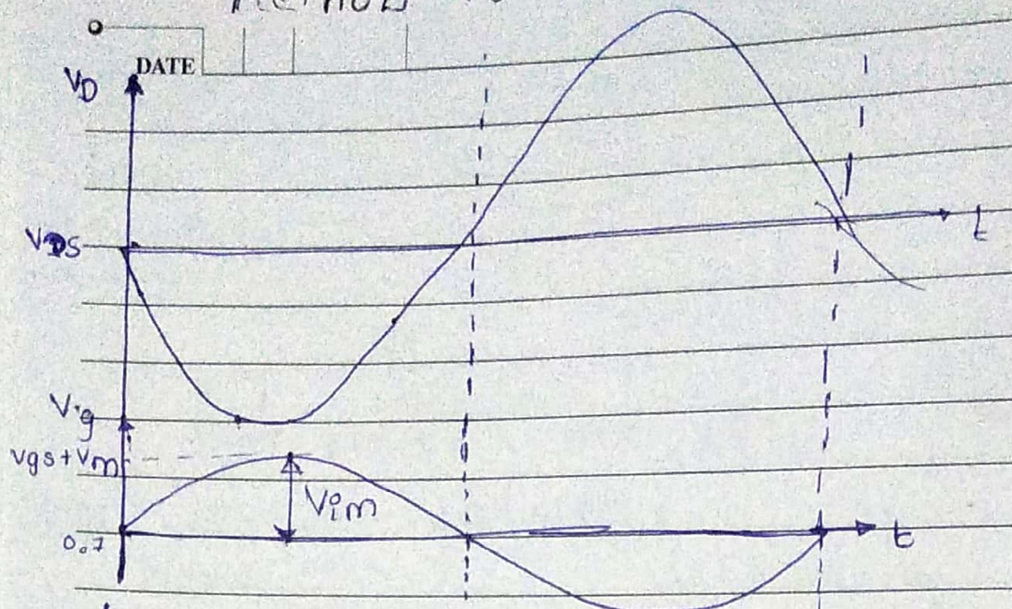
$g_{m2} =$

For finding max input swing of any ckt theoretically



- Absolute potential of gate $V_g = V_{gs} + V_m$

METHOD TO FIND MAX INPUT SWING LIMITS:

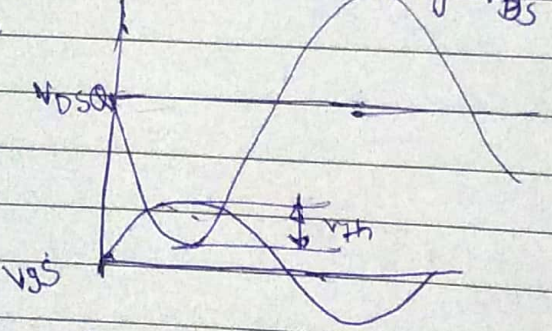


As we increase the v_{gs} (input), my output will also amplify till what value of

$V_0 = V_{DS} - g_m I_D V_{in}$

$V_0 = V_{DS} - g_m I_D V_{im}$

To keep in saturation my V_{DS} can go one V_{th} below the gate

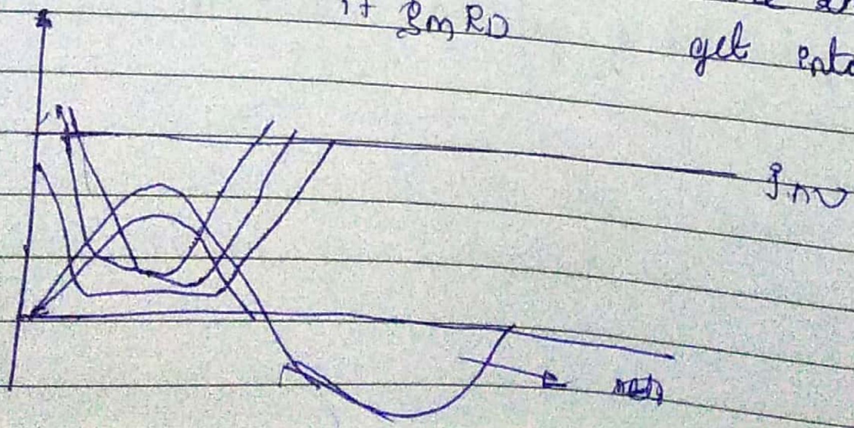


$V_{DS} - g_m R_D V_{im} = (V_{gs} + V_{th}) - V_{th}$

$V_{DS} - g_m R_D V_{im} + V_{th} = V_{gs} + V_{th}$

$V_m = \frac{V_{DS} - V_{gs} + V_{TH}}{1 + g_m R_D}$

More than this, it will get into triode not sat^n^



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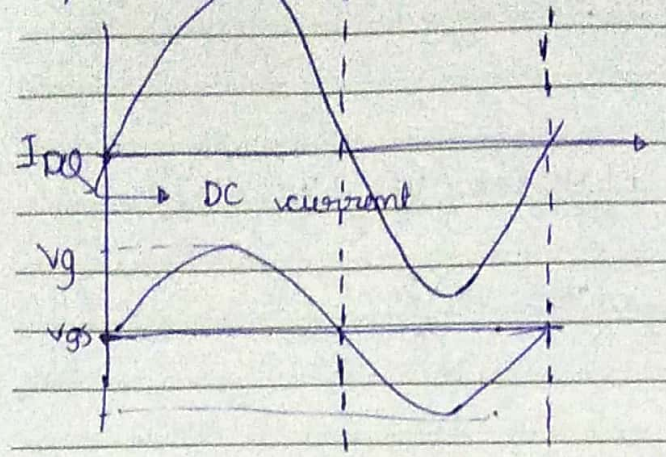
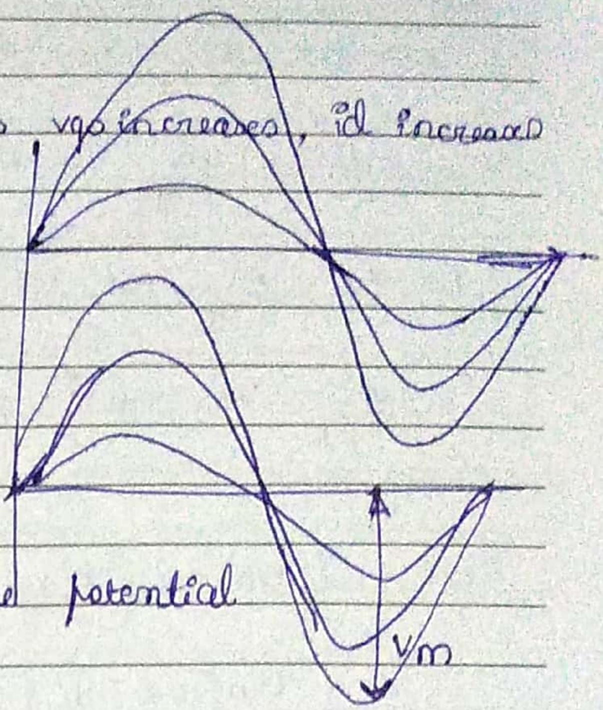
plot absolute current drain?

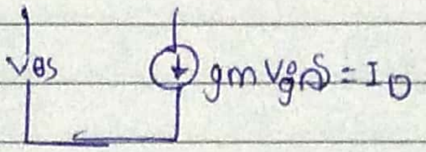
as vgs increases, id increases





In negative cycle the current at some potential it become zero coz $V_{gs} < V_{th}$.

* Now it will enter into cut off.



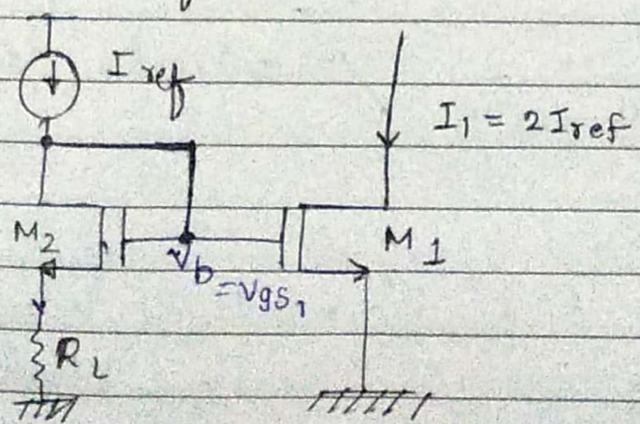
$$V_m = \frac{I_D}{g_m}$$

$$V_{in} = V_{m(max)_1} = \frac{V_{DS} - V_{gs} + V_{th}}{1 + g_m R_D}$$

$$V_{m(max)_2} = \frac{I_D}{g_m}$$

$$\boxed{V_{in} \{ V_{m(max)_1} \cdot V_{m(max)_2} \} \times 2.}$$

Q. For the following ckt, determine R_L ∋ current $I_1 = 2 I_{ref}$



$$I_1 = \frac{(W/L)_1}{(W/L)_2} \times I_{ref}$$

$$2 \cancel{I_{ref}} = \frac{(W/L)_1}{(W/L)_2} \times \cancel{I_{ref}}$$

$$\left(\frac{W}{L}\right)_1 = 2 \left(\frac{W}{L}\right)_2$$

$$\cancel{I_{R_1} = 2 I_R}$$

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$$I_1 = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (V_{GS}-V_{th})_1^2$$

$$I_{ref} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_2 (V_{GS}-V_{th})_2^2$$

$$\cancel{\frac{1}{2}\mu_n C_{ox}}\left(\frac{W}{L}\right)_1 (V_{GS}-V_{th})_1^2 = 2\cdot\cancel{\frac{1}{2}\mu_n C_{ox}}\left(\frac{W}{L}\right)_2 (V_{GS}-V_{th})_2^2$$

$$\left(\frac{W}{L}\right)_1 (V_{GS}-V_{th})_1^2 = 2\left(\frac{W}{L}\right)_2 (V_{GS}-V_{th})_2^2$$

$$I_{ref} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_2 (V_{GS_2}-V_{th_2})^2$$

$$= \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_2 \left(V_{GS_1} - I_{ref}R_L - V_{th_2}\right)^2 \longrightarrow (1)$$

$$I_1 = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (V_{GS_1}-V_{th_1})^2 \longrightarrow (2)$$

$$V_{GS_1} = \sqrt{\frac{2I_1}{\mu_n C_{ox}\left(\frac{W}{L}\right)_1}} + V_{th}$$

$$= 2\sqrt{\frac{I_{ref}}{\mu_n C_{ox}\left(\frac{W}{L}\right)_1}} + V_{th} \longrightarrow (3)$$

Substitute (3) in (1)

$$I_{ref} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_2 \left[2\sqrt{\frac{I_{ref}}{\mu_n C_{ox}\left(\frac{W}{L}\right)_1}} + \cancel{V_{th_1}} - I_{ref}R_L - \cancel{V_{th_2}}\right]^2$$

$$I_{ref} = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_2 \left[\frac{4 I_{ref}}{\mu_n C_{ox}\left(\frac{W}{L}\right)_1} + I_{ref}^2 R_L^2 - 4 I_{ref}R_L \times \sqrt{\frac{I_{ref}}{\mu_n C_{ox}\left(\frac{W}{L}\right)_1}}\right]$$

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$$\frac{2 I_{ref}}{u_n C_{ox}\left(\frac{W}{L}\right)_2} = \left(2\sqrt{\frac{I_{ref}}{u_n C_{ox}\left(\frac{W}{L}\right)_1}} - I_{ref} R_L\right)^2$$

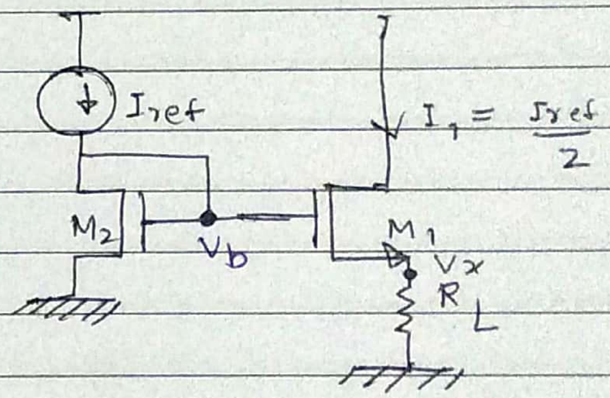
Taking square root both sides.

$$\sqrt{\frac{2 I_{ref}}{u_n C_{ox}\left(\frac{W}{L}\right)_2}} = 2\sqrt{\frac{I_{ref}}{u_n C_{ox}\left(\frac{W}{L}\right)}} - I_{ref} R_L$$

$$I_{ref} R_L = 2\sqrt{\frac{I_{ref}}{u_n C_{ox}\left(\frac{W}{L}\right)}} - \sqrt{\frac{2 I_{ref}}{u_n C_{ox}\left(\frac{W}{L}\right)}}$$

$$R_L = \frac{2-\sqrt{2}}{\sqrt{I_{ref}\, u_n C_{ox}\left(\frac{W}{L}\right)}}$$

If $I_1 = \frac{I_{ref}}{2}$



$V_b = V_{gs_2}$

$V_x = I_1 R_L$

$= \frac{I_{ref} \cdot R_L}{2}$

$$I_1 = \frac{1}{2} u_n C_{ox}\left(\frac{W}{L}\right)_1 \left(V_{gs_1} - V_{th}\right)^2$$

$$I_{ref} = \frac{1}{2} u_n C_{ox}\left(\frac{W}{L}\right)_2 \left(V_{gs_2} - V_{th}\right)^2$$

$$V_{gs1} = V_b - V_x = V_{gs2} - \frac{I_{ref} \cdot R_L}{2}$$

$$V_{gs_2} = \sqrt{\frac{2 I_{ref}}{u_n C_{ox}\left(\frac{W}{L}\right)_2}} + V_{th}$$

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$$V_{gs1} = \sqrt{\frac{2 I_{ref}}{\mu_n C_{ox} \left(\frac{W}{L}\right)_2}} + V_{th} - \frac{I_{ref} R_L}{2}$$

$$I_{ref} = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L}\right)_2$$

$$I_1 = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L}\right)_1$$