Slide No:

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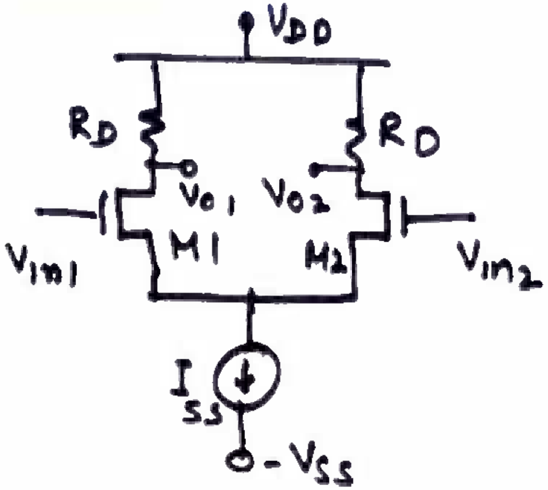
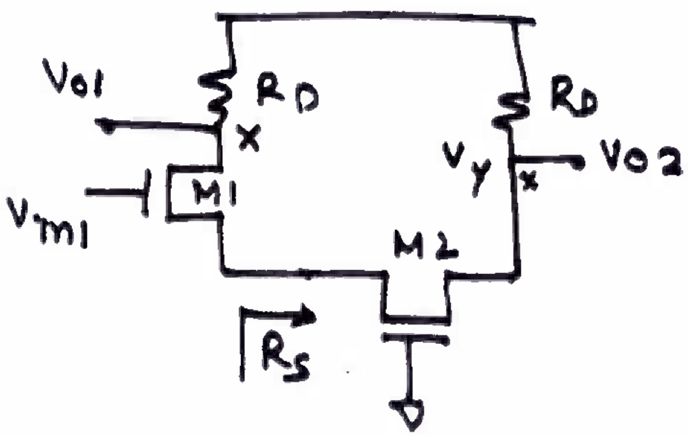
Small Signal Analysis of DIFFAMP



$\boxed{A}$ Method of Superposition

We evaluate V_{o1} & V_{o2} with each input indivisually & then add the two.

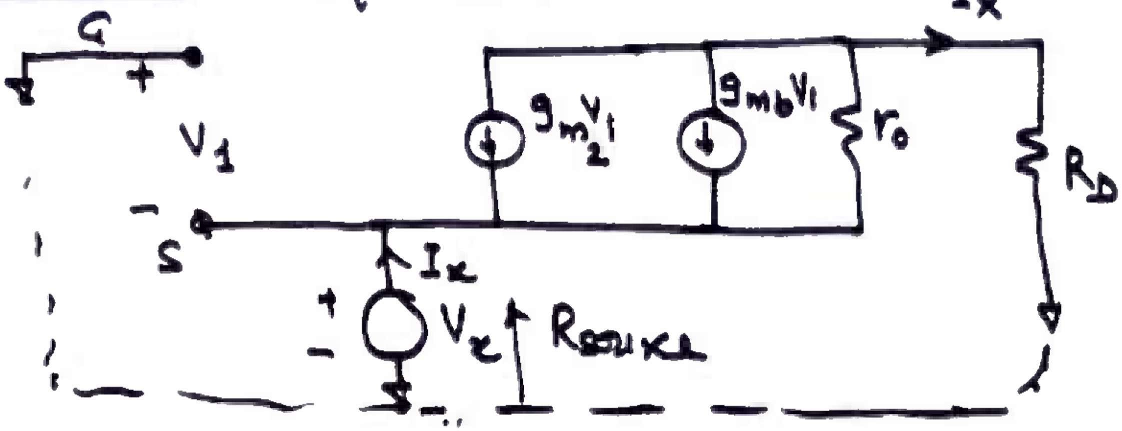
Step 1 : Set $V_{a2} = V_{in2} = 0$ (We only take ac eq. circuit)



Step 2 :- Evaluate V_{o1} & V_{o2} as f^n of V_{in1}

Step 3 : We observe that M2 acts like Source Resistance for M1 driver, forming CS Amplifier with Source Degeneration

Eq. circuit is



$$\therefore \; I_x R_D + [I_x - (g_m + g_{mb}) V_x] r_o = V_x$$

[since $V_x = -V_1$ and current through r_o $= I_x + (g_m + g_{mb}) V_1$

$= I_x - (g_m + g_{mb}) V_x$

& $V_x = V_{ro} + V_{RD}$]

$$\therefore \; \frac{V_x}{I_x} = R_{source\,M1} = \frac{R_D + r_o}{1 + (g_{m2} + g_{mb}) r_o}$$

Slide No: 3

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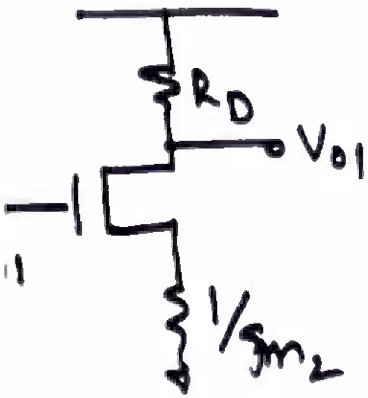
or $R_{source\,M1} = \dfrac{R_D/r_o}{g_{m2}+g_{mb}} + \dfrac{1}{g_{m2}+g_{mb}}$

If $R_D << r_o$, then $R_{source\,M1} \cong \dfrac{1}{g_{m2}+g_{mb}}$

$\cong 1/g_{m2}$ if $g_{m2} >> g_{mb}$.

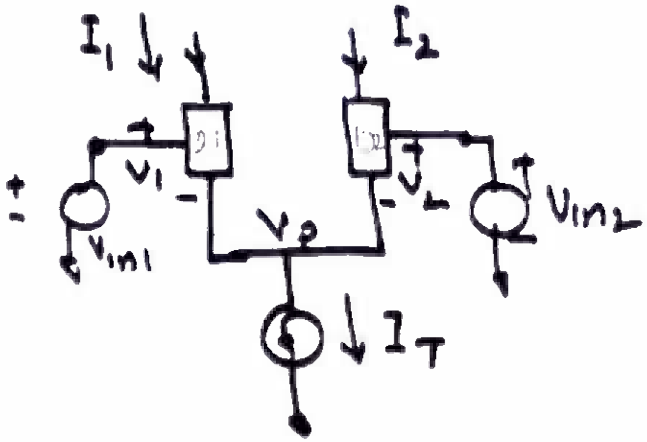


$\therefore \dfrac{V_{o1}}{V_{in1}} = -\dfrac{R_D}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}}$ $\left[-\dfrac{g_{m1}R_D}{1+g_{m1}R_s} \right.$

Now we calculate $\dfrac{V_{o2}}{V_{in1}}$

Step 4. Now we can say that M2 is driven by M1 as Source Follower.

Half Circuit Analysis



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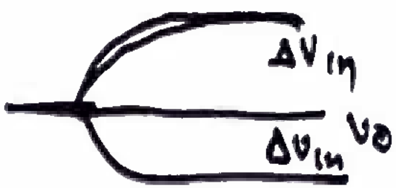
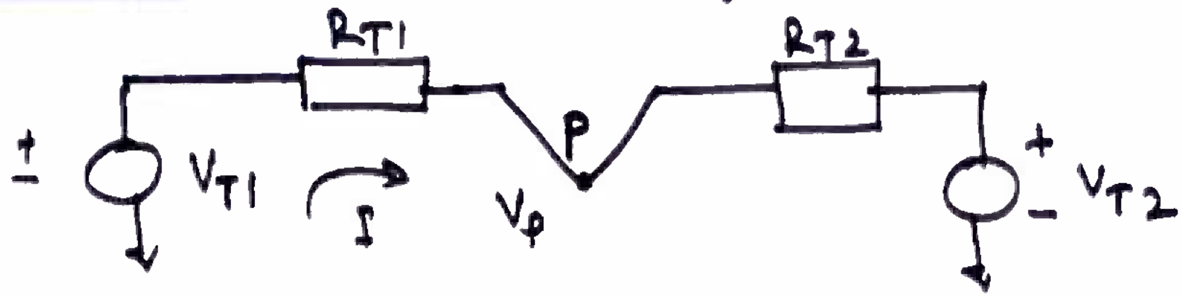
Lemma: Consider the Symmetric Circuit with D1 & D2. If V_{in1} changes from its equilibrium value V_0 to $V_0 + \Delta V_{in}$ and similarly V_{in2} changes to $V_0 - \Delta V_{in}$, then by this Lemma, if circuit still remains linear (i.e. g_m constant), then node voltage V_p does not change.



Slide No: 5

Equivalently saying



$$V_P = V_{T1} - IR_{T1} \quad — ①$$

$$V_P = IR_{T2} - V_{T2} \quad — ②$$

or $\quad 2V_P = V_{T1} - V_{T2} \qquad$ If $R_{T1} = R_{T2}$

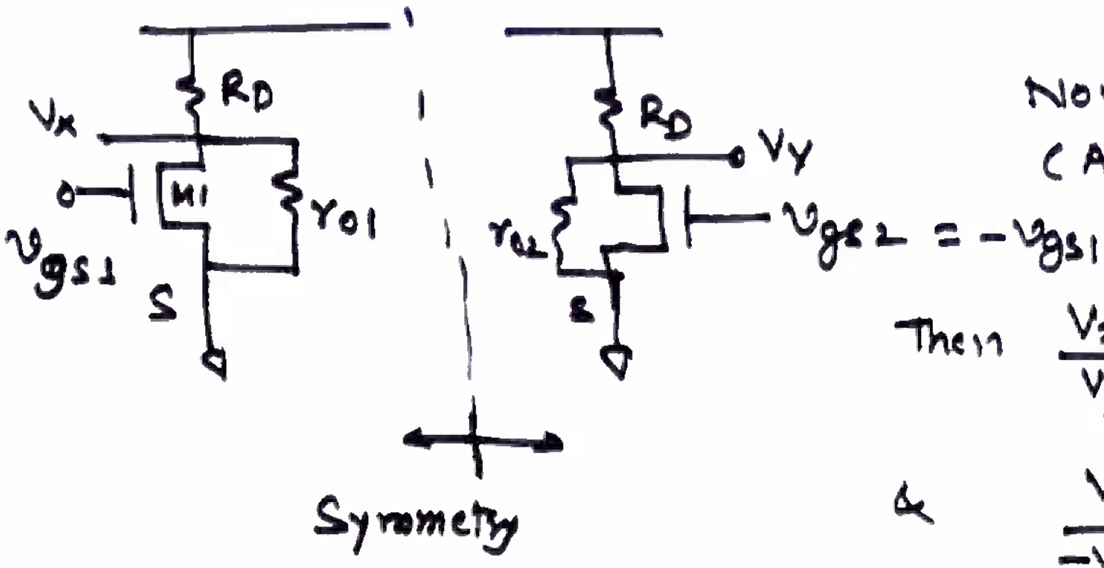
or $\quad V_P = \frac{V_{ID}}{2}$. $\quad$ Now $V_{ID} = V_{T1} + \Delta V_T - (V_{T2} - \Delta V_T)$

$\therefore$ V_P remains constant $\qquad$ If V_{T1} changes to $V_{T1} + \Delta V_T$

& V_{T2} " to $V_{T2} - \Delta V_T$

Slide No: 6

Using Half Circuit Method



Now V_p is at Ground (AC circuit)

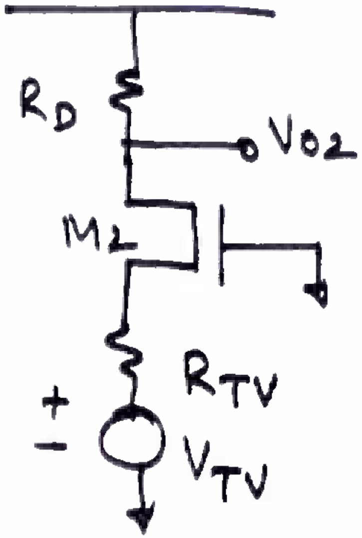
Then $\dfrac{V_x}{V_{gs1}} = -g_{m1}(R_D \| r_{o1})$

& $\dfrac{V_y}{-V_{gs1}} = -g_{m2}(R_D \| r_{o2})$

or $\dfrac{V_x - V_y}{2V_{gs1}} = -\frac{1}{2}\left[g_{m1}(R_D \| r_{o1}) + g_{m2}(R_D \| r_{o2})\right]$

If $g_{m1} = g_{m2} = g_m$ and $r_{o1} = r_{o2} = r_o$

Then $\dfrac{V_x - V_y}{2V_{gs1}} = -g_m(r_o \| R_D) = \dfrac{V_x - V_y}{V_{gs1} - V_{gs2}} = \dfrac{V_{out}}{V_{diff}}$



R_{TV} & V_{TV} are Thevenin's Resistance & Voltage Source

clearly $V_{TV} = V_{in1}$

and $R_{TV} = 1/g_{m1} = R_{source}$.

Then
$$\frac{V_{o2}}{V_{in1}} = \frac{g_{m2} r_{o2} R_D}{r_{o2}(1 + g_{m2} R_S) + R_S + R_D}$$

$$\cong \frac{R_D}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}}$$

Step V

Differential Gain

$$= \frac{V_{o1} - V_{o2}}{V_{in1}} = \frac{-2R_D}{1/g_{m1} + 1/g_{m2}} = -g_m R_D$$

If $g_m = g_{m1} = g_{m2}$
$\Downarrow$

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Hence for Common Source Amplifier with source degeneration

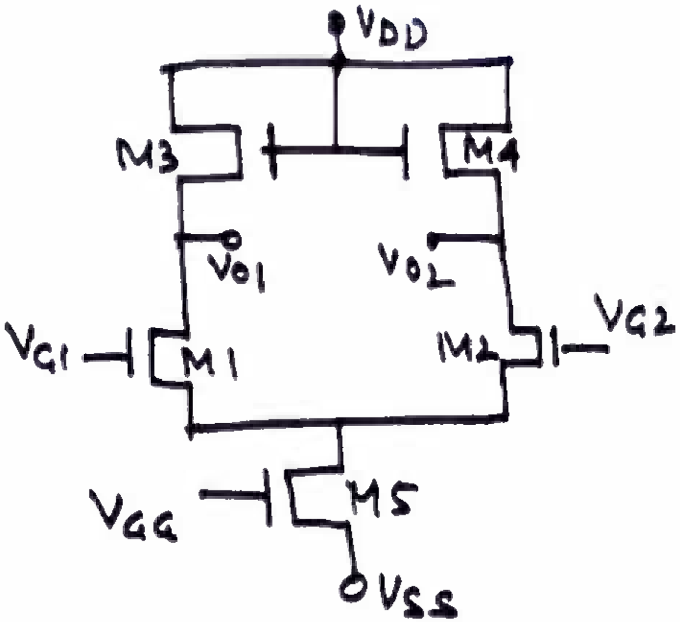
$$A_{VCM} = \frac{V_O}{V_{mcm}} = -\frac{g_m R_D/2}{1 + 2 R_{SS} g_m}$$

$$A_{VCM} \cong -\frac{g_m R_D/2}{2 R_{SS} g_m} = -\frac{R_D}{2R_{SS}}$$

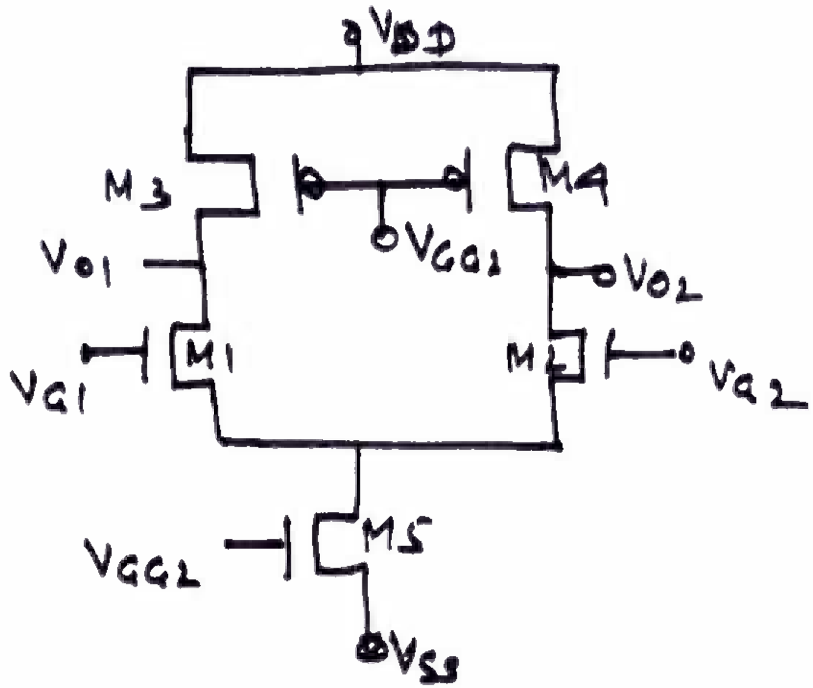
Iff $R_{SS} \to \infty$ $A_{VCM} \to 0$ Or Else A_{VCM} is Small but Finite

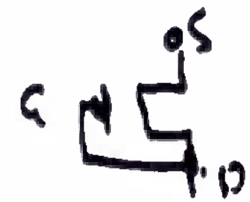
$\therefore$ CMRR $= \frac{A_{Vdm}}{A_{Vcm}}$ is Finite

Differential Amplifier with Different Kind of Loads (Active)



Normal Active Load

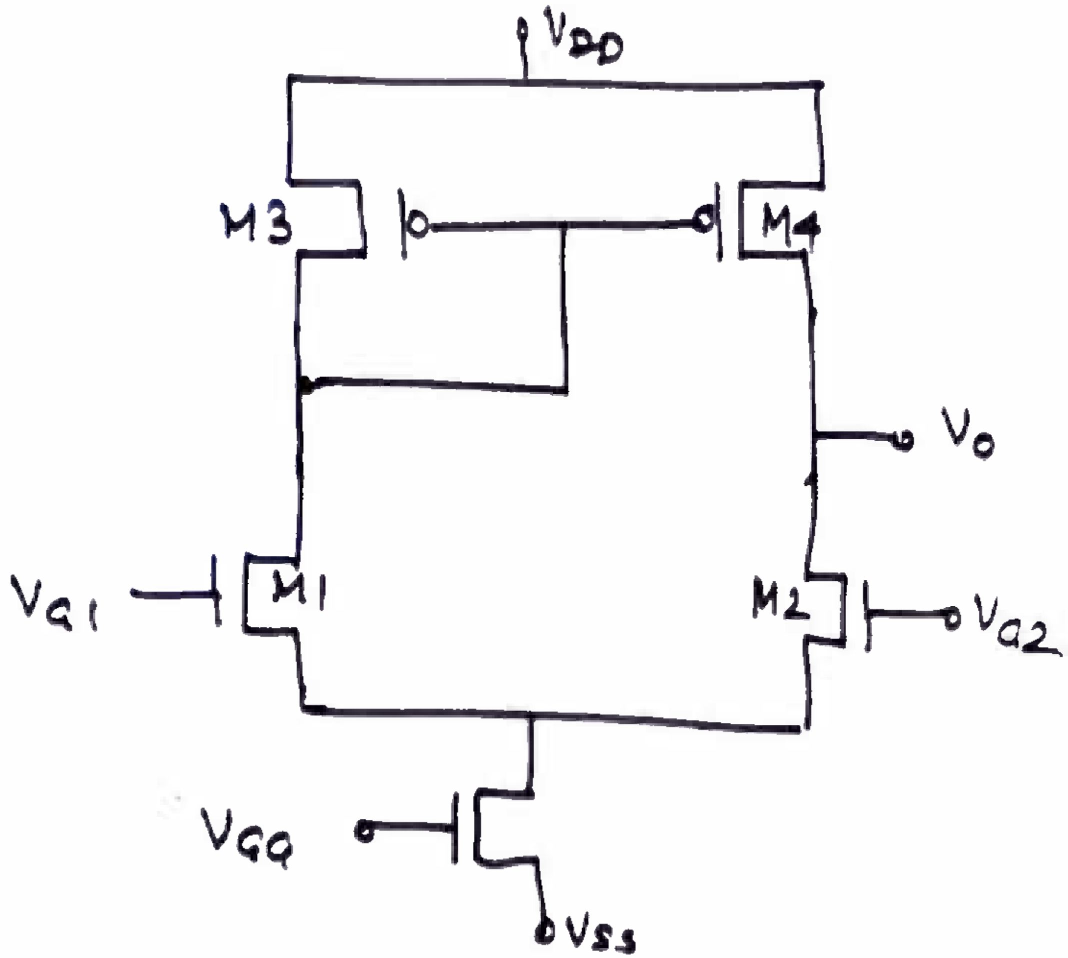


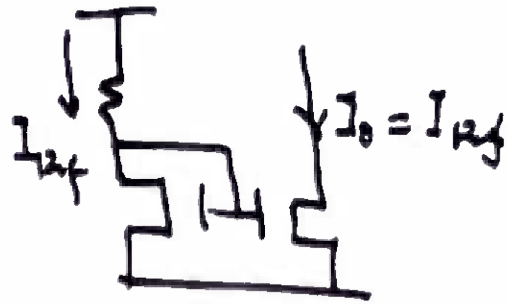


Current Source Load

Slide No. 10

Current Mirror Load





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M_1 & M_2 being in parallel, We say

$$W_1 + W_2 = 2W$$

and current in each is $\frac{I_{ss}}{2}$ or in

$$(M_1 + M_2) = \frac{I_{ss}}{2} + \frac{I_{ss}}{2} = I_{ss}$$

We have $g_m = \sqrt{2\beta_n'\left(\frac{W}{L}\right) I_{DS}}$

$$\therefore \quad g_{m(M_1+M_2)} = \sqrt{2\beta_n'\left(\frac{2W}{L}\right) \cdot 2\left(\frac{I_{ss}}{2}\right)}$$

where $g_{m_{M_1}} = g_{m_{M_2}} = \sqrt{2\beta_n'\left(\frac{W}{L}\right)\left(\frac{I_{ss}}{2}\right)} = g_m$

or $g_{m(M_1+M_2)} = 2g_{m_1} = 2g_{m_2} = 2g_m$

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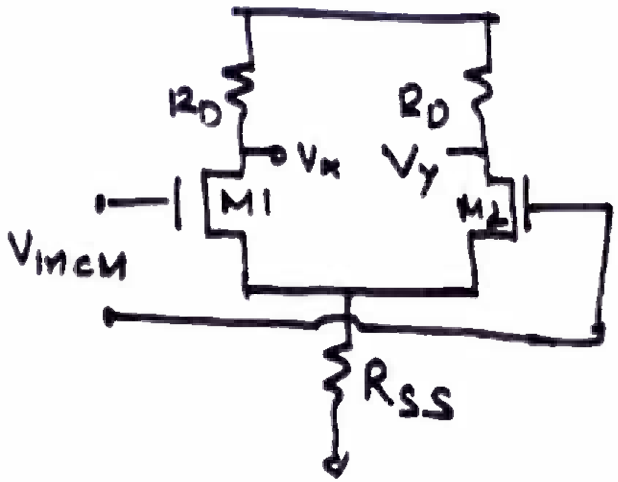
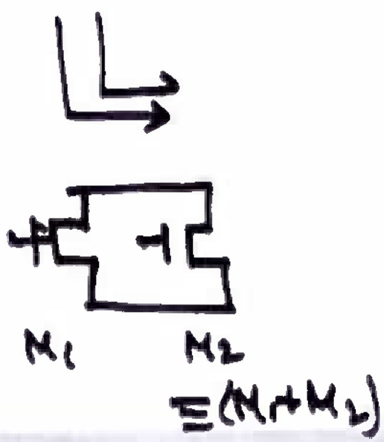
If Current Source I_{SS} is not ideal we see DIFFAMP as shown for Common Mode Input

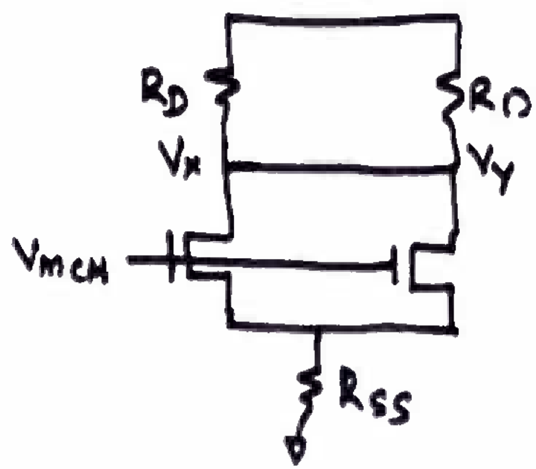
$V_{incM} = V_{in1} = V_{in2}$

Due to symmetry $V_x = V_y = V_{o1} = V_{o2}$

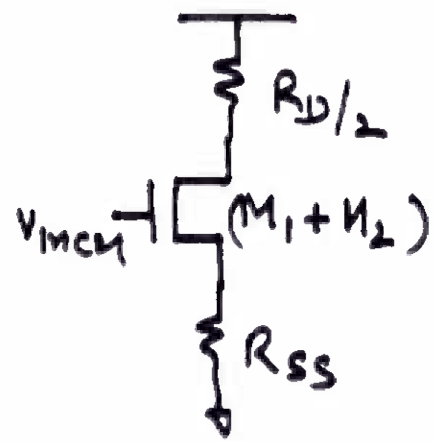
Then $V_x - V_y = 0 = V_{o1} - V_{o2}$







$\equiv$



Then $v_o = V_x - V_y = V_{o1} - V_{o2}$

$v_{diff} = v_{id} = V_{in1} - V_{in2}$

$$\therefore \frac{v_o}{v_{id}} = -\frac{1}{2}\left[g_{m1}(R_D \| r_{o1}) + g_{m2}(R_D \| r_{o2})\right]$$

If $g_m = g_{m1} = g_{m2}$ & $r_{o1} = r_{o2} = r_o$

Then $$\frac{v_o}{v_{id}} = -g_m(R_D \| r_o) = A_{dm} = A_{vdm}$$

for Identical M1 & M2 $\quad A_{CM}$ = Common Mode Gain $= A_{vCM}$

$= 0$

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$$\therefore\ V_{in1} = \frac{(V_{in1} - V_{in2})}{2} + \frac{(V_{in1} + V_{in2})}{2}$$

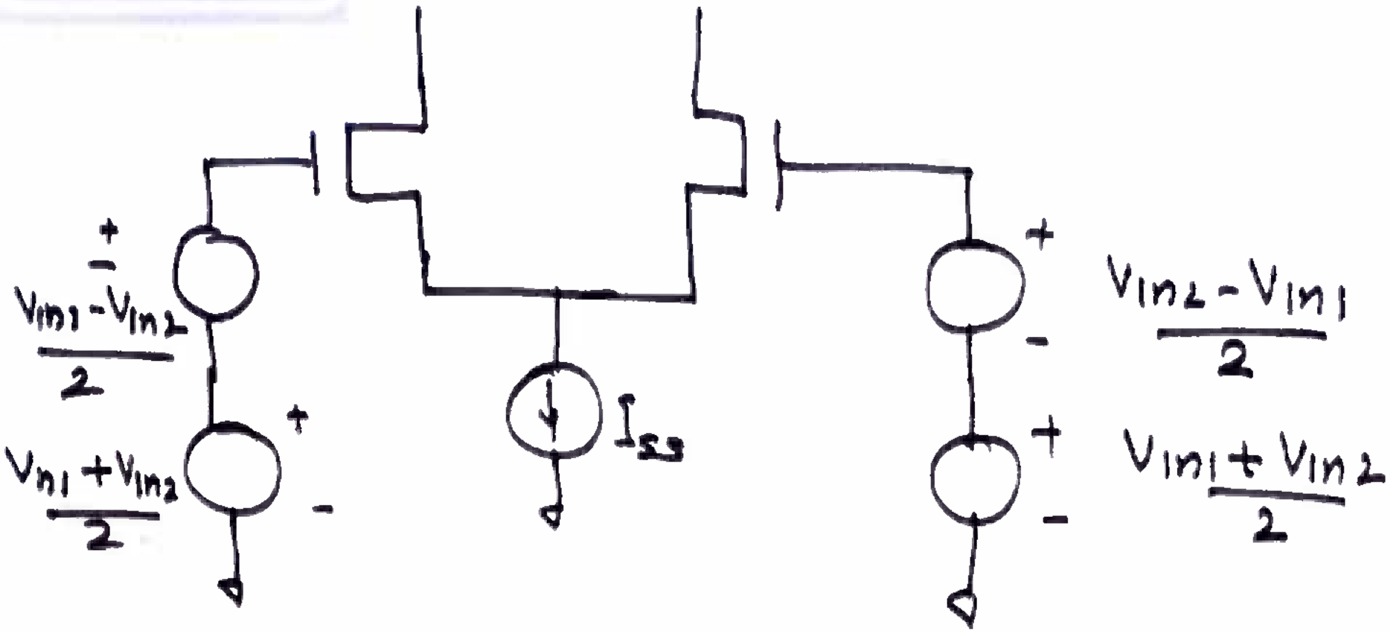
$$v_{in2} = \frac{(V_{in2} - V_{in1})}{2} + \frac{(V_{in1} + V_{in2})}{2}$$

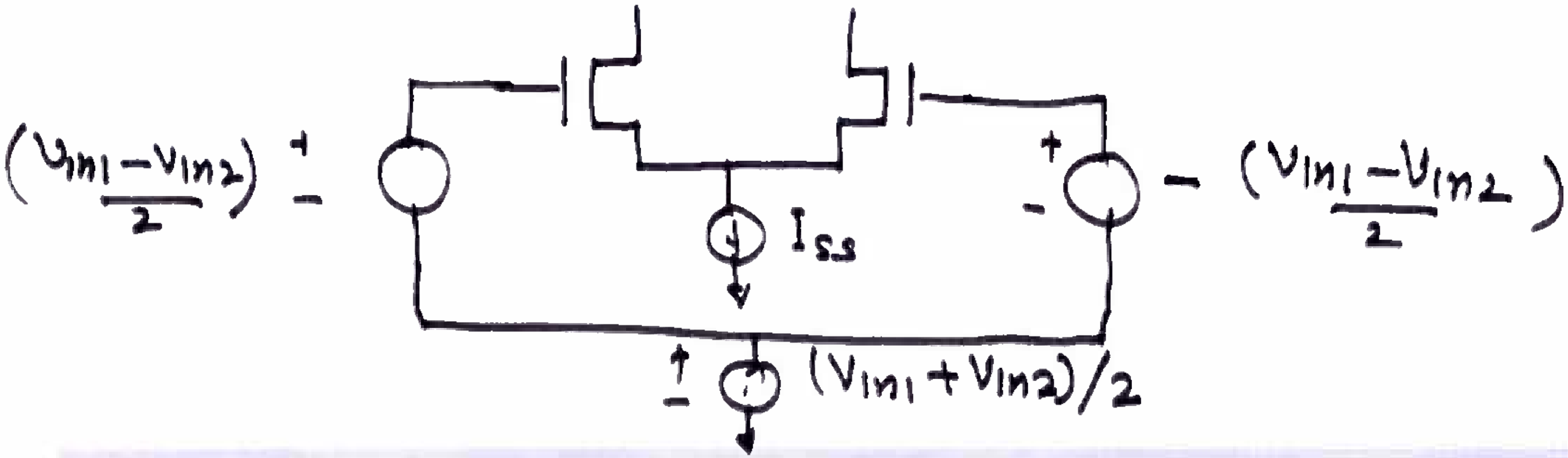
Difference Signal   Common Mode Signal

We use Superposition Theorem for each type of Signal.

Then

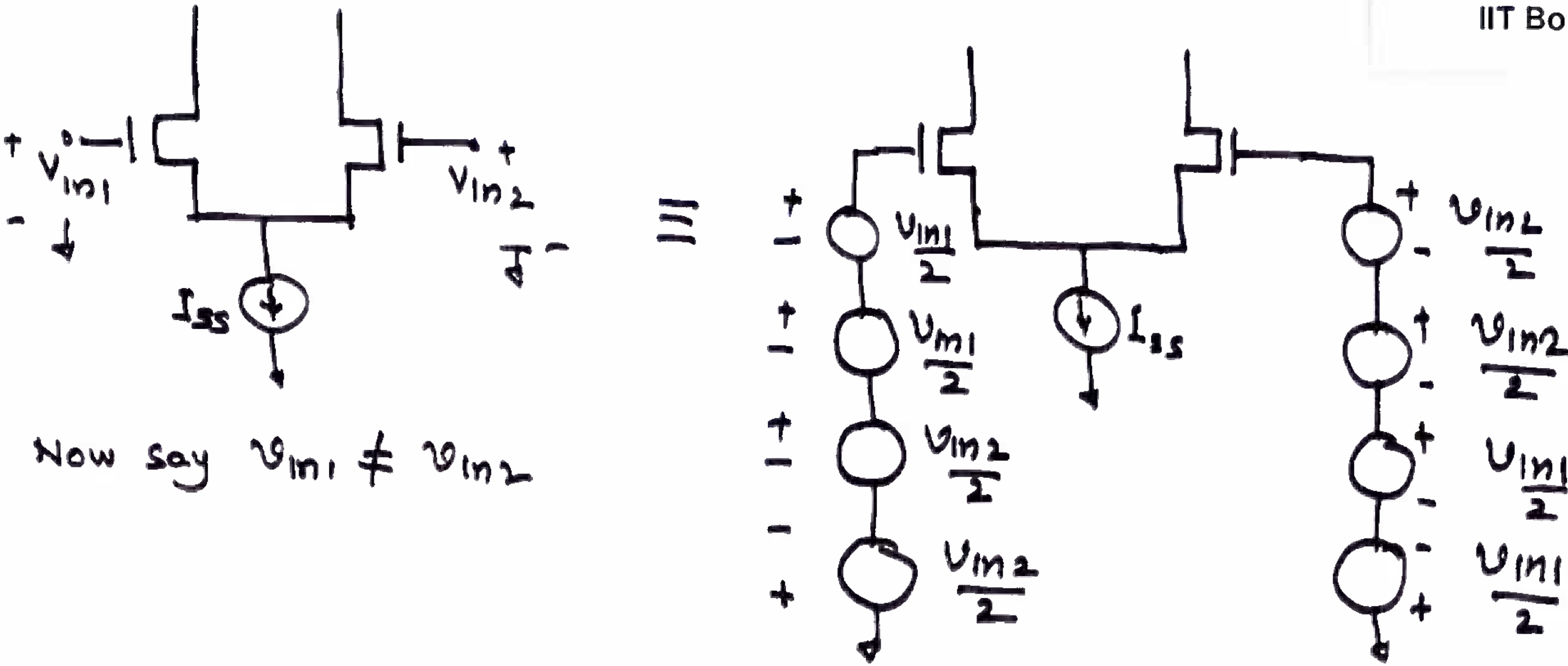
$$\left.\begin{aligned} V_x &= V_{o1} = -g_m (R_D \| r_{o1}) \left(\frac{v_{in1} - v_{in2}}{2}\right) \\ v_y &= V_{o2} = -g_m (R_D \| r_{o2}) \left(\frac{v_{in2} - v_{in1}}{2}\right) \end{aligned}\right\} \text{Difference Signal}$$


+
−
$\frac{V_{in1}-V_{in2}}{2}$
+
$\frac{V_{in1}+V_{in2}}{2}$
−
I_{SS}
+
$\frac{V_{in2}-V_{in1}}{2}$
−
+
$\frac{V_{in1}+V_{in2}}{2}$
−


$\left(\frac{v_{in1}-v_{in2}}{2}\right)$
+
−
I_{SS}
+
−
$-\left(\frac{V_{in1}-V_{in2}}{2}\right)$
+
−
$(V_{in1}+V_{in2})/2$

Slide No: 16

Even if Circuit is not fully Differential, we can see that Symmetry can be achieved.



Now say $v_{in1} \neq v_{in2}$