Differential Amplifier with Different Kind of Loads (Active)

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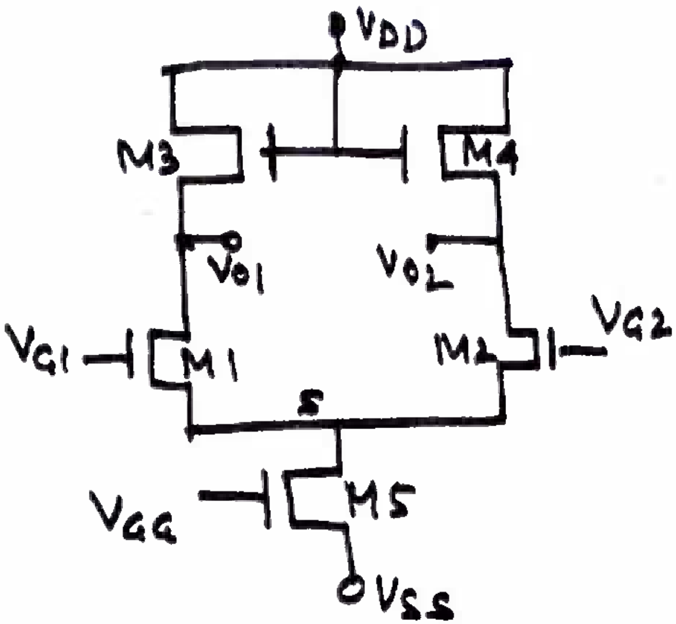
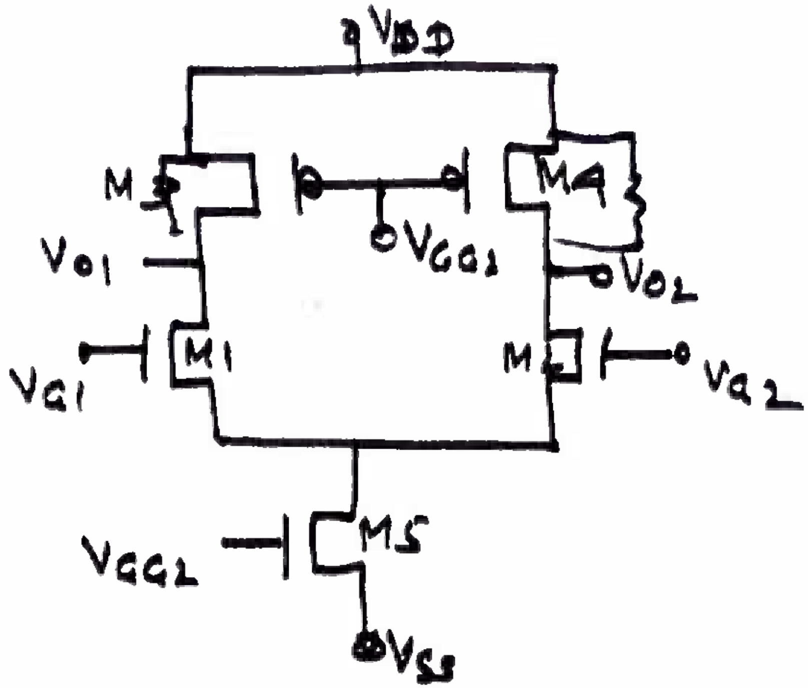
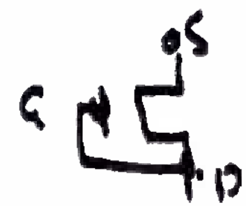


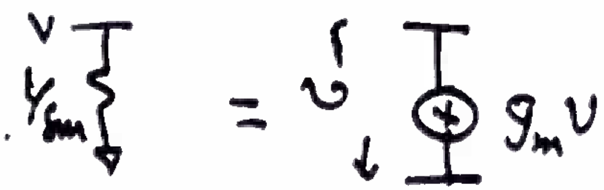
Normal Active Load



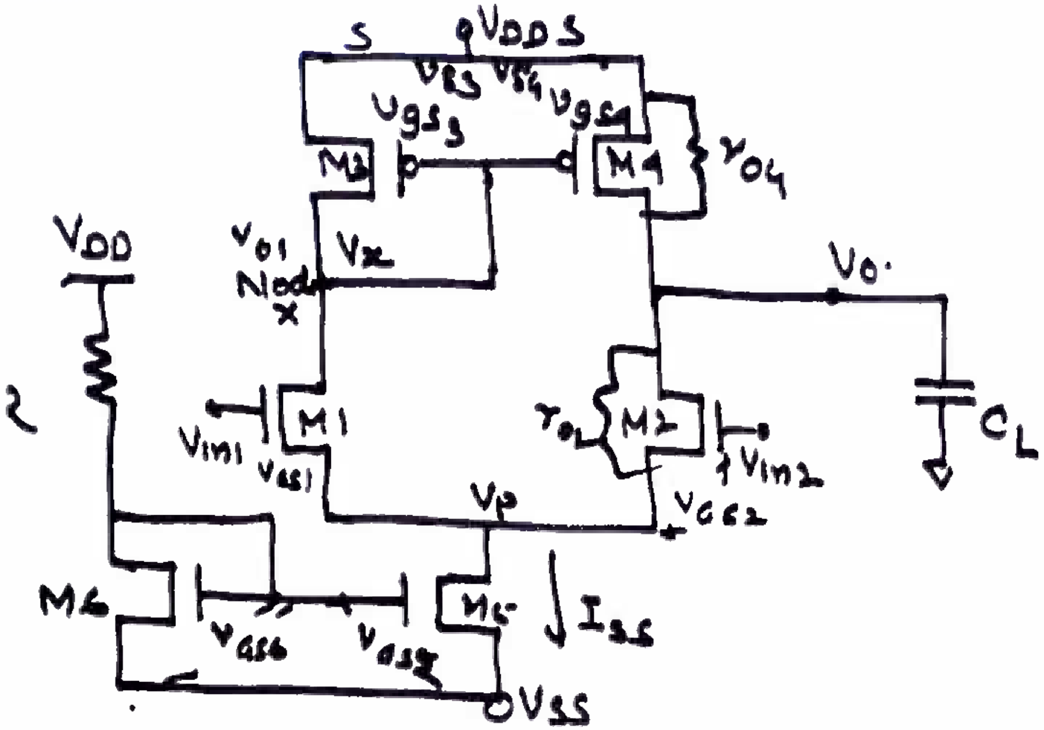
Current Source Load



$$\lambda = \frac{\lambda'}{L}$$



Current Mirror Load CMOS Diffamp



$V_{in1} - V_{in2} = V_{id} = V_{GS_1} - V_{GS_2}$

We as usual apply $\frac{v_{id}}{2}$ to Gate of M1 and $-\frac{v_{id}}{2}$ to the Gate of M2

$V_{GS1} = V_{G1}$ $V_{GS2} = V_{G2}$

If r_{o5} is v. high
Then $V_p \to 0$ (V_{SS}) for ac.

Due to Mirror Connection between M3 & M4

$v_{gs3} = v_{gs4}$

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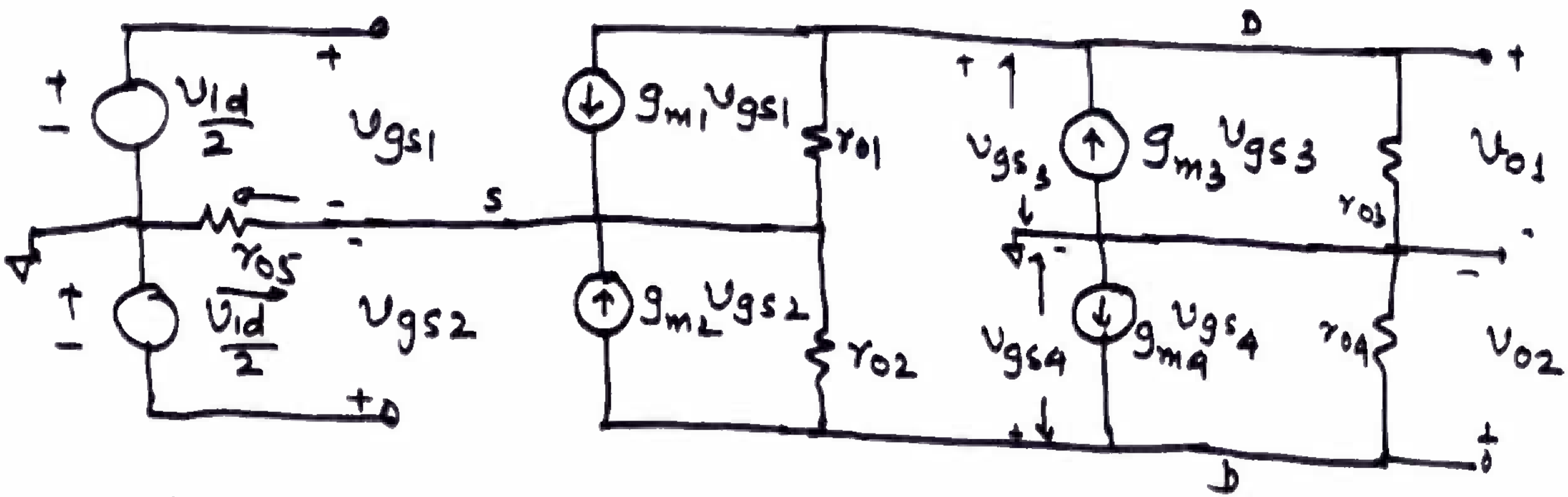
For the Differential Amplifier with Active load

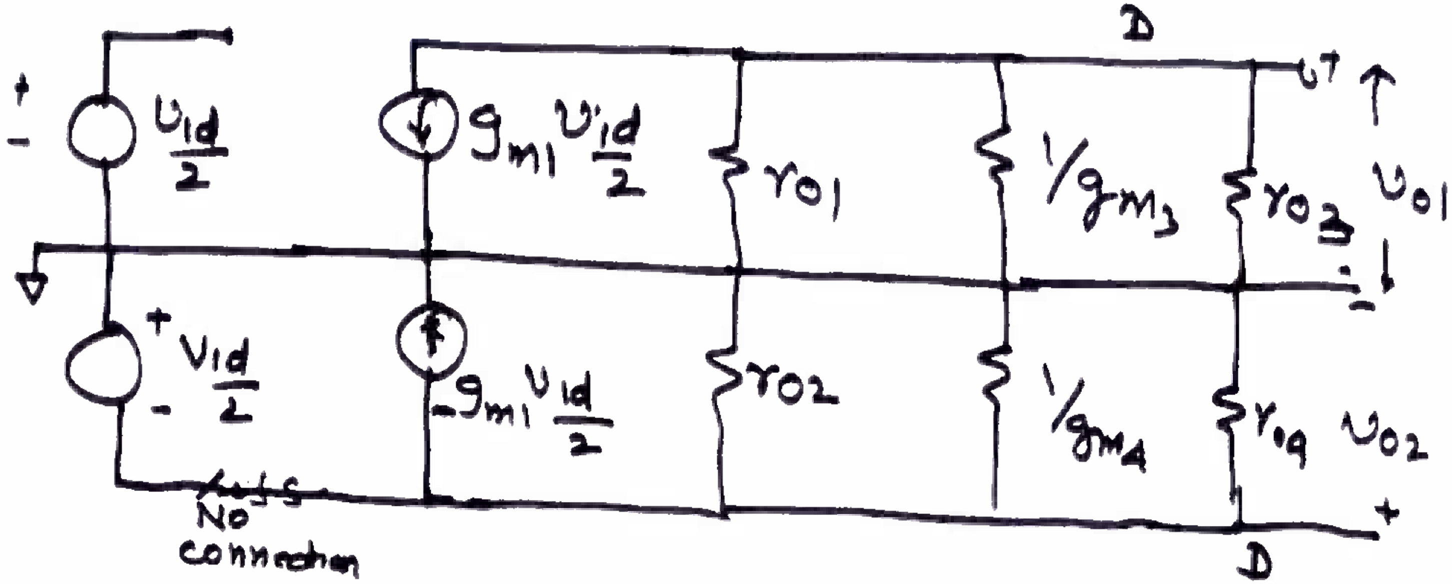
$$v_{gs1} = -v_{gs2} = v_{gs} = \frac{v_{id}}{2}$$

The Equivalent Ckt is

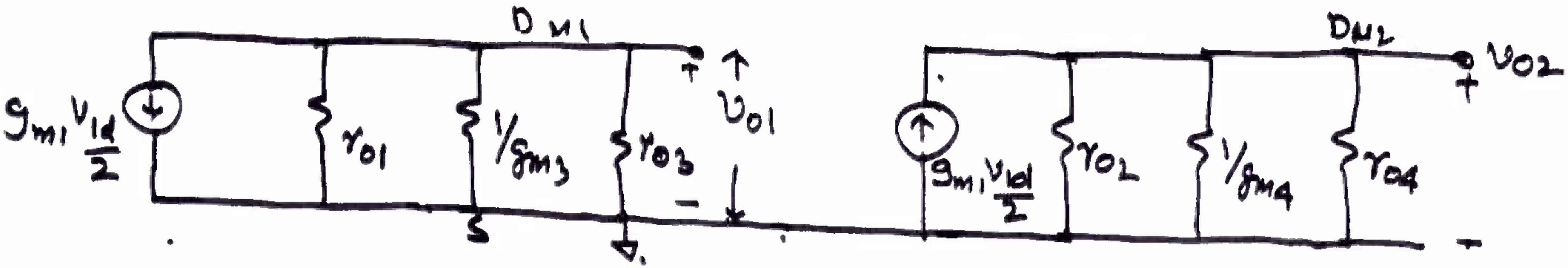


As current through r_{os} is $g_{m1}\frac{v_{id}}{2}$ & $-g_{m2}\frac{v_{id}}{2}$, we can assume '0' current in r_{os} (ac current) $\therefore$ terminal S can be treated as Ground.

Then the Equivalent circuit reduces to



Assuming $g_{m1} = g_{m2}$



$$v_{1d} = \frac{v_{1d}}{2} - \left(-\frac{v_{1d}}{2}\right)$$

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$$\therefore A_{vd1} = \frac{v_{o1}}{v_{1d}/2} = \frac{-g_{m1}}{2(g_{m3} + g_{o1} + g_{o3})}$$

Normally $g_m >> g_o$

$$\therefore A_{vd1} \simeq -\frac{g_{m1}}{2 g_{m3}} = -\frac{1}{2}\frac{\sqrt{2\beta_n'\left(\frac{W_1}{L_1}\right) I_{ss}/2}}{\sqrt{2\beta_n'\left(\frac{W_3}{L_3}\right) I_{ss}/2}}$$

$$= -\frac{1}{2}\sqrt{\frac{W_1}{W_3}}$$

$$\left\{ \begin{array}{l} L_1 = L_2 \\ = L_3 \\ = L_4 \end{array} \right.$$

Similarly

$$A_{vd2} \simeq +\frac{g_{m1}}{2 g_{m3}} = +\frac{1}{2}\sqrt{\frac{W_1}{W_3}}$$

$$\left\{ \begin{array}{l} g_{m1} = g_{m2} \\ g_{m3} = g_{m4} \end{array} \right.$$

$$\therefore A_{vd} = \frac{v_{o1} - v_{o2}}{v_{1d}} = -\frac{g_{m1}}{2 g_{m3}} - \frac{g_{m1}}{2 g_{m4}} = -\frac{g_{m1}}{g_{m3}} = -\sqrt{\frac{W_1}{W_3}}$$

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Output Resistances.

$$R_{O1} = \frac{1}{g_{m3} + g_{o1} + g_{o3}} \simeq \frac{1}{g_{m3}}$$

$$R_{O2} = \frac{1}{g_{m4} + g_{o2} + g_{o4}} \simeq \frac{1}{g_{m4}}$$

$$\therefore R_{OD} = R_{O1} + R_{O2} = \frac{1}{g_{m3}} + \frac{1}{g_{m4}} = \frac{2}{g_{m3}}$$

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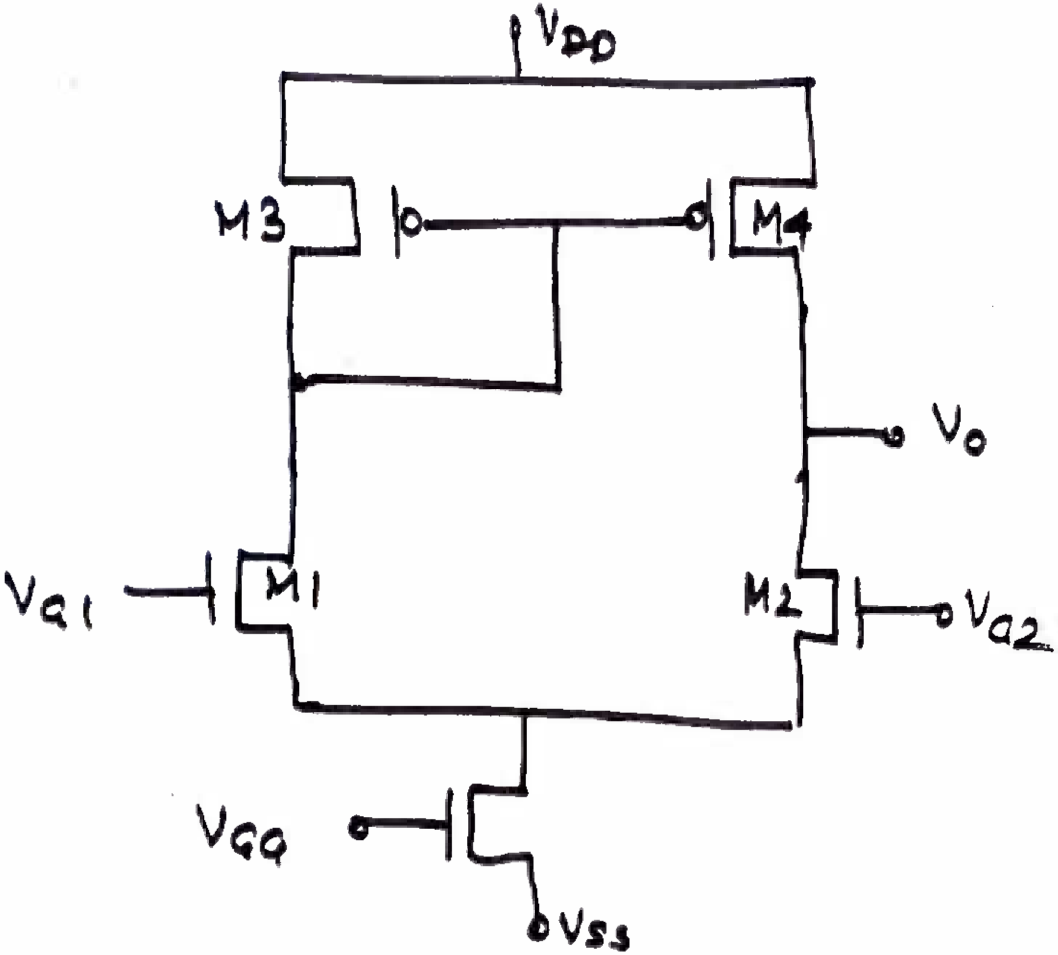
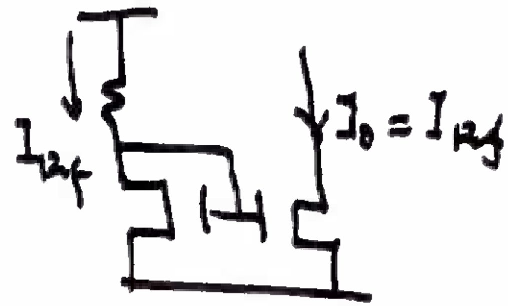
Current Mirror Load





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We see

$$-v_{gs4} = v_{s4} - V_x = v_{s3} - V_x = v_{gs3}$$

However V_x is output v_{o1} due to Diffamp inputs

$$\therefore V_x = V_{o1} = -g_{m1}\left(\frac{v_{id}}{2}\right)\left[r_{o1} \parallel r_{o3} \parallel 1/g_{m3}\right]$$

We define $\dfrac{1}{r_{o13gm}} = \dfrac{1}{r_{o1}} + \dfrac{1}{r_{o3}} + g_{m3}$

If r_{o1} & r_{o3} $>> 1/g_{m3}$

Then $r_{o13gm} = 1/g$

Then $V_x = v_{o1}$

$$= -g_{m1}\left(\frac{v_{id}}{2}\right) r_{o13gm}$$

$$\cong -\frac{g_{m1}}{g_{m3}}\left(\frac{v_{id}}{2}\right)$$

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Output Resistance $R_o = r_{o2} \parallel r_{o4}$

Clearly the Diffamp with Current Mirror Load has following features

1. The Difference Gain $A_{vd} \propto \sqrt{(W/L)_1}$ or $\sqrt{(W/L)_2}$

$$\propto \frac{1}{\sqrt{I_{SS}}}$$

$\propto 1/\lambda$ values of M2 & M4

2 The Output Resistance $R_o = r_{o2} \parallel r_{o4} = \dfrac{1}{g_{o2} + g_{o4}}$

$$= \frac{1}{(\lambda_2+\lambda_4)} \cdot \frac{1}{I_{SS}}$$

$\therefore R_o \propto \dfrac{1}{I_{SS}}$

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Then $$v_o = \left[\frac{g_{m1} g_{m4} v_{id}}{2 g_{m3}} + \frac{g_{m2} v_{id}}{2} \right] r_{o24}$$

$$= \left[\frac{g_{m1} v_{id}}{2} + \frac{g_{m1} v_{id}}{2} \right] r_{o24}$$

$$= \frac{g_{m1} v_{id}}{g_{o2} + g_{o4}}$$

$$\therefore \quad \frac{v_o}{v_{id}} = \frac{g_{m1}}{g_{o2} + g_{o4}} = A_{vdd}$$

or $$A_{vdd} = \frac{\sqrt{\beta_n' (W/L)_1 I_{SS}}}{(\lambda_2 + \lambda_4)(I_{SS}/2)} = \frac{2\sqrt{\beta_n' (W/L)_1 / I_{SS}}}{\lambda_2 + \lambda_4}$$

$$\therefore\ v_{gs4} = -\frac{g_{m1} v_{id}}{2\, g_{m3}} \quad - ①$$

Now we see that V_o (Main Output at 2^{nd} node) is governed by inputs at M2 as well as at M4 (v_{gs4}).

i.e. $V_o = v_o\big|_{v_{gs4}} + v_o\big|_{-\frac{v_{id}}{2}\ (\text{at } M2)}$

$$= +\left[-g_{m4} v_{gs4} + g_{m2} \cdot \frac{v_{id}}{2}\right] r_{o24}$$

$$\frac{1}{r_{o24}} = \frac{1}{r_{o2}} + \frac{1}{r_{o4}}$$

We can make ~~make~~ M1 & M2 identical, so also M3 & M4 identical

Then $g_{m1} = g_{m2}$, $r_{o1} = r_{o2}$, $g_{m3} = g_{m4}$, $r_{o3} = r_{o4}$