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Hence $V_{GS1} = \frac{V_{id}}{2}$ and $V_{GS2} = -\frac{V_{id}}{2}$
is reasonable assumption.

We also observe that $V_{GS3} = V_{GS4}$
or ($V_{GS3} = V_{GS4}$ for small signal case)

$$\text{Then } V_{GS3} = V_{S4} - V_x = V_{S3} - V_x$$

But V_x is output voltage at node x

$$\begin{aligned} \therefore V_{out1} &= -g_{m1} \left(\frac{V_{id}}{2} \right) \left[r_{o1} \parallel r_{o3} \parallel \frac{1}{g_{m3}} \right] \\ &\equiv -g_{m1} r_{o13} g_m \frac{V_{id}}{2} \quad \leftarrow \frac{1}{g_{m3}} \equiv r_{o13} g_m \right. \\ &= -\frac{g_{m1}}{2g_{m3}} \cdot V_{id} \end{aligned}$$



However

$$\begin{aligned} V_{out} &= V_0 \text{ with } -\frac{V_{id}}{2} \text{ input} \\ &+ V_0 \text{ with } V_{gs4} \text{ input} \end{aligned} \quad \left. \vphantom{\begin{aligned} V_{out} &= V_0 \text{ with } -\frac{V_{id}}{2} \text{ input} \\ &+ V_0 \text{ with } V_{gs4} \text{ input} \end{aligned}} \right\} \text{Superposition}$$

$$\therefore V_{out} = -g_{m4} r_{o24} \cdot V_{gs4} + g_{m2} r_{o24} \frac{V_{id}}{2}$$

$$\text{But } V_{gs4} = -V_{out1} = -V_{o1}$$

$$\therefore V_{out} = -g_{m4} r_{o24} \cdot [-g_{m1} r_{o13} g_m] \frac{V_{id}}{2} + g_{m2} r_{o24} \frac{V_{id}}{2}$$

If we
Assume

$$g_{m1} = g_{m2}, \quad r_{o1} = r_{o2}$$

$$g_{m3} = g_{m4}$$

$$r_{o3} = r_{o4}$$

Then

$$V_{out} = + \left[\frac{g_{m1} g_{m4}}{g_{o1} + g_{o3} + g_{m3}} \cdot \frac{1}{g_{o2} + g_{o4}} + \frac{g_{m1}}{g_{o2} + g_{o4}} \right] \frac{V_{id}}{2}$$



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$$\therefore \frac{V_{out}}{V_{id}} = \frac{g_{m1}}{2} \left[1 + \frac{g_{m3}}{g_{o1} + g_{o3} + g_{m3}} \right] \left[\frac{1}{g_{o2} + g_{o4}} \right]$$

As $g_{m3} \gg g_{o1}$ or g_{o3}

$$\therefore \frac{V_{out}}{V_{id}} \approx \frac{g_{m1}}{g_{o2} + g_{o4}}$$

$$A_{UDM} = \frac{\sqrt{2 \left(\frac{I_{SS}}{2} \right) \left(\frac{W}{L} \right)_1 \beta_n'}}{(\lambda_2 + \lambda_4) \frac{I_{SS}}{2}}$$

$$= \frac{2}{\lambda_2 + \lambda_4} \sqrt{\beta_n' \left(\frac{W_1}{L_1} \right) / I_{SS}}$$

$$R_{out} = \frac{1}{g_{o2} + g_{o4}} = \frac{1}{(\lambda_2 + \lambda_4) \frac{I_{SS}}{2}} = \frac{1}{\lambda I_{SS}} \quad \text{If } \lambda_2 = \lambda_4 = \lambda$$

Further our assumption of $g_{m1} = g_{m2}$
& $g_{m3} = g_{m4}$

gives

$$(W/L)_1 = (W/L)_2$$

$$(W/L)_3 = (W/L)_4$$



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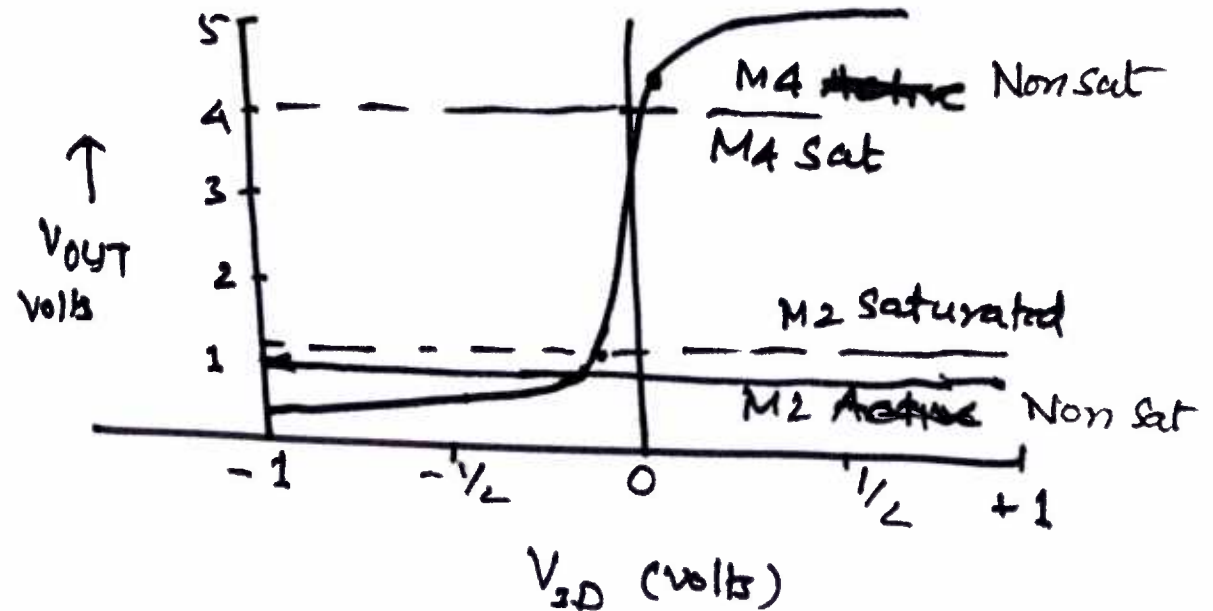
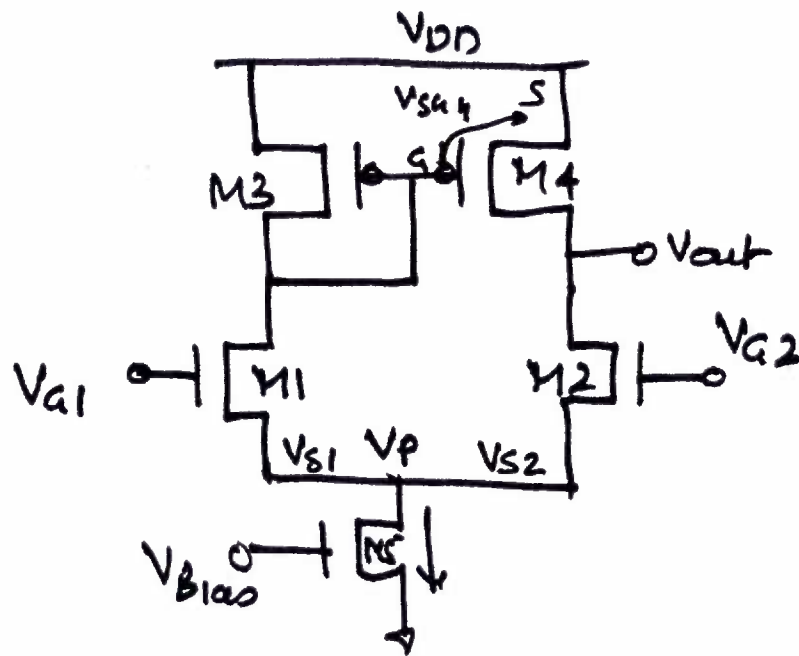
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Voltage Transfer Characteristics for a DIFFAMP under Large Signal Condition



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This Case: $V_{DD} = 5V$

$$V_{T0N} = 0.7 \pm 0.15V$$

$$V_{T0P} = -0.7 \pm 0.15V$$

$$\beta_n^1 = 110 \mu A/V^2, \beta_p^1 = 55 \mu A/V^2 \pm 10\%$$

Here $V_{GS} = 2V$ fixed

(W/L) for all transistors = 2

Gain can only occur when both
M2 & M4 are in Saturation

Now M2 is saturated when

$$V_{DS2} \geq V_{GS2} - V_{TN}$$

$$\text{or } V_{out} - V_{S1} \geq V_{ICM} - 0.5V_{ID} - V_{S1} - V_{TN}$$

If transition of sat to Non sat occurs close
to $V_{ID} = 0$

$$\text{Then } V_{out} \geq V_{ICM} - V_{TN}$$

Similarly M4 is saturated when

$$V_{DS4} \geq V_{SG4} - |V_{TP}| \quad \text{But } V_{DS4} = V_{DD} - V_{out}$$

$$\therefore V_{out} \leq V_{DD} - V_{SG4} + |V_{TP}|$$



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clearly Output Swing of the DIFFAMP [A]

is $V_{out\ max} - V_{out\ min}$

where $V_{out\ max} = V_{DD} - V_{SA4} + |V_{TP}|$

$V_{out\ min} = V_{ICM} - V_{TN}$

Output Swing is one of the major specs for
Diffamp.

Another important specification for DIFFAMP is called
Input Common Mode Range (ICMR)



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Input Common Mode Range [B]

From V_{DD} we can reach V_{a1} through

$M3$ and $M1$

Similarly from V_{DD} to V_{a2} we can reach through $M4$ and $M2$

Each path will give us $V_{icmax} = V_{a1max} \text{ or } V_{a2max}$

The smaller value we shall use V_{icmax} (limit)

$$\text{both } \left\{ \begin{array}{l} \textcircled{1} \\ \textcircled{2} \end{array} \right. \left\{ \begin{array}{l} V_{ICMmax1} = V_{a1max} = V_{DD} - V_{S_{Q3}} - V_{DS1} + V_{GS1} \\ \text{However } V_{DS1} = V_{GS1} - V_{TN} \\ \therefore V_{ICMmax1} = V_{DD} - V_{S_{Q3}} + V_{TN} \end{array} \right. \text{ at saturation of } M1 \text{ --- } \textcircled{1}$$

$$\text{R.H. } \left\{ \begin{array}{l} \textcircled{2} \\ \textcircled{3} \end{array} \right. \left\{ \begin{array}{l} V_{ICMmax2} = V_{DD} - V_{DS4(sat.)} - V_{DS2} + V_{GS2} \\ \text{As } V_{DS2} = V_{GS2} - V_{TN} \end{array} \right. \text{ at saturation of } M2$$



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$$\therefore V_{ICmax_2} = V_{DD} - V_{DS4} + V_{TN}$$

But $V_{DS4} = V_{GS3} - |V_{TP1}|$

As $V_{GS3} = V_{GS4}$

$$V_{SG} = -V_{GS}$$

$$V_{ICmax_2} = V_{DD} + V_{SG3} + 2V_{TN}$$

Clearly $V_{ICmax_1} < V_{ICmax_2}$

We thus choose smaller value as limiting case

$$\therefore \boxed{V_{ICmax} = V_{DD} - V_{SG3} + V_{TN}}$$



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We now evaluate V_{icmin} .
 V_{icmin} is obtained from V_{a1} or V_{a2}
to V_{ss} path. As $M1$ & $M2$ are identical
and hence paths from V_{a1} to V_{ss} or V_{a2} to V_{ss} are same

$$\begin{aligned} \text{Now } V_{ICmin} &= V_{a1min} = V_{a2min} \\ &= V_{ss} + V_{DSs} + V_{GS1} \quad \text{if } V_{ss} = 0 \end{aligned}$$

then $V_{ICmin} = V_{DSat_s} + V_{GS1} \text{ (or } V_{GS2})$

Typically $V_{DSs,sat}$ for a good current source $\approx 200mV$

$$\therefore ICMR = V_{DD} - V_{SQ3} + V_{TN} - (V_{DSat_s} + V_{GS1})$$