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 ($v_{gs_3} = v_{gs4}$ for Small Signal case)

Then $v_{gs3} = v_{s4} - v_x = v_{s3} - v_x$

But V_x is output voltage at node x

$$\therefore \; V_{out1} = -g_{m1}\left(\frac{v_{id}}{2}\right)\left[r_{o1} \,\|\, r_{o3} \,\|\, \frac{1}{g_{m3}}\right]$$

$$\simeq -g_{m1}\, r_{o13g_m}\, \frac{v_{id}}{2}$$

$\longleftrightarrow \; r_{o13g_m} \simeq \frac{1}{g_{m3}}$

$$= -\frac{g_{m1}}{2g_{m3}} \cdot v_{id}$$

However

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

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

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

$$\therefore \quad V_{out} = -g_{m4} r_{o24} \cdot \left[-g_{m1} r_{o13gm} \right] \frac{v_{id}}{2} + g_{m2} r_{o24} \frac{v_{id}}{2}$$

If we Assume $g_{m1} = g_{m2}$, $r_{o1} = r_{o2}$ $g_{m3} = g_{m4}$ $r_{o3} = r_{o4}$

Then

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

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

As $g_{m3} >> g_{o1}$ or g_{o3}

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

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

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

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

Further our assumption of $g_{m1} = g_{m2}$

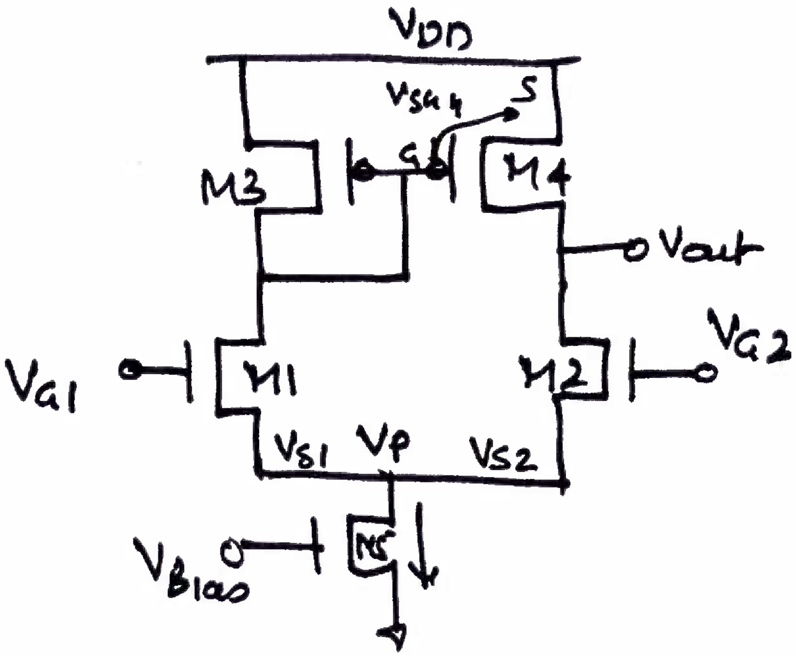
& $g_{m3} = g_{m4}$

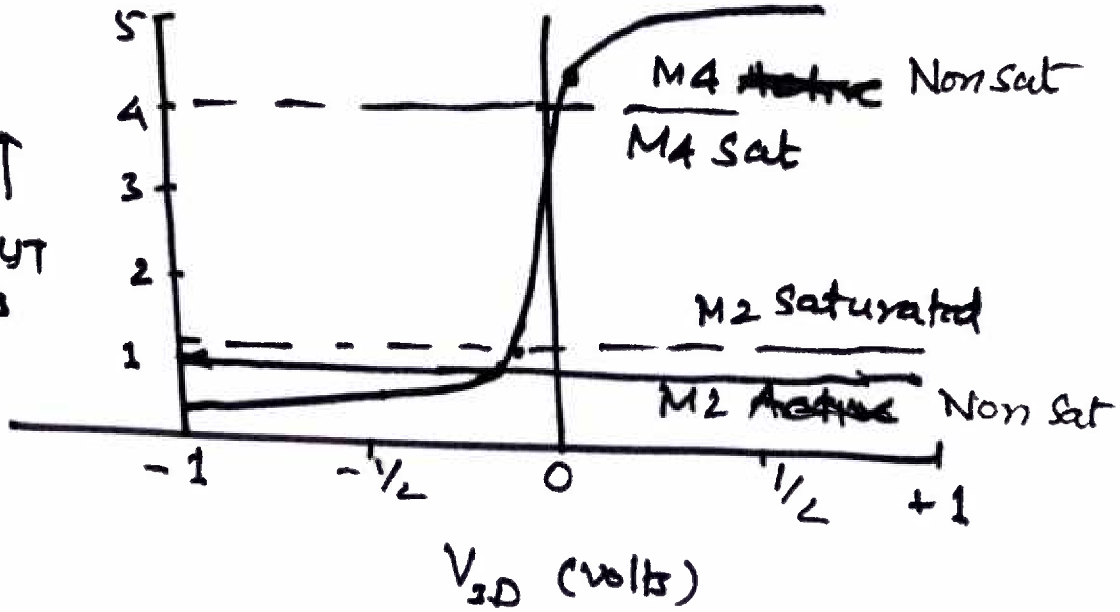
gives

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

$$(W/L)_3 = (W/4)_4$$

Voltage Transfer Characteristics for a DIFFAMP under Large Signal Condition





Here $V_{ICM} = 2$V fixed

This Case: $V_{DD} = 5$ V
$V_{Ton} = 0.7 \pm 0.15$ V
$V_{Top} = -0.7 \pm 0.15$ V
$\beta_n' = 110\ \mu A/V^2$, $\beta_p' = 55\ \mu A/V^2 \pm 10\%$ (W/L) for all transistors = 2

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

Now M2 is saturated when

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

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

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

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

Similarly M4 is saturated when

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

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

Clearly output Swing of the DIFFAMP [A]

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

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

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

Output Swing is one of the major specs for Diffamp.

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

Input Common Mode Range [B]

From V_{DD} we can reach V_{G1} through M3 and M1

Similarly from V_{DD} to V_{G2} we can reach through M4 and M2

Each path will give us $V_{IC_{max}} = V_{G1_{max}}$ or $V_{G2_{max}}$

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

① Path①
$$V_{ICM_{max_1}} = V_{G1_{max}} = V_{DD} - V_{SG_3} - V_{DS1} + V_{GS1}$$

However $V_{DS1} = V_{GS1} - V_{Tn}$ at Saturation of M1

$$\therefore V_{ICMax_1} = V_{DD} - V_{SG3} + V_{Tn} \quad -①$$

② Path ②
$$V_{ICM_{max_2}} = V_{DD} - V_{DS_4}(sat.) - V_{DS2} + V_{GS2}$$

As $V_{DS2} = V_{GS2} - V_{Tn}$ at saturation } M2

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

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

As
$\underline{V_{GS_3} = V_{GS4}}$

$V_{ICmax_2} = V_{DD} + V_{SG_3} + 2V_{Tn}$

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

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

We thus choose smaller value as limiting case

$$\therefore \boxed{V_{IC_{max}} = V_{DD} - V_{SG3} + V_{Tn}}$$

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We now evaluate V_{ICmin}.

V_{ICmin} is obtained from V_{G1} or V_{G2} to V_{SS} path. As M1 & M2 are identical and hence paths from V_{G1} to V_{SS} or V_{G2} to V_{SS} are same

Now $V_{ICmin} = V_{G1min} = V_{G2min}$

$= V_{SS} + V_{DS_5} + V_{GS1}$ If $V_{SS} = 0$

Then $\boxed{V_{ICmin} = V_{Dsat_5} + V_{GS1} \ (\text{or } V_{GS2})}$

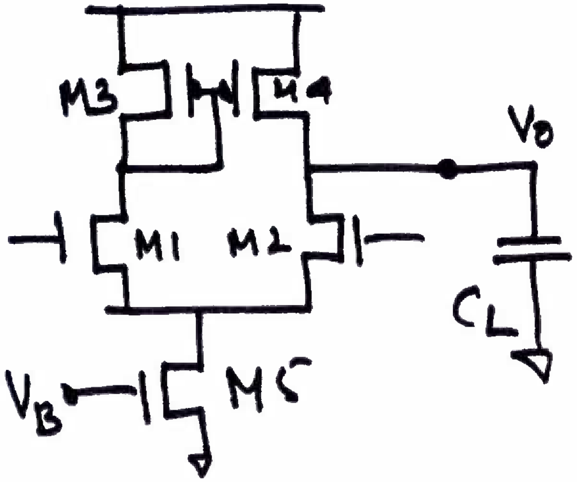
Typically V_{DS_5sat} for a good current source ≃ 200mV

$\therefore$ ICMR $= V_{DD} - V_{SG_3} + V_{Tn} - (V_{Dsat_5} + V_{GS1})$

Power Dissipation $= (V_{DD} + |V_{SS}|) \cdot I_{DS_5}$ [D]

Generally we will be given PD max or to I_{DS_5} available $= \dfrac{PD_{max}\text{(allowed)}}{(V_{DD} + |V_{SS}|)}$

Slew Rate $= SR = \dfrac{dV_0}{dt} = C_L \dfrac{dV_0}{dt} / C_L$ [E]



$$= \frac{I_{DS5}}{C_L}$$

or $I_{DS_5} \geq C_L \cdot SR$

If Dominant Pole is specified then

$f_{-3db} = \dfrac{1}{2\pi R_{out} \cdot C_L}$, can provide me Rout

$$R_{out} = \frac{1}{2\pi f_{-3db} \cdot C_L}$$

However Rout for Single-ended DIFFAMP is given

$$R_{out} = \frac{1}{g_{o2}+g_{o4}} = \frac{1}{(\lambda_n+\lambda_p)\frac{I_{DS5}}{2}}$$

However Difference Gain A_{VDM}

$$A_{VDM} \cong \frac{g_{m1}}{g_{o2}+g_{o4}} = \frac{g_{m1}}{(\lambda_n+\lambda_p)(I_{DS5}/2)}$$

$$= \frac{\sqrt{2\left(\frac{I_{DS5}}{2}\right)\beta_n'\left(\frac{W}{L}\right)_1}}{(\lambda_n+\lambda_p)(I_{DS5}/2)}$$

From given data I_{DS5} can be evaluated and hence A_{VDM} can be found. If $A_{VDM\,cal} < A_{VDM\,specs}$ Then increase $(W/L)_1$ or I_{DS5} so that all specs are met.

In case of short channel devices used in DIFFAMP, we wish to know Effect of this scaling on Linearity ($\frac{\text{Output Current}}{I_{SS}}$) Difference core behavior.

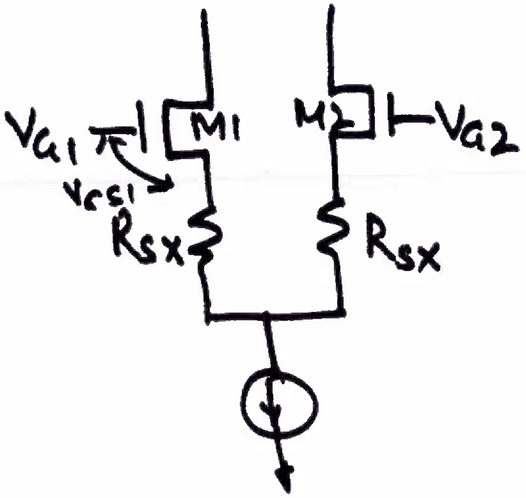
A few Short Channel Effects are :—

1. Mobility variation with Fields ($\mathcal{E}_x$ & $\mathcal{E}_y$)
2. V_T reduces with reduction in L
3. R_S & R_D increases
4. Leakage currents increase.

. . etc etc

Short-Channel Effects.

The First & Foremost effect is the increase of Source & Drain resistance. This leads to eq.ckt change giving



$$\cancel{V_{G1} - V_{G2} =}$$

$$V_{G1} - V_{GS1} - I_{DS1} R_{SX}$$

$$= V_{G2} - V_{GS2} - I_{DS2} R_{SX}$$

We define $I_{ODS} = I_{DS1} - I_{DS2} = g_m V_{id}$

We recollect

$$V_{GS1} = V_{TN} + \sqrt{\frac{2 I_{DS1}}{\beta_1}}$$

$$V_{GS2} = V_{TN} + \sqrt{\frac{2 I_{DS2}}{\beta_2}}$$

In long Channel case (without Rsx)

$$\frac{I_{ODS}}{I_{SS}} = \frac{V_{id}}{V_{ov}} - \frac{1}{8}\left(\frac{V_{id}}{V_{ov}}\right)^3 + \cdots$$

However in short channel case (with Rsx)

$$\frac{I_{ODS}}{I_{SS}} = \left[\frac{V_{id}}{(1+g_m R_{SS})V_{ov}}\right] - \frac{1}{8}\left[\frac{V_{id}}{(1+g_m R_{SS})V_{ov}}\right]^3 + \cdots$$

Since Denominator increases in Short channel case, Differential Amplifier with Rsx will show better 'Linear Characteristics' than that for Long Channel case.

But $I_{DS}R_{SX}$ drop will also reduce g_m at a given current