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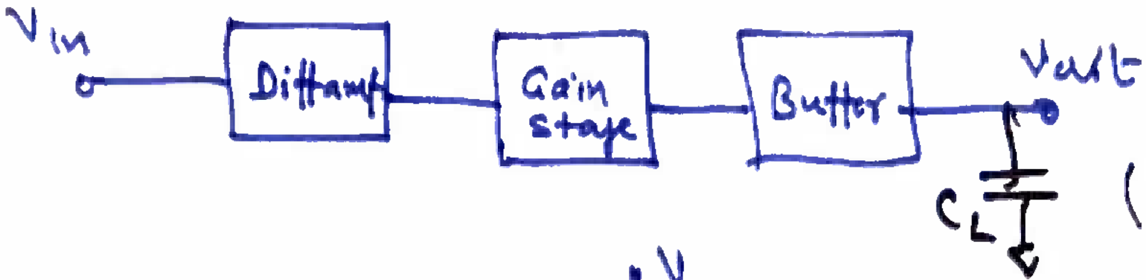
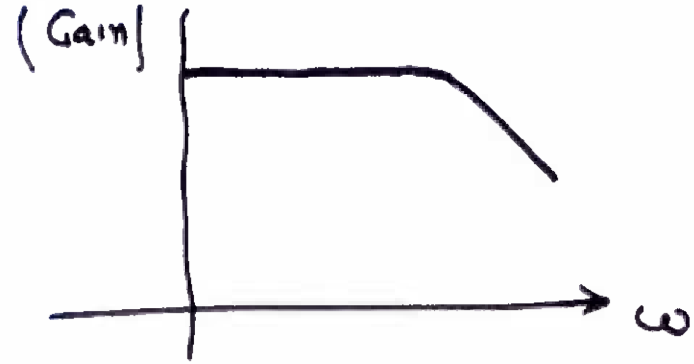
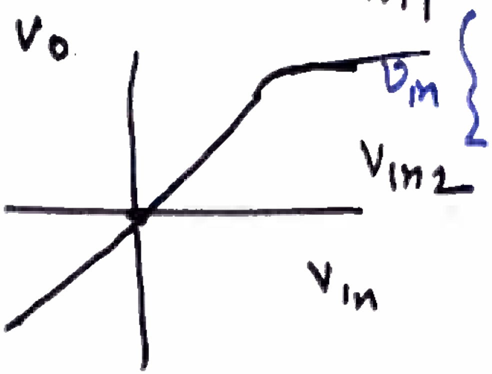
Slew Rate

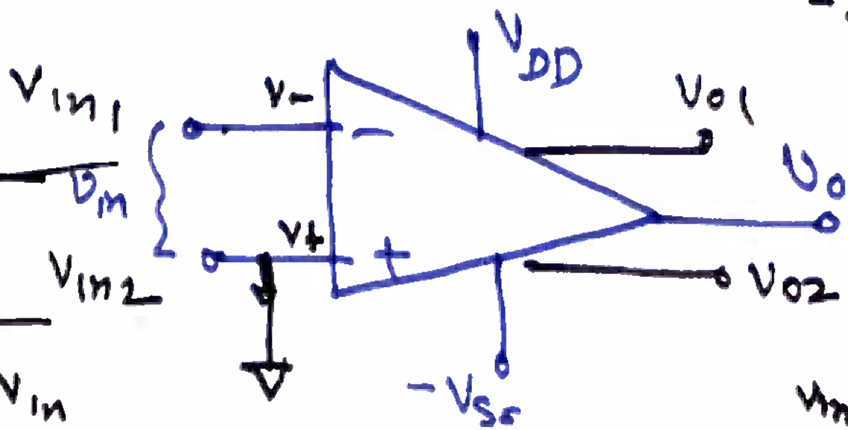
OPAMP

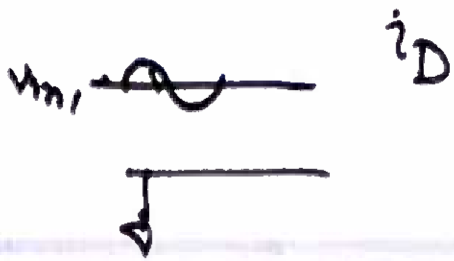
$$C_L \frac{dV_o}{dt} = \frac{I_{SS}}{C_L}$$











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Differential Amplifier

1. MOS DIFFAMP
2. BJT DIFFAMP

Differential Amplifier has two inputs v_{in1}, & v_{in2}.

This gives :—

$$\left.\begin{array}{ll} \text{Difference Signal } v_{id} = v_{in1} - v_{in2} \\ \text{and} \quad \text{Common Mode Signal } v_{cM} = \dfrac{v_{in1} + v_{in2}}{2} \end{array}\right] \text{Inpu}$$

Major advantages of Diffamp is much Higher Immunity to environmental Noise, Higher Voltage Swings, with disadvantage of additional Area in an IC.

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The Minimum Occures, such that V_S which is Source Voltage M1 & M2, has value enough for creating Current Source I_{SC}

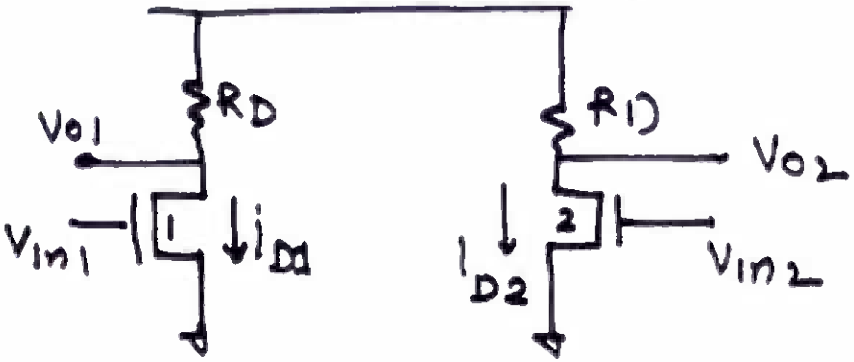
$$V_{DS} \text{ for CSource} = V_S - (-V_{SS})$$

$$\therefore V_{CM_{MIN}} = V_{GS} + V_T + V_{CS} - V_T - V_{SS}$$

$$\boxed{V_{CM_{min}} = V_{OV} + V_T + V_{CS} - V_{SS}}$$

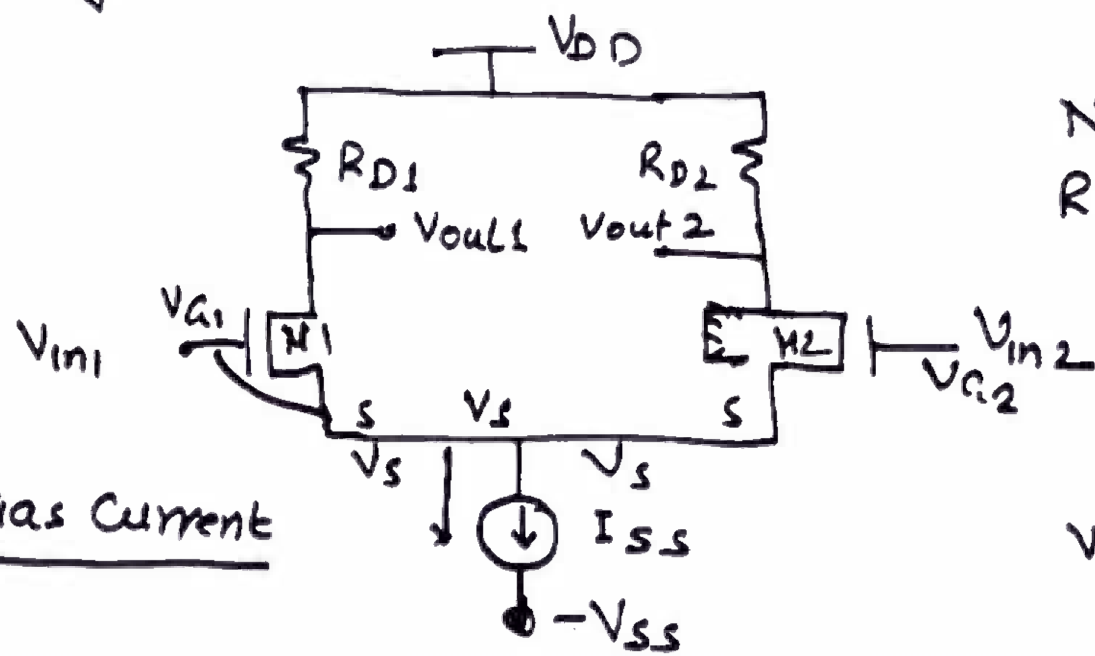
Range ICMR $= V_{cmax} - V_{CMmin}$

A Diffamp consists of Two Single Ended Amplifier.



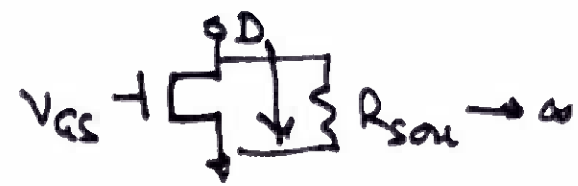
Modified Version :

V_G



Normally
$R_{D1} = R_{D2} = R_D$

I_{SS} is DC Bias Current



Input Common Mode Range (ICMR)

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$V_{CM_{Max}}$, $V_{CM_{min}}$ are two limits of Common Mode Inputs.

① $V_{CM_{max}}$ occures when M1 & M2 are at edge of 'Saturation' i.e. $\underline{V_{GS} - V_T = V_{DS}}$

In our case it means

$$V_{CM_{max}} - V_T = V_{DD} - \frac{I_{SS}}{2} R_D$$

or $$V_{CM_{MAX}} = V_T + V_{DD} - \frac{I_{SS}}{2} R_D .$$

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Clearly $v_{id} = v_{GS1} - v_{GS2}$

If v_{id} is +tive $v_{GS1} > v_{GS2}$

$\therefore \quad i_{DS1} > i_{DS2}$

But if v_{id} is -ve $v_{GS2} > v_{GS1}$

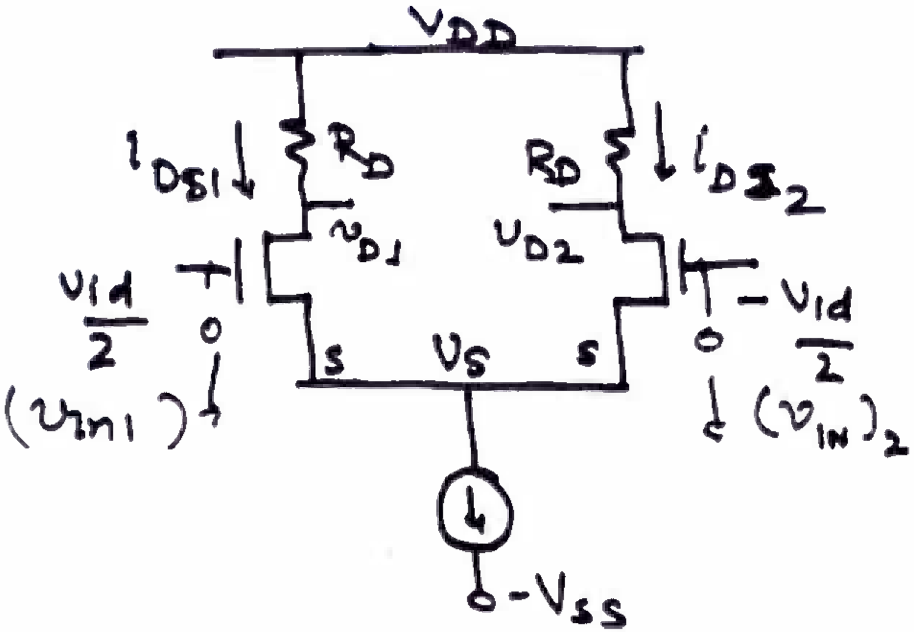
& then $i_{DS2} > i_{DS1}$

It is possible that at a value of v_{id}, only one transistor is ON (Saturated) and the other OFF.

$\therefore$ All the I_{SS} flows through 'ON' transistor $= i_{DS1}$ (say)

Then $i_{DS1} = I_{SS} = \frac{\beta_n'}{2}\left(\frac{W}{L}\right)\left[V_{GS1} - V_T\right]^2 \qquad (\lambda = 0)$

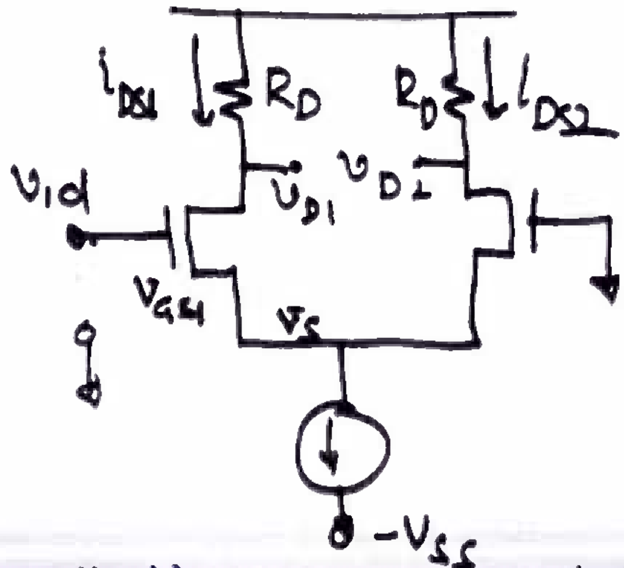
Differential Mode Input Response



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

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

Alternatively →



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OR $v_{GS1} = V_T + \sqrt{2 I_{SS} / [\beta_n' (W/L)]}$

We define V_{OV} (over voltage)

$$= \sqrt{2 \frac{I_{SS}}{2} / \beta' (W/L)}$$ where V_{OV} is for $\frac{I_{SS}}{2}$

$\therefore \quad v_{GS1} = V_T + V_{OV} (\sqrt{2})$

$\therefore \quad V_{id\,max} = v_{GS1} + v_S$

But min v_S can be obtained from M_2 as $v_{GS2} = 0$

$\therefore \quad v_{in2} = 0 - V_S$ or $v_S = 0 - v_T = -V_T$

$\therefore \quad v_{id\,max} = V_T + \sqrt{2} V_{OV} - V_T = \sqrt{2} V_{OV}$

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Diffamp with Common Input Voltage

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$v_{in1} = v_{in2} = v_{G1} = v_{G2}$

As Source is common to both sides

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

Then $V_{CM} = v_{in1} = v_{in2} = v_{GS1} = v_{GS2}$

$\therefore \quad v_S = V_{CM} - V_{GS}$

But we have $\quad V_{OV} = V_{GS} - V_t$

Since $V_{GS1} = V_{GS2}$, hence M1 & M2 will have <u>SAME</u> Current. That $i_{D1} = i_{D2}$

But $i_{D1} + i_{D2} = I_{SS}$

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$$\therefore \; i_{D1} = i_{D2} = \frac{I_{SS}}{2}$$

$$\therefore \; i_{D1} = i_{D2} = \frac{I_{SS}}{2} = \frac{1}{2}\,\frac{\beta_n'(W/L)}{2}\,(V_{GS}' - V_T)^2$$

One Trans

$$\text{or} \quad \frac{I_{SS}}{2} = \frac{\beta_n'(W/L)}{4}\,(V_{OV})^2$$

$$\therefore \; V_{OV} = \sqrt{\frac{2 I_{SS}}{\beta_n'(W/L)}}$$

Then $v_{D1} = v_{D2} = V_{O1} = V_{O2} = V_{DD} - \frac{I_{SS}}{2} \cdot R_D$

Then $\underline{V_{O1} - V_{O2} = 0}$

Hence $V_o = V_{o1} - V_{o2} = 0$

and input $= V_{CM}$

$\therefore$ Common Mode Voltage Gain

$$A_{CM} = \frac{V_o}{V_{CM}} = 0$$

$$CMRR = \frac{A_{dm}}{A_{CM}}$$ (80 db – 120 db)

Assumption here was, M1 & M2 are Identical i.e.

$V_{T1} = V_{T2}$

I_{SS} is Ideal current Source.

and $R_{D1} = R_{D2} = R_D$

Thus any Noise overriding both V_{in1} & V_{in2} will act like Common Mode Signal & Gets Rejected at the Output

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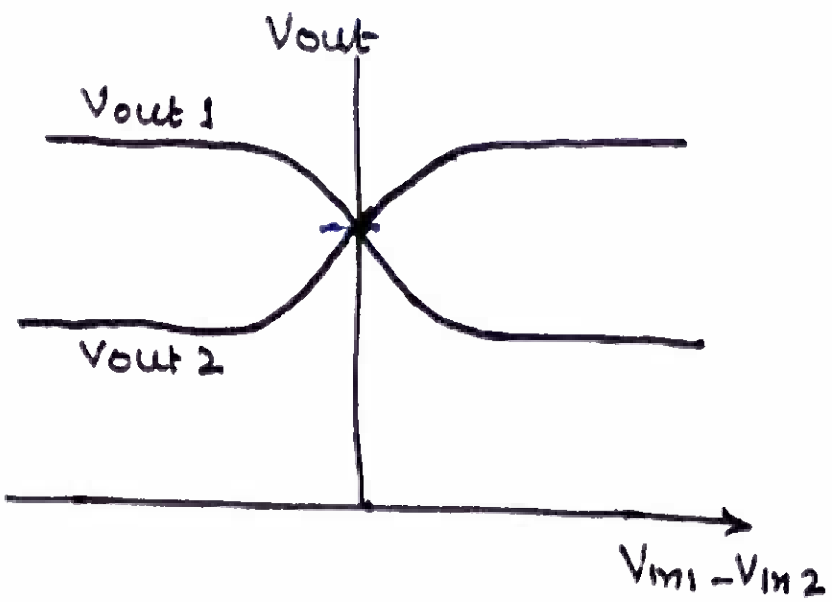
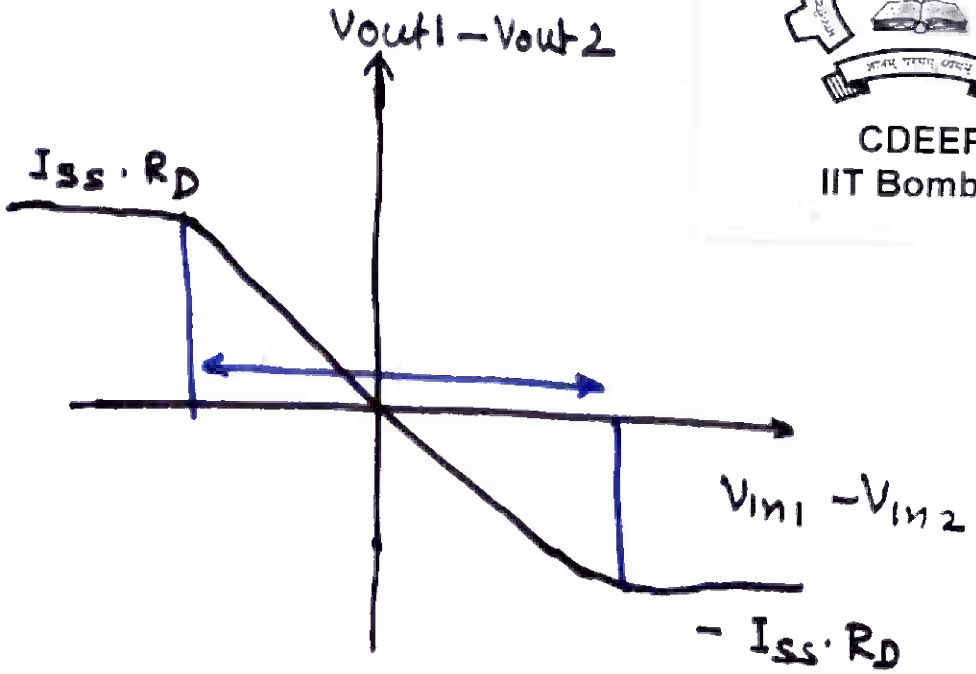
I/O Characteristics





$V_{out1} = V_{DD} - I_{SS} R_D$

$V_{out2} = V_{DD} - I_{SS} R_D$

when $V_{in1} - V_{in2}$ swings from $-\infty$ to $+\infty$

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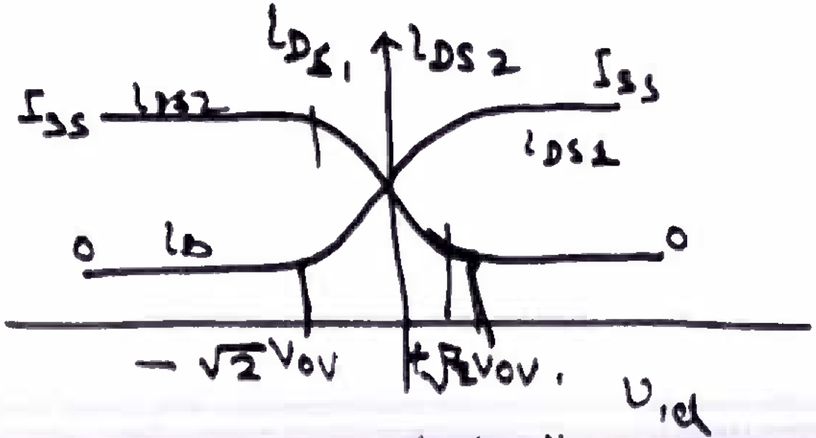
By complementary argument

$$v_{id\,min} = -\sqrt{2}V_{OV}$$

$\therefore$ Currents in M1 & M2 goes from Max to Min in the range

$$-\sqrt{2}V_{OV} \le v_{id} < \sqrt{2}V_{OV}.$$

It $v_{id}/2$, Both M_1 & M_2 carries $I_{SS}/2$ current



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Large signal operation

For the Diffamp under review

$$v_{id} = V_{GS1} - V_{GS2} = V_{G1} - V_{G2}$$

In choice of Biasing, we assure that M_1 & M_2 when 'ON' are in Saturation.

We have

$$i_{DS1} = \frac{\beta_n'}{2} (V_{GS1} - V_T)^2 (W/L) \quad -(i) \quad (\lambda = 0)$$

$$i_{DS2} = \frac{\beta_n'}{2} (W/L) (V_{GS2} - V_T)^2 \quad -(ii)$$

or

$$\sqrt{i_{DS1}} = \sqrt{\frac{\beta_n'}{2}(W/L)} \, (V_{GS1} - V_T) \quad -(iii)$$

$$\sqrt{i_{DS2}} = \sqrt{\frac{\beta_n'}{2}(W/L)} \, (V_{GS2} - V_T) \quad -(iv)$$

However $v_{GS1} - v_{GS2} = v_{id}$

$= v_{G1} - v_{G2}$

$$\therefore \sqrt{i_{DS1}} - \sqrt{i_{DS2}} = \sqrt{\frac{\beta_n'(W/L)}{2}}\, v_{id} \quad -(vi)$$

However $i_{DS1} + i_{DS2} = I_{SS} \quad -(vii)$

Squaring (vi)

$$\left[\sqrt{i_{DS1}} - \sqrt{i_{DS2}}\right]^2 = \frac{\beta_n}{2} v_{id}^2$$

or $$\underline{i_{DS1} + i_{DS2}} - 2\sqrt{i_{DS1} i_{DS2}} = \frac{\beta_n}{2} v_{id}^2$$

or $$I_{SS} - 2\sqrt{i_{DS1} i_{DS2}} = \frac{\beta_n}{2} (v_{id})^2$$

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Solving

$$i_{DS1} = \frac{I_{SS}}{2} \pm \sqrt{\beta_n I_{SS}}\left(\frac{v_{id}}{2}\right)\left[1 - \frac{(v_{id}/2)^2}{I_{SS}/\beta_n}\right]$$

$$\therefore \quad i_{DS1} = \frac{I_{SS}}{2} + \sqrt{\beta_n I_{SS}}\left[1 - \frac{(v_{id}/2)^2}{I_{SS}/\beta_n}\right]\left(\frac{v_{id}}{2}\right)$$

$$\& \quad i_{DS2} = \frac{I_{SS}}{2} - \sqrt{\beta_n I_{SS}}\left[1 - \frac{(v_{id}/2)^2}{I_{SS}/\beta_n}\right]\left(\frac{v_{id}}{2}\right)$$

(Please note $i_{DS1} + i_{DS2} = I_{SS}$)

At $v_{id} = 0$ $\quad i_{DS1} = I_{SS}/2$ $\quad$ & then $v_{GS1} = v_{GS2} = V_{GS}$

$i_{DS2} = I_{SS}/2$

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If $v_{id}/V_{ov} < 1$

$$i_{DS1} = \frac{I_{SS}}{2} + \frac{I_{SS}}{V_{ov}}\left(\frac{v_{id}}{2}\right)$$

$$i_{DS2} = \frac{I_{SS}}{2} - \frac{I_{SS}}{V_{ov}}\left(\frac{v_{id}}{2}\right)$$

$\therefore$ $i_{ds1} \propto v_{id}$ Linear operation

$\therefore$ Condition for Linear Operation is $v_{id} << V_{ov}$

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Then $\frac{I_{SS}}{2} = \frac{\beta_n'}{2}\left(\frac{W}{L}\right)(v_{GS} - V_T)^2$

$= \frac{1}{2}\beta_n v_{ov}^2$

$\therefore \frac{I_{SS}}{\beta_n} = v_{ov}^2$

$\therefore i_{DS1} = \frac{I_{SS}}{2} + \frac{I_{SS}}{V_{ov}}\left(\frac{v_{id}}{2}\right)\sqrt{1 - \left(\frac{v_{id}/2}{V_{ov}}\right)^2}$

$i_{DS2} = \frac{I_{SS}}{2} - \frac{I_{SS}}{V_{ov}}\left(\frac{v_{id}}{2}\right)\sqrt{1 - \left(\frac{v_{id}/2}{V_{ov}}\right)^2}$

Clearly at $v_{id} = 2V_{ov}$ $\quad i_{DS1} = i_{DS2} = I_{SS}/2$