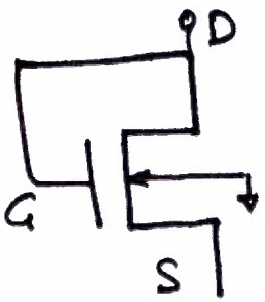
# Loads in MOS Amplifiers

(i) Resistive Load — Actual Resistor as Load

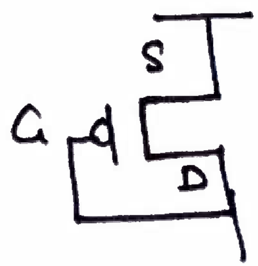
(ii) Active load — Device as Resistor

Active Loads :—

(A) Diode Connected Loads :




n-MOS




PMOS

In this case $V_{GD} = 0$

We have $V_{DS} = V_{GS} + V_{GD}$ for Normal case.

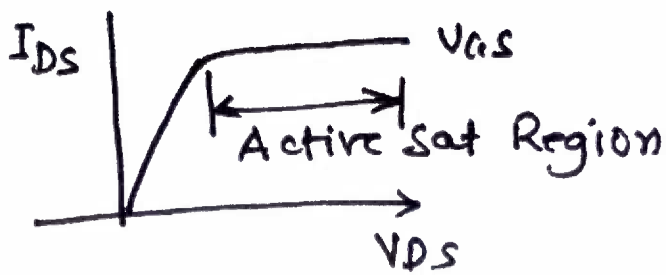
$\therefore$ Here $V_{DS} = V_{GS}$

or $V_{GS} - V_T < V_{DS}$ Device is Always in Saturation. Then

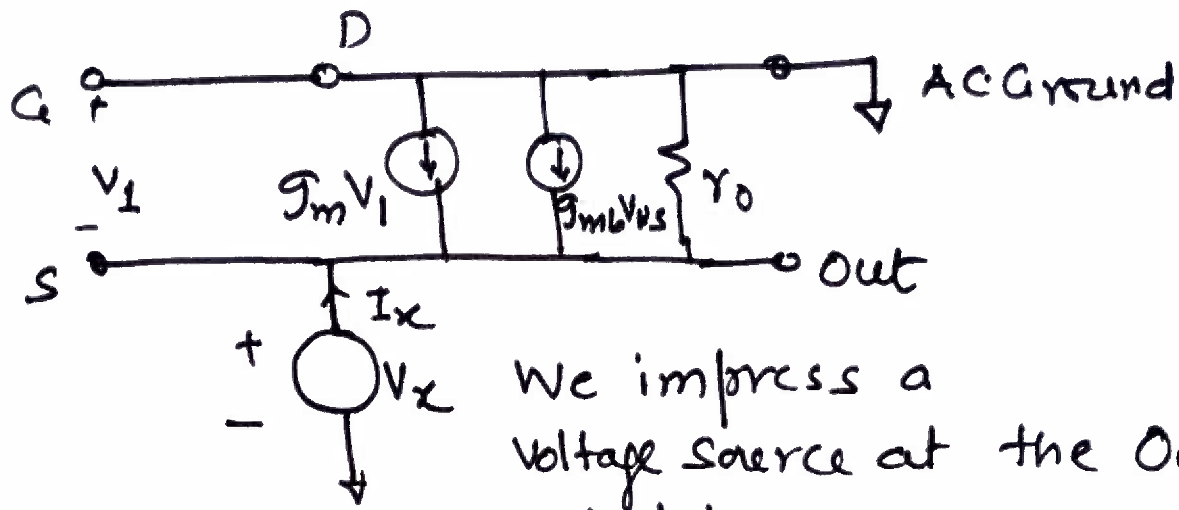
$$I_{DS} = \frac{\beta}{2} (V_{GS} - V_T)^2$$

If $\lambda$ is v. small

This is constant Current Source.



Eq. Ckt to evaluate $R_o$ of Current Source.




We impress a voltage source at the Output as $V_x$ and let us say $I_x$ is the current

Then $R_o = \dfrac{V_x}{I_x}$ Here $V_{bs} = 0 - V_x$

$$I_x = +(g_m + g_{mb})V_x + \frac{V_x}{r_o}$$

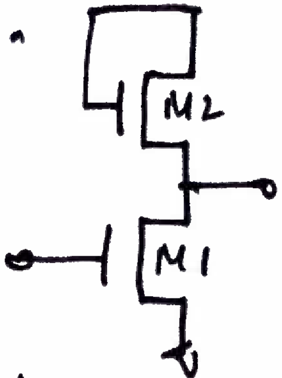
or $I_x = \left[g_m + g_{mb} + \frac{1}{r_o}\right]V_x$

$$\therefore \quad R_o = \frac{V_x}{I_x} = \frac{r_o}{1 + (g_m + g_{mb})r_o} \simeq \frac{1}{g_m + g_{mb}}.$$

To improve of $r_{out}$ we must reduce $g_m$ of Load transistor. But

$$g_m = \sqrt{2\beta'\left(\frac{W}{L}\right)}\,(I_{DS})^{1/2}$$

For a set value of $I_{DS}$, reduction in $W/L$ reduces $g_m$, or increases $R_o$ of load source.



Amplifier

Then Gain $= -g_{m_1} R_{out}$

Here $R_{out} = R_{o_2} \,||\, r_{o1} = \dfrac{r_{o1}}{g_{m_2}+g_{mb_2}} \Big/ \left(r_{o1} + \dfrac{1}{g'_m}\right)$

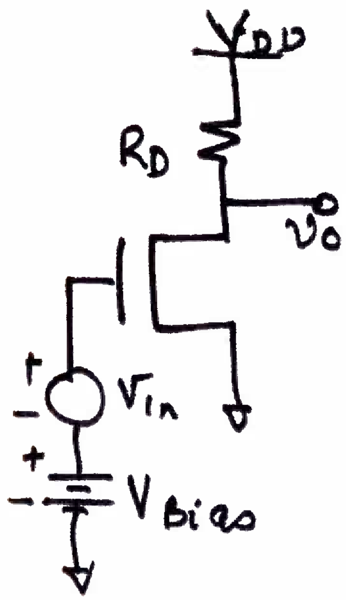
$$\therefore \quad A_{vo} = -\cancel{\frac{g_{m1} r_{o1}}{g_{m2}}} \;\; \cancel{\frac{1}{1+\eta}} \qquad \eta = \cancel{\frac{g_{mb}}{g_m}}$$

$$A_{vo} = -\frac{g_{m1} r_{o1}}{(1+\eta)\, g_{m_2} r_{o1} + 1} \simeq -\frac{g_{m1}}{g'_{m2}} = -\frac{\sqrt{2\beta'(W/L)_1 I_{DS}}}{(1+\eta)\sqrt{2\beta'(W/L)_2 I_{DS}}}$$

or $A_{vo} = \sqrt{\dfrac{(W/L)_1}{(W/L)_2}} \cdot \dfrac{1}{1+\eta}$

# Differential Amplifier

In Single Stage Amplifier (CS, CG or CD), one of the issue is 'Biasing' for a Q-point. Since Gain of the Amplifier is constant only if $g_m$ & $r_o$ are constant.




However position of $V_{Bias}$ along with Input Signal $V_{in}$, cannot keep these two parameters ($g_m$ & $r_o$) as constant. Stating Precisely, we observe that output voltage is not constant in particular case of large 'Gain' Amplifier.

If we use constant current Biasing, may be this issue can be addressed

A typical Biasing System could be

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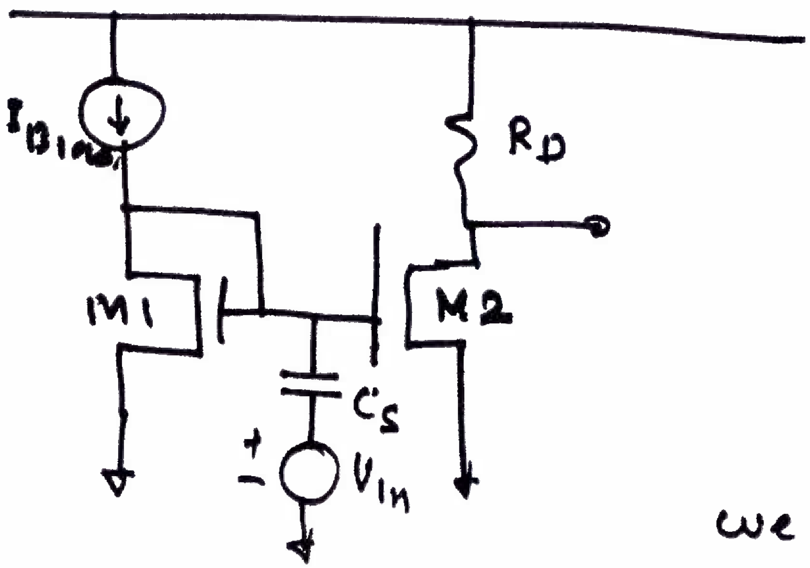
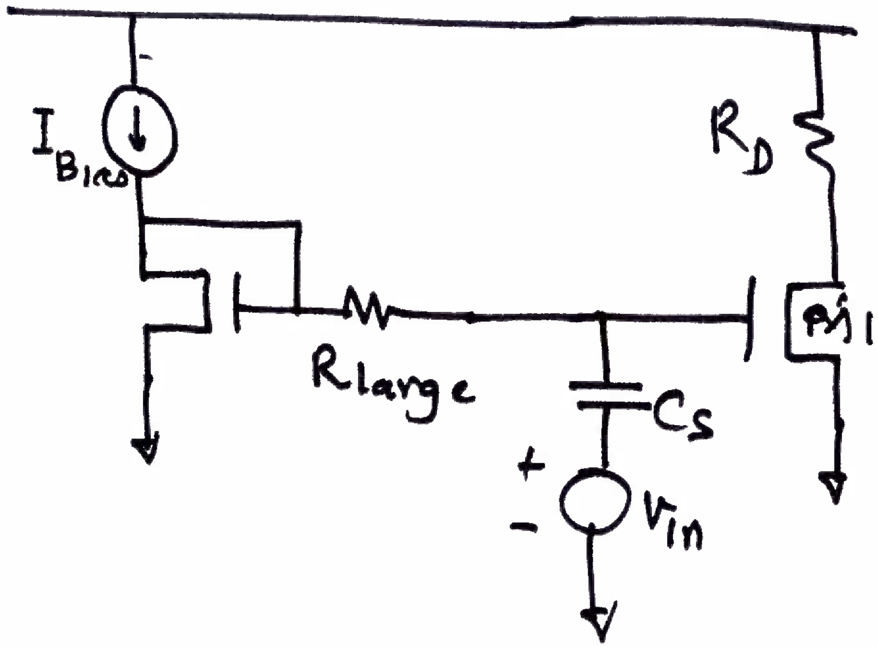



$C_s$ is large Series capacitance to block DC from $v_{in}$.

To achieve better blocking we need a High Pass Filter at Input.

# Modified Biasing scheme may be




High Pass Filter Cut off frequency

$$f_c = \frac{1}{2\pi R_{Large} C_s}$$

For $f_c$ to be lower both R and C should be v. large.

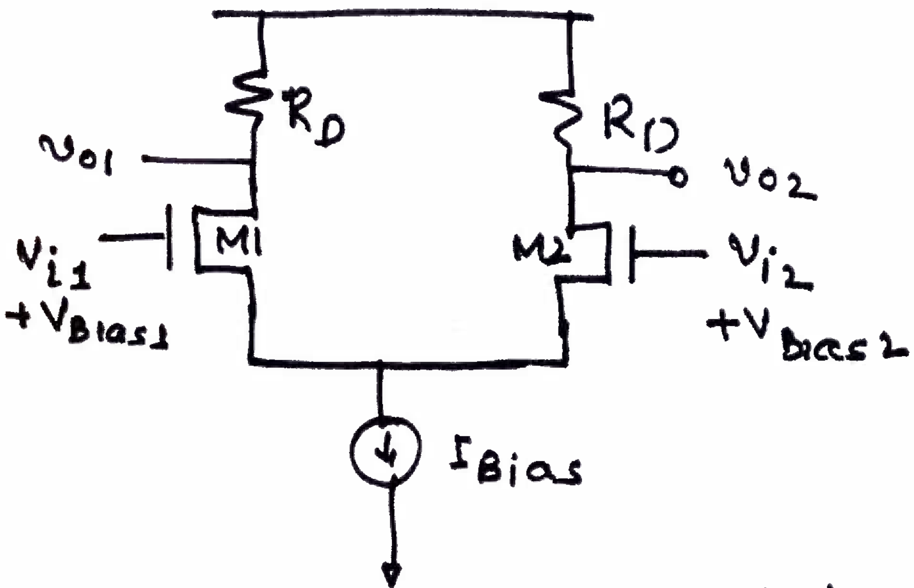
Which means they will require large Area.

However with this Scheme, $g_m$ of M1 will only be decided by $I_{Bias}$ and not by $V_{Bias}$

Differential Amplifier is a better solution to this Biasing Problem





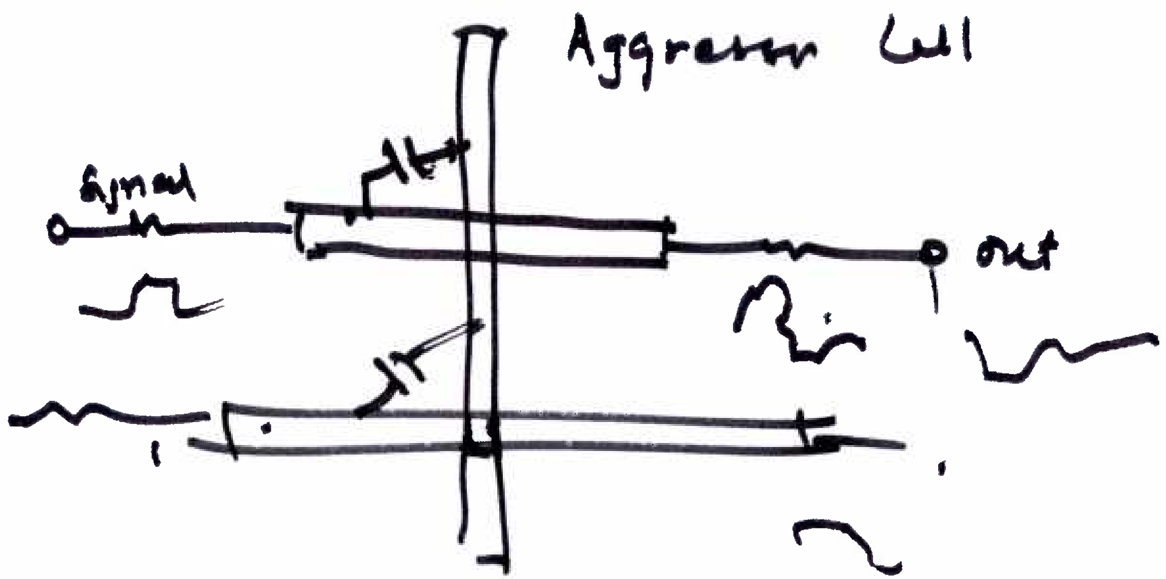



If $V_{Bias1} = V_{Bias2}$

then we see that

$g_m$ for M1 & M2 are decided by Tail current Source $I_{Bias}$

An Interesting outcome is that Difference ($v_{o1} - v_{o2}$) Voltage is proportional to Input difference voltage ($v_{i1} - v_{i2}$)


Aggressor Cell
Signal
out

We have

$$I_{DS} = \frac{\beta}{2}(V_{GS} - V_T)^2$$

or

$$V_{GS} = \sqrt{\frac{2I_{DS}}{\beta}} + V_T$$

$$\therefore V_{in1} - V_{in2} = \sqrt{\frac{2I_{DS1}}{\beta}} + V_T - \sqrt{\frac{2I_{DS2}}{\beta}} - V_T$$

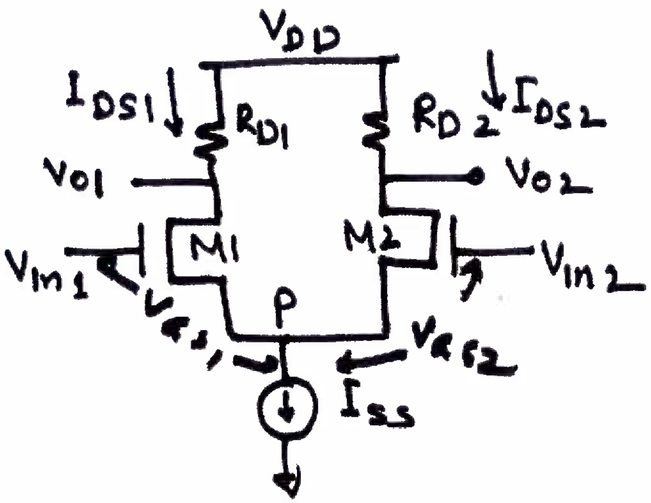
$$= \sqrt{\frac{2I_{DS1}}{\beta}} - \sqrt{\frac{2I_{DS2}}{\beta}}$$

Further $I_{DS_1} + I_{DS_2} = I_{SS}$ for all cases.

$$(V_{in1} - V_{in2})^2 = \frac{2I_{DS1}}{\beta} + \frac{2I_{DS_2}}{\beta} - \frac{4}{\beta}\sqrt{\frac{I_{DS1} I_{DS2}}{1}}$$

$$= \frac{2}{\beta}(I_{SS}) - \frac{4}{\beta}\sqrt{I_{DS1} I_{DS_2}}$$

# Large signal Behavior of DIFFAMP.




$V_{in1}$ & $V_{in2}$ are Inputs to M1 & M2

By Circuit Analysis

$$V_{O1} = V_{DD} - I_{DS_1} R_{D1}$$

$$V_{O2} = V_{DD} - I_{DS_2} R_{D2}$$

$$\therefore \quad V_{O1} - V_{O2} = I_{DS_2} R_{D2} - I_{DS_1} R_{D_1}$$

$$= (I_{DS_2} - I_{DS1}) R_D \quad \text{if } R_{D1} = R_{D2} = R_D$$

Further

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

We assume for all case now onward that $\lambda = 0$ if not stated otherwise.

or $$\frac{\beta}{2}(V_{in1}-V_{in2})^2 - I_{SS} = -2\sqrt{I_{DS1} I_{DS2}}$$

However

$$(I_{DS1}+I_{DS2})^2 - (I_{DS1}-I_{DS2})^2 = 4 I_{DS1} I_{DS2}$$

or $$I_{SS}^2 - (I_{DS1}-I_{DS2})^2 = \left(2\sqrt{I_{DS1} I_{DS2}}\right)^2$$

or $$(I_{DS1}-I_{DS2})^2 = I_{SS}^2 - \left(2\sqrt{I_{DS1} I_{DS2}}\right)^2$$

$$= I_{SS}^2 - \left[\frac{\beta}{2}(V_{in1}-V_{in2})^2 - I_{SS}\right]^2$$

$$= -\frac{1}{4}\beta^2(V_{in1}-V_{in2})^4 + \beta I_{SS}(V_{in1}-V_{in2})^2$$

$$= \beta^2(V_{in1}-V_{in2})^2\left[-\frac{1}{4}(V_{in1}-V_{in2})^2 + \frac{I_{SS}}{\beta}\right]$$

or $$I_{DS1} - I_{DS2} = \frac{\beta}{2}(V_{in1}-V_{in2})^2\left[\frac{4I_{SS}}{\beta} - (V_{in1}-V_{in2})^2\right]$$

If $V_{in1} = V_{in2}$ $\quad I_{DS1} = I_{DS2} = \frac{I_{SS}}{2}$

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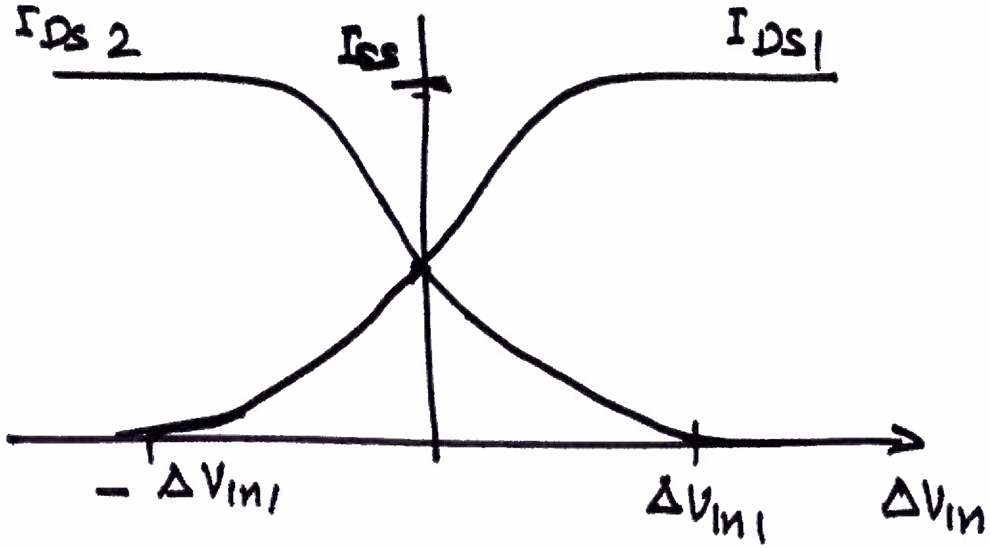
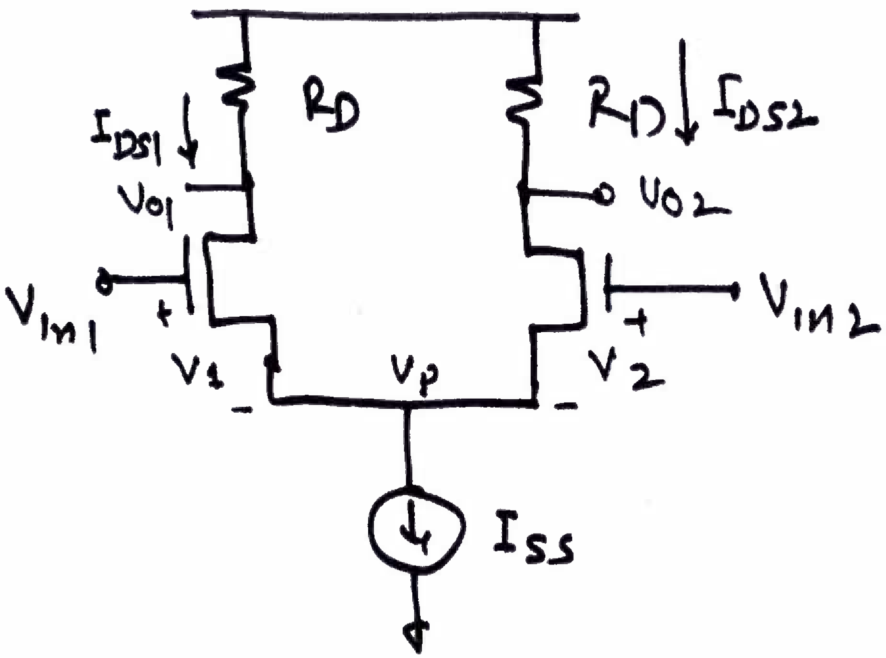



where $\Delta V_{in1} = \sqrt{\frac{2I_{SS}}{\beta}}$

# Differential Amplifier with Resistive Load






## Half Circuit Method

If the circuit shows symmetry for two inputs $V_{in1}$ & $V_{i2}$ as shown in Diffamp ckt shown here, Then we can treat each input Independent to a CS Amplifier and evaluate $V_{o1}$ & $V_{o2}$

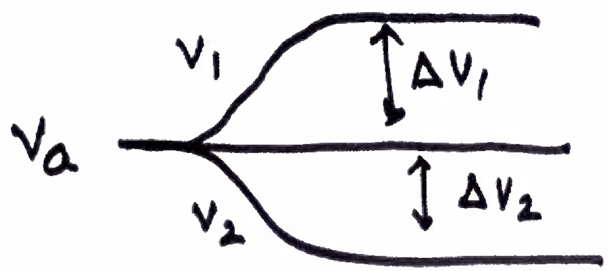
Validity of Half Circuit concepts, rests on the principle of Symmetry, such that $V_p$ remains Constant for any input combination of $V_{in1}$ & $V_{in2}$

For $M_1$ $\quad V_{in1} - V_p = V_1 = V_{GS1}$
or $\quad V_{in1} - V_1 = V_p$ $\quad \Bigg\} - (1)$

& for $M_2$ $\quad V_{in2} - V_p = V_2 = V_{GS2}$
or $\quad V_{in2} - V_2 = V_p$ $\quad \Bigg\} - (2)$

$$\therefore \quad V_{in1} - V_1 = V_{in2} - V_2$$

We assume that $V_a$ is the equilibrium value of $V_1$ & $V_2$
And each change by $\Delta V_1$ & $\Delta V_2$




Now $\quad I_{DS1} = g_m \Delta V_1$
$\quad i_{DS2} = g_m \Delta V_2$ $\quad \Bigg\} - (3)$

However $\quad I_{DS1} + I_{DS2} = I_{SS}$

or $\quad g_m \Delta V_1 + g_m \Delta V_2 = 0 \quad$ for $\Delta I_{SS} = 0$

$$\therefore \quad \Delta V_1 = -\Delta V_2 \quad - (4)$$

As we have shown earlier

$$V_{in1} - V_1 = V_{in2} - V_2 \quad \text{— (5)}$$

If we define $V_{IN}$ as equilibrium value of $V_{in1}$ & $V_{in2}$, and $V_{in}$ changes by $\Delta V_{in}$, then

$$V_{in1} = V_{IN} + \Delta V_{in} \quad \& \quad V_{in2} = V_{IN} - \Delta V_{in}$$

Substituting $V_{n1}$ & $V_{in2}$ in (5)

$$V_{IN} + \Delta V_{in} - V_1 = V_{IN} - \Delta V_{in} - V_2$$

or $$V_{IN} + \Delta V_{in} - (V_a + \Delta V_1) = V_{IN} - \Delta V_{in} - (V_a + \Delta V_2)$$

$$\Delta V_{in} - \Delta V_1 = -(\Delta V_{in} - \Delta V_2)$$

or $$2\,\Delta V_{in} = \Delta V_1 - \Delta V_2 = 2\,\Delta V_1$$

or $$\Delta V_{in} = \Delta V_1 \quad (= -\Delta V_2)$$

Change in Input is absorbed in change in $\Delta V_1$ (or $\Delta V_2$) $\Rightarrow V_p$ constant