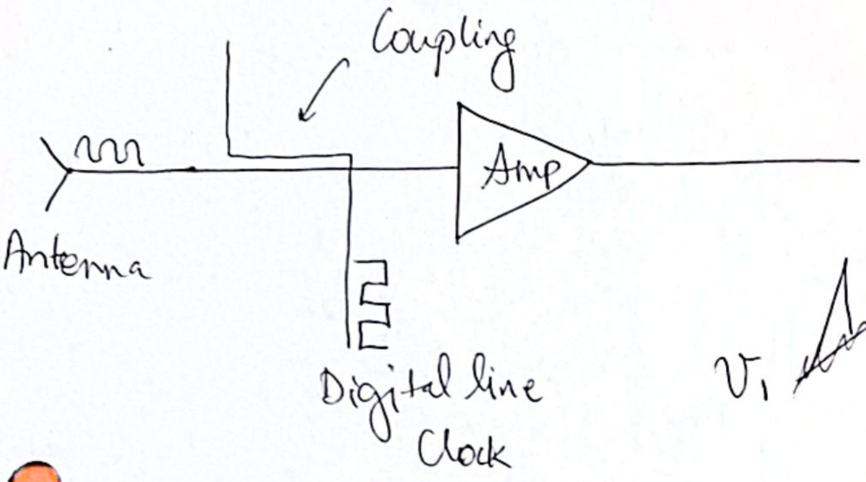
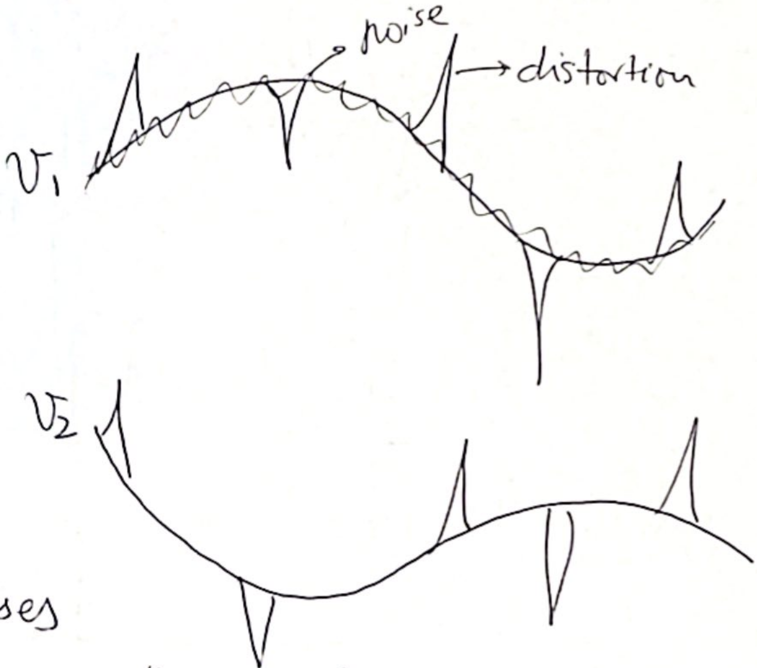
Lec 25 Differential Amplifiers

Common mode noise & distortion

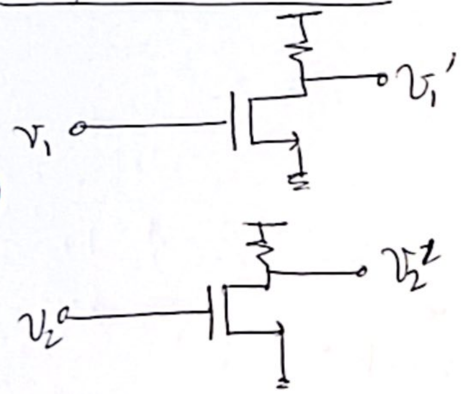




> Fix? Differential Signals.

$V_d = V_1 - V_2 \Rightarrow$ Suppresses "common mode" signals.

Implementation?



Is this good enough?

No because this also amplifies the common mode.

> Differential & common mode representation.

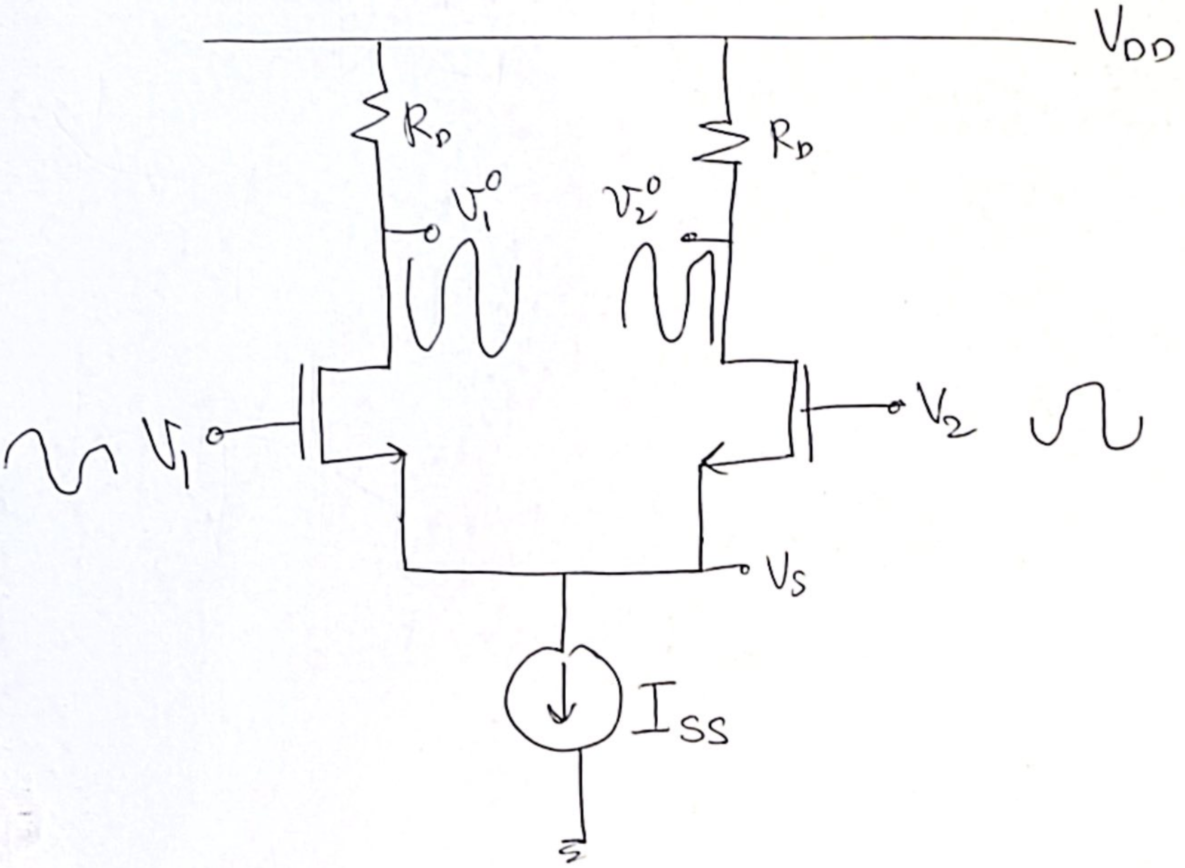
Given V_1, V_2 $\Rightarrow$ $V_c = \frac{V_1 + V_2}{2}$ $\longrightarrow$ Common mode

$V_1 = \frac{V_d}{2} + V_c$ $\quad$ $V_d = V_1 - V_2$ $\longrightarrow$ Differential mode.

$V_2 = V_c - \frac{V_d}{2}$

We want V_d to have gain & V_c to have loss!

Solution: Differential amplifier.



$V_1 \uparrow$ & $V_2 \downarrow$ $\Rightarrow$ I_{SS} is steered in branch 1

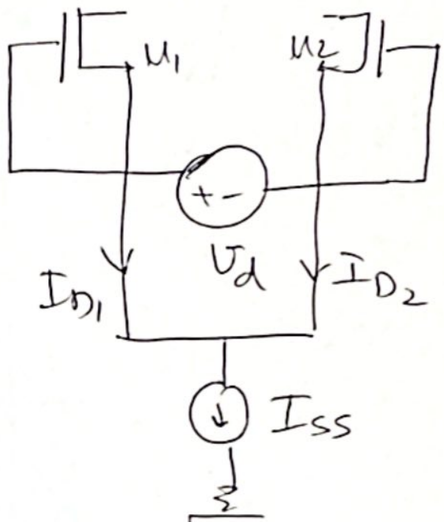
$V_2 \uparrow$ & $V_2 \uparrow$ $\Rightarrow$ Current cannot change $\rightarrow$ $V_S \uparrow$ to keep V_{GS} constant. (In reality I_{SS} is not ideal)

Large Signal Analysis

$$\left.\begin{aligned} V_{GS1} &= V_1 - V_S \\ V_{GS} &= V_2 - V_S \end{aligned}\right\} \Rightarrow V_{GS1} - V_{GS2} = V_1 - V_2 = V_d.$$

$$I_{D_1} = \underbrace{\frac{1}{2}\mu_n C_{ox}\frac{W}{L}}_{K'}(V_{GS_1} - V_T)^2$$

$$\Rightarrow V_{GS_1} = V_T + \sqrt{\frac{I_D}{K'}}$$



$$\Delta I = I_{D_1} - I_{D_2}$$

$$\& \quad I_{SS} = I_{D_1} + I_{D_2}$$

$$\Rightarrow I_{D_1} = \frac{I_{SS} + \Delta I}{2}$$

$$I_{D_2} = \frac{I_{SS} - \Delta I}{2}$$

$$V_d = V_T + \sqrt{\frac{I_{D_1}}{K'}} - V_T - \sqrt{\frac{I_{D_2}}{K'}}$$

[If $M_1 = M_2 \Rightarrow V_T$ cancels & K' is the same]

$$V_d = \frac{1}{\sqrt{2K'}}\left[\sqrt{I_{SS} + \Delta I} - \sqrt{I_{SS} - \Delta I}\right]$$

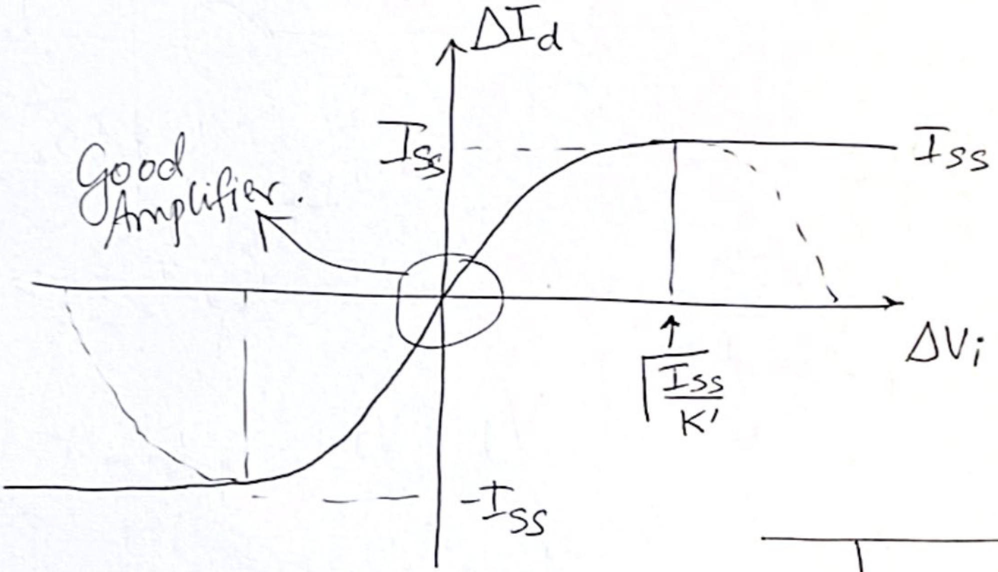
$$\Rightarrow 2K' V_d^2 = I_{SS} + \cancel{\Delta I} + I_{SS} - \cancel{\Delta I} - 2\sqrt{I_{SS}^2 - \Delta I^2}$$

$$= 2 I_{SS} - 2\sqrt{I_{SS}^2 - \Delta I^2}$$

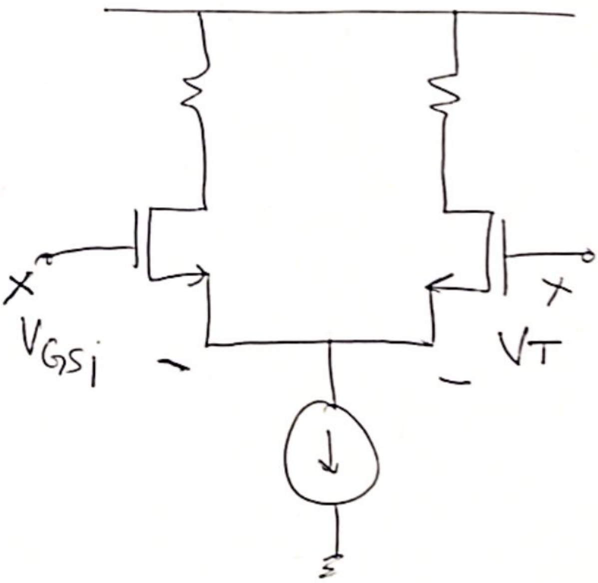
$$\Rightarrow \sqrt{I_{ss}^2-\Delta I^2} = I_{ss} - K'\Delta V_i^2 \qquad \Delta V_i = V_d$$

$$\Rightarrow \cancel{I_{ss}^2} - \Delta I^2 = \cancel{I_{ss}^2} + K'^2\Delta V_i^4 - 2K'\Delta V_i^2 I_{ss}$$

$$\Rightarrow \boxed{\Delta I_d = K'\Delta V_i\sqrt{\frac{2I_{ss}}{K'}-\Delta V_i^2}}$$



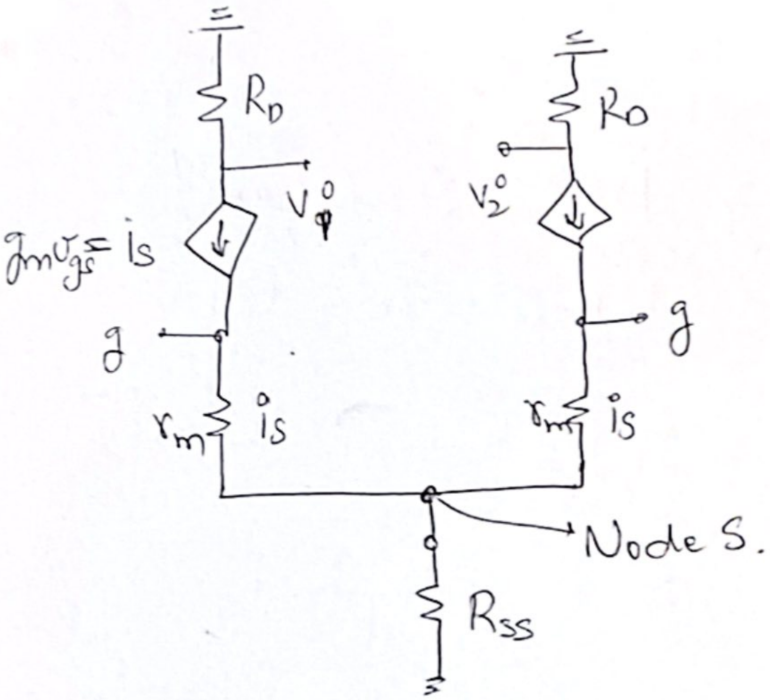
$$I_{ss} = K'(V_{GS}-V_T)^2$$

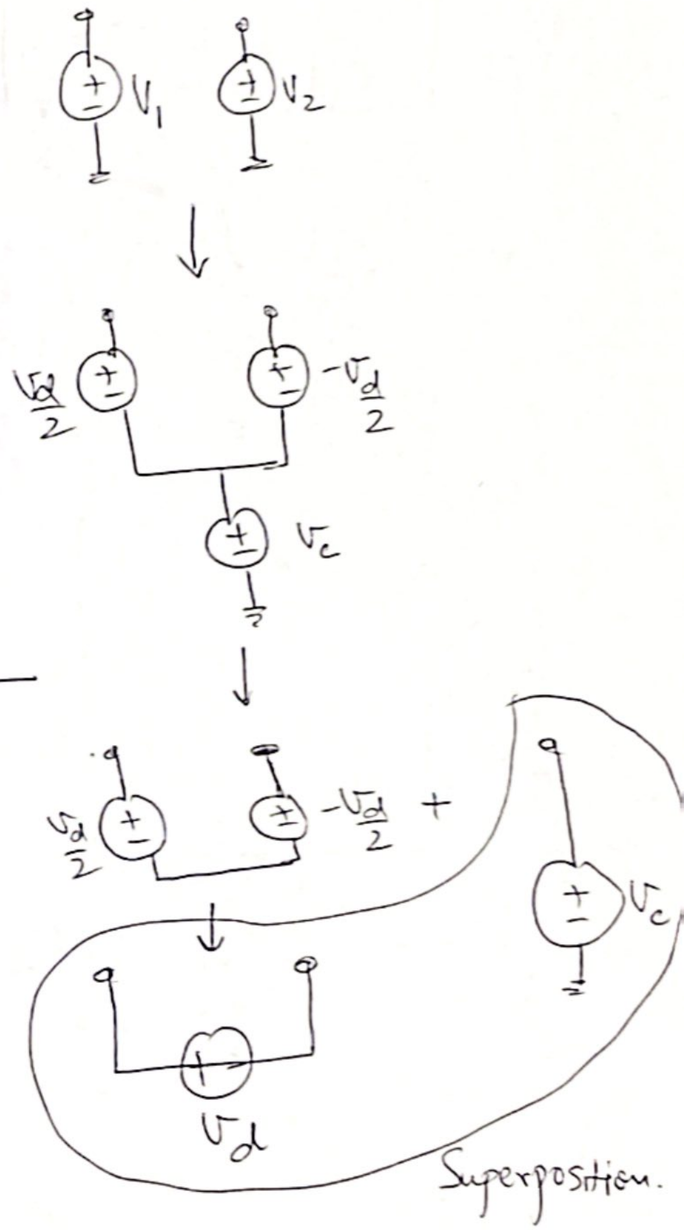


$$\Rightarrow V_{GS_1} = V_T + \sqrt{\frac{I_{ss}}{K'}}$$

$$\Rightarrow \boxed{\Delta V_i = \sqrt{\frac{I_{ss}}{K'}}}$$ → In reality there is subthreshold current.

Small Signal Analysis



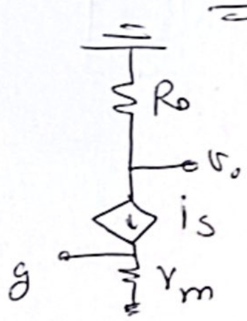


Differential mode / odd mode

> v_d is applied.

⇒ Node S is always at 0 voltage. (Note this is "small signal" analysis so we ignore bias points.

⇒ Each half circuit is



~~⇒ CS with Source degeneration.~~

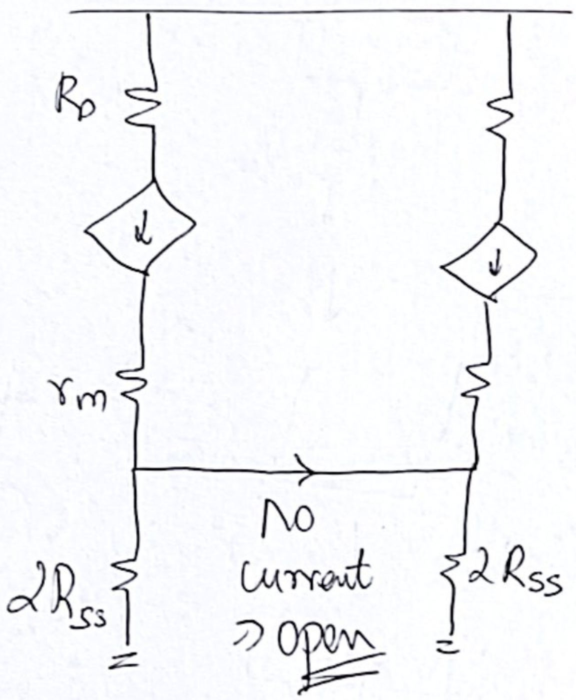
⇒ Common Source! ⇒ $A_v = -g_m R_D$

$$\frac{v_{od}/2}{v_{id}/2} = A_v = -g_m R_D$$

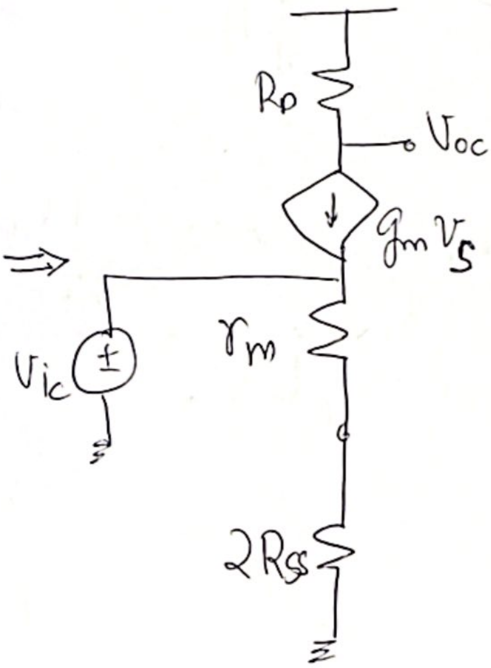
$$\vec{A}_{vd} \quad \boxed{\frac{V_{od}}{V_{id}} = -g_m R_D} \rightarrow \text{Differential Gain!}$$

But note g_m is half

Common Mode



⇒



$$\vec{A}_{vc} \quad \boxed{\frac{V_{oc}}{v_{ic}} = \frac{-g_m R_D}{1 + 2g_m R_{SS}}}$$

$$CMRR = \frac{-g_m R_D}{-g_m R_D / 1 + 2g_m R_{SS}} = \underline{1 + 2g_m R_{SS}}$$

Note $R_{ss} \uparrow \infty$
⇒ CMRR ↑ ∞