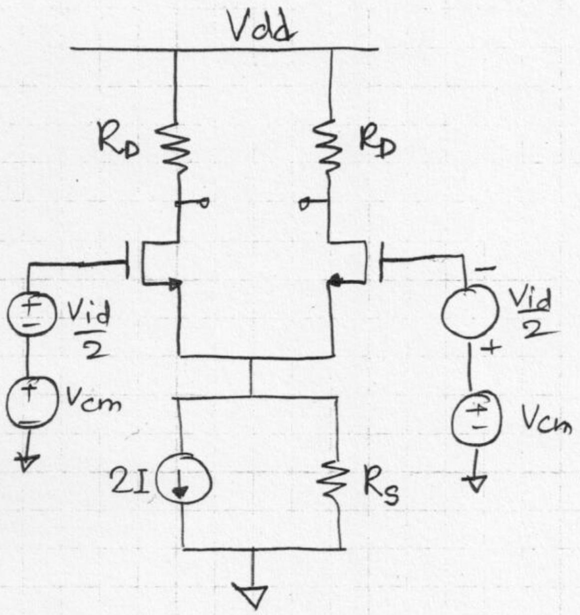
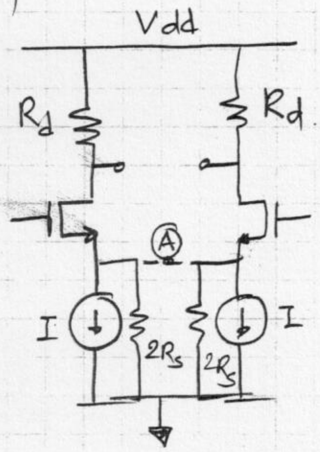


Goal

Large Differential gain A_{dm}

Small Common-mode gain A_{cm} (over large range of V_{cm})

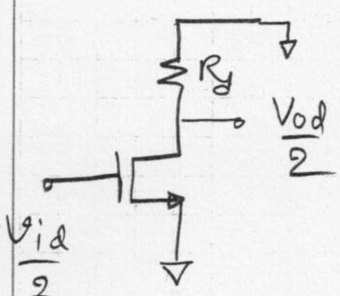
Symmetric Half Ckt



For differential i/p, — NO ac small signal V_{cm} is applied (only DC V_{cm} bias)

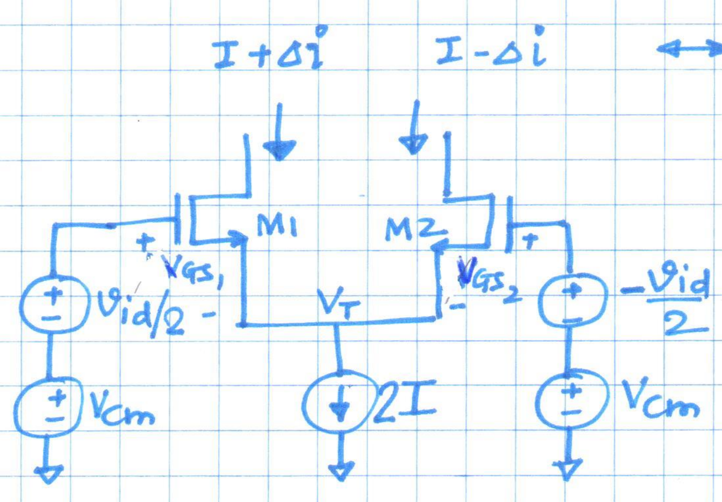
(A) → virtual ground

Half ckt analysis



$$A_{dm} = \frac{-g_{m1}}{g_{ds1} + \frac{1}{R_d}} = \frac{-g_m R_d}{1 + g_{ds} R_d}$$

Differential Pair Virtual Ground concept



KCL
$\leftrightarrow (I+\Delta i) + (I-\Delta i) = 2I$

Valid only for differential inputs

Assume V_{GS_1} & V_{GS_2} have equilibrium value of V_{eq}. They change by ΔV_{GS_1} & ΔV_{GS_2} on application of differential signal V_{id}.

Since the circuit is linearized around operating pt.

$(I+\Delta i) + (I-\Delta i) = 2I \rightarrow I_1 + I_2 = 2I$

$g_m \Delta V_{GS_1} + g_m \Delta V_{GS_2} = 0 \leftarrow$

$$\Rightarrow \Delta V_{GS_1} = -\Delta V_{GS_2} \quad \text{—— (1)}$$

<u>KVL</u> $V_{cm} + \frac{V_{id}}{2} - \Delta V_{GS_1} - V_{eq} = V_T = V_{cm} - \frac{V_{id}}{2} - \Delta V_{GS_2} - V_{eq}$

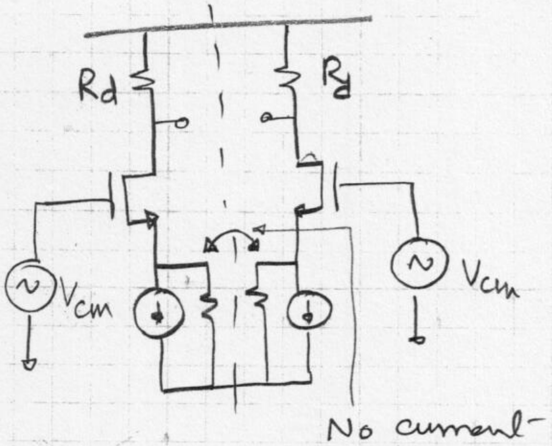
$$\Rightarrow \Delta V_{GS_1} - \Delta V_{GS_2} = V_{id} \quad \text{—— (2)}$$

FROM (1) & (2) V_T doesn't change.

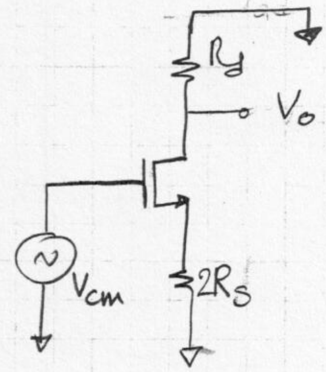
Differential signal V_{id} is consumed by V_{GS_1} & V_{GS_2}. V_T doesn't change.

Hence <u>Virtual Ground</u>.

For common mode i/p $v_{id} = 0$, AC current @ V_{cm}



$\Rightarrow$



(ac equivalent ckt)

PROVE: $A_{cm} = \dfrac{-g_m r_o R_d}{R_d + r_o + 2R_s\left(1 + (g_m + g_{mbs}) r_o\right)}$

approximating

$$A_{cm} \cong -\frac{g_m r_o R_d}{2 R_s g_m r_o} = -\frac{R_d}{2R_s}$$

CMMR - common mode rejection ratio

$$= 20 \log \left| \frac{A_{dm}}{A_{cm}} \right| = 20 \log \left| \frac{g_m R_d r_o \cdot 2R_s}{(r_o + R_d) R_d} \right|$$

$$= 20 \log \left(\frac{2 (g_m r_o) R_s}{(r_o + R_d)} \right)$$

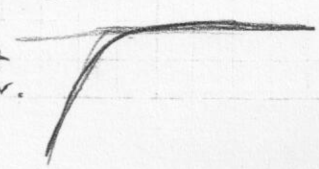
In CMOS implementation $R_d = r_o$ (PMOS)

$$= 20 \log (g_m R_s)$$

current source o/p resistance as high as possible

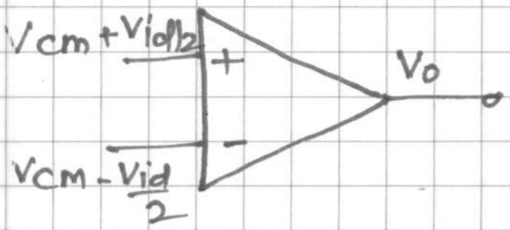
$$g_m R_s = \frac{2I}{(V_{GS} - V_T)} \cdot \frac{V_A}{I} = \frac{2V_A}{(V_{dsat})}$$

Early voltage; current src; diff pair.



Current source quality $\rightarrow$ CMRR

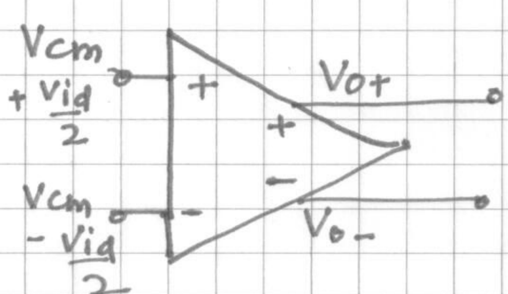
About COMMON-MODE REJECTION.



$$\underbrace{A_{cm} \cdot V_{cm}}_{\text{undesired}} + \underbrace{A_{dm} \cdot V_{id}}_{\text{Desired}}$$

$$CMRR = 20 \log \left| \frac{A_{dm}}{A_{cm}} \right|.$$

Consider amplifier with differential outputs



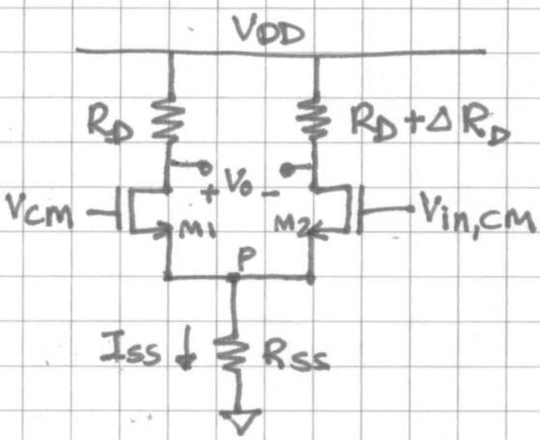
$$A_{cm} \cdot V_{cm} + A_{dm} \frac{V_{id}}{2} + A_{CMDM} (V_{cm})$$

$$\underbrace{A_{cm} \cdot V_{cm}}_{} + \underbrace{A_{dm}\left(-\frac{V_{id}}{2}\right)}_{\text{Desired.}} + \underbrace{A_{CMDM}(-V_{cm})}_{}$$

* Will be rejected by Next Diff Amp
* Only changes bias points
  → may alter small signal gain
* can limit output voltage swing

Common-Mode to Diff. mode conversion
* Corrupts desired differential signal
* Due to ~~Assy~~ Asymmentry due to Mismatches
* Frequency dependent effects.
  Example: High frequency CM → Modifies tail current source — parasitic cap across tail current.

Example A_{CM-DM} due to mismatch.



SF concept

$$\Delta V_p = \frac{R_{ss}}{R_{ss} + 1/2g_m} \Delta V_{in,cm}$$

$$= \frac{2g_m R_{ss}}{1 + 2g_m R_{ss}} \Delta V_{in,cm}$$

$$\Delta I_{ss} = \frac{2g_m R_{ss}}{1 + 2g_m R_{ss}} \cdot \frac{\Delta V_{in,cm}}{R_{ss}}$$

split equally on both sides

$$\Delta I_{D1} = \Delta I_{D2} = \frac{\cancel{2}g_m}{1 + 2g_m R_{ss}} \cdot \Delta V_{in,cm}$$

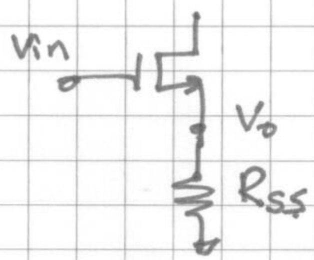
$$\Delta V_{out_{CM-DM}} = -\Delta I_{D1} R_D - \left[-\Delta I_{D2} (R_D + \Delta R_D) \right]$$

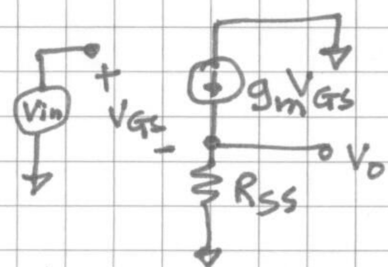
$$= \Delta I_D \cdot \Delta R_D = \frac{g_m \Delta R_D}{1 + 2g_m R_{ss}} \cdot \Delta V_{in,CM}.$$

$$\therefore A_{CM-DM} = \frac{g_m \Delta R_D}{1 + 2g_m R_{ss}}.$$

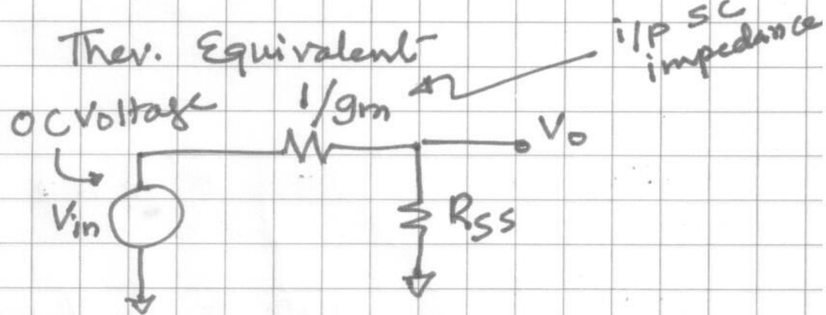
Side Note.

Source Follower





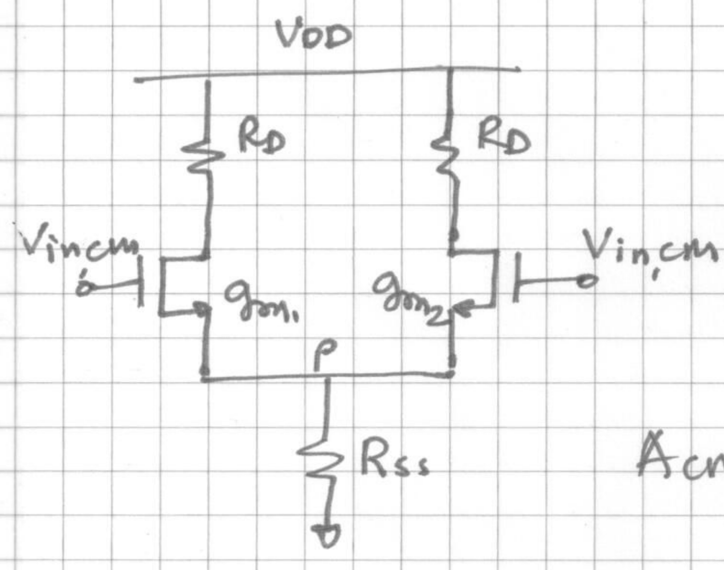
Thev. Equivalent



$$\frac{V_o}{V_{in}} = \frac{R_{ss}}{R_{ss} + 1/g_m}.$$

Insight: R_{SS} → Current Source output impedance

R_{SS} should be large to achieve good CMRR.



$g_{m1} \neq g_{m2}$ (mismatches)

⇐ HW prove.

$$A_{CM-DM} = -\frac{\Delta g_m R_D}{1 + (g_{m1} + g_{m2}) R_{SS}}$$

R_{SS} – current source o/p impedance.

For a fully differential circuit:
Input and output both are differential

$$CMRR = \left| \frac{A_{DM}}{A_{CM-DM}} \right|$$