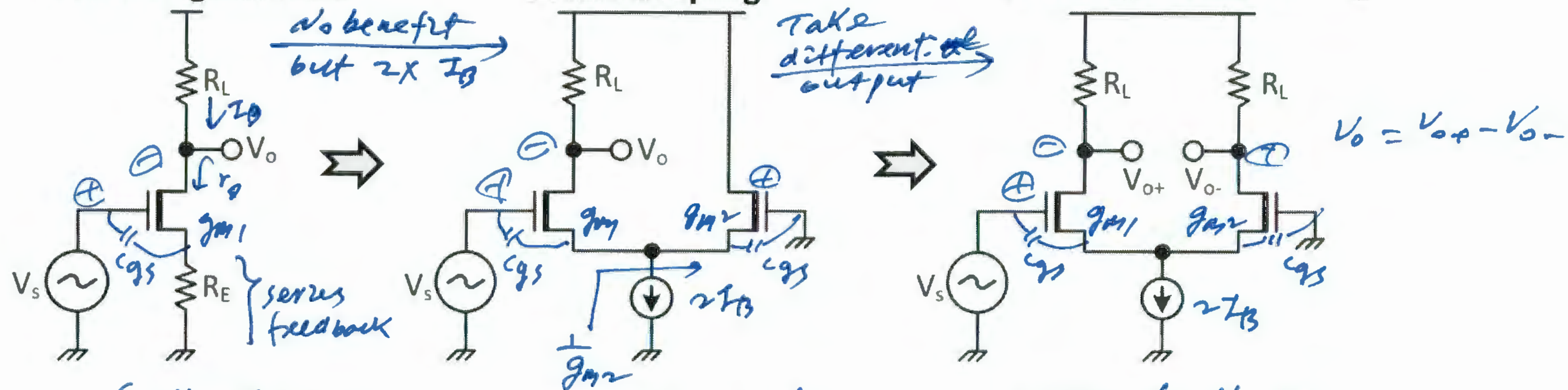
Source Coupling

- What's the benefit of differential topology ?

Source Degeneration | **Source Coupling** | **Differential Topology (with single-ended driving)**



series feedback

loop gain → $T = g_{m1} R_E$

$A_v = \dfrac{g_{m1} R_L}{1 + g_{m1} R_E}$

$C_{gs} \rightarrow \dfrac{C_{gs}}{1 + g_{m1} R_E}$

$r_o \rightarrow r_o(1 + g_{m1} R_E)$

series feedback

$T = g_{m1} \cdot \dfrac{1}{g_{m2}}$

$A_v = \dfrac{g_{m1} R_L}{1 + g_{m1} \frac{1}{g_{m2}}}$

$C_{gs} \rightarrow \dfrac{C_{gs}}{1 + g_{m1} \frac{1}{g_{m2}}}$

$r_o \rightarrow r_o\left(1 + g_{m1} \frac{1}{g_{m2}}\right)$

series feedback

$T = g_{m1} \cdot \dfrac{1}{g_{m2}}$

$A_v = \dfrac{g_{m1} R_L}{1 + g_{m1} \frac{1}{g_{m2}}} \times 2$

$C_{gs} \rightarrow \dfrac{C_{gs}}{1 + g_{m1} \frac{1}{g_{m2}}}$

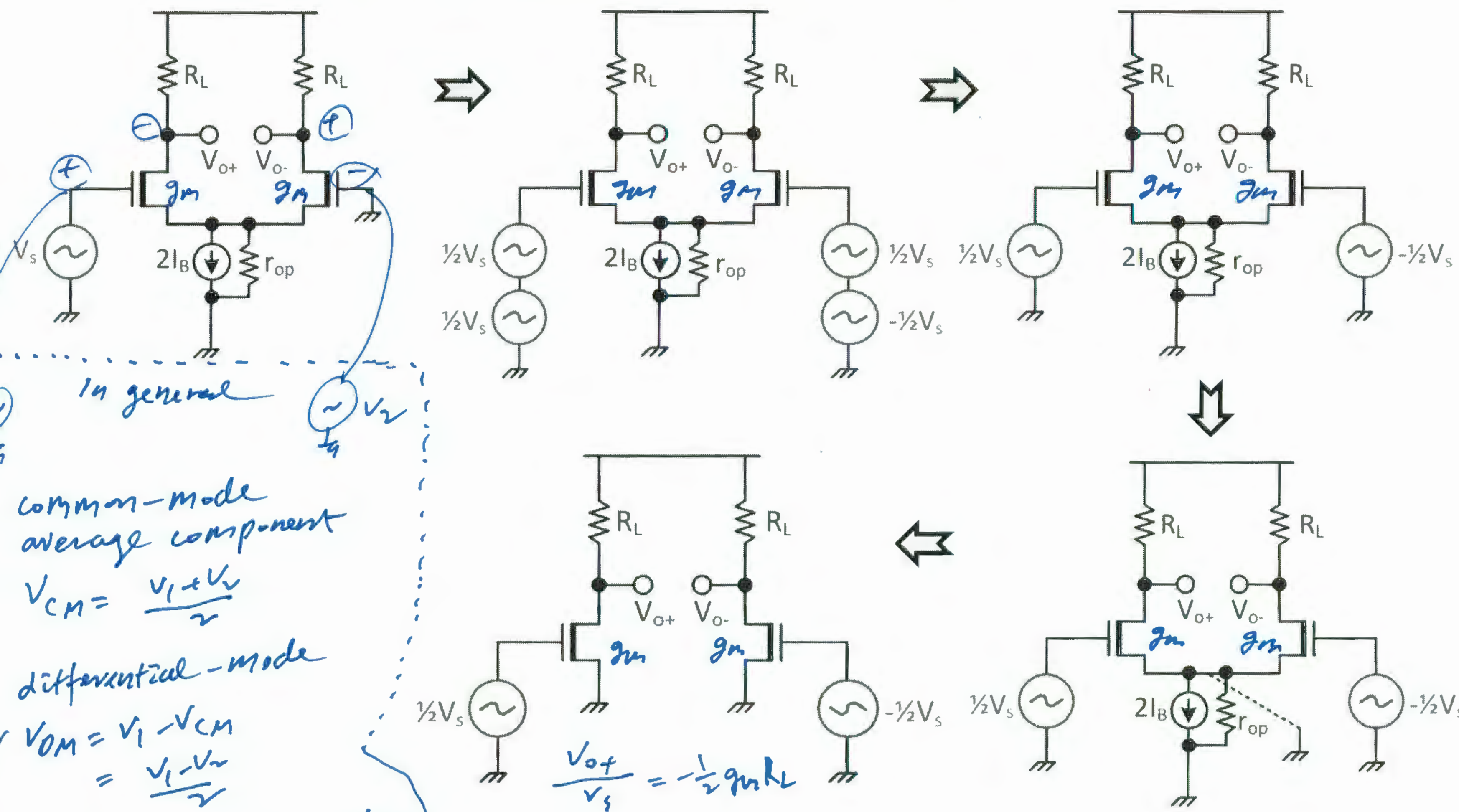
$r_o \rightarrow r_o\left(1 + g_{m1} \frac{1}{g_{m2}}\right) \times \frac{1}{2}$

Single-ended output impedance

differential output impedance

Single-Ended vs. Differential Driving

- Topological equivalence in terms of differential-mode driving



in general

v_1, v_2

→ common-mode

→ average component

→ $V_{CM} = \frac{v_1 + v_2}{2}$

→ differential-mode

→ $V_{DM} = v_1 - V_{CM} = \frac{v_1 - v_2}{2}$

$-V_{DM} = -\frac{v_1 - v_2}{2} = v_2 - V_{CM}$

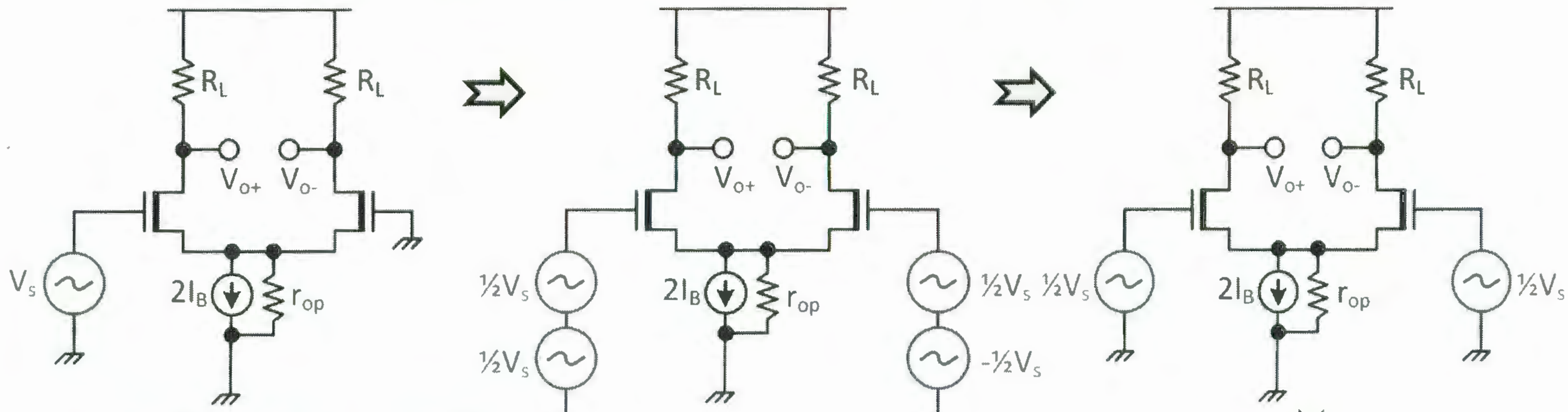
$\frac{V_{o+}}{V_s} = -\frac{1}{2} g_m R_L$

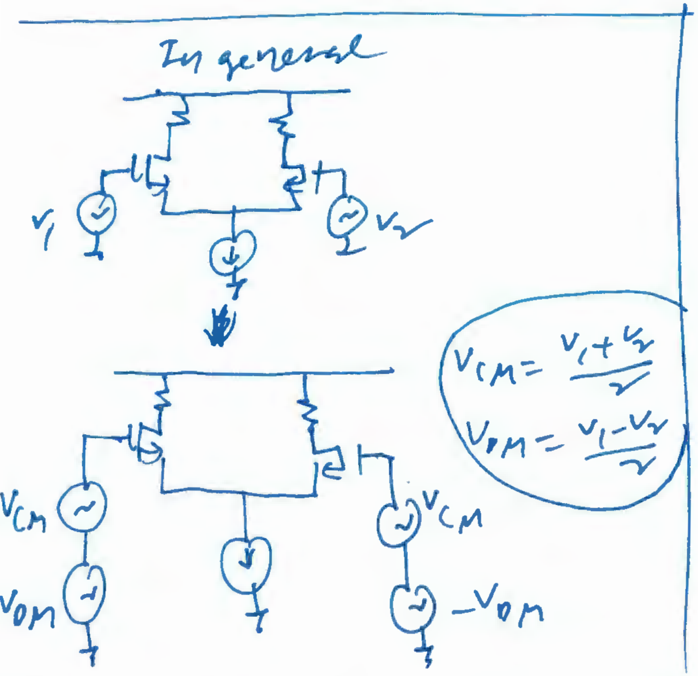
$\frac{V_{o-}}{V_s} = \frac{1}{2} g_m R_L$

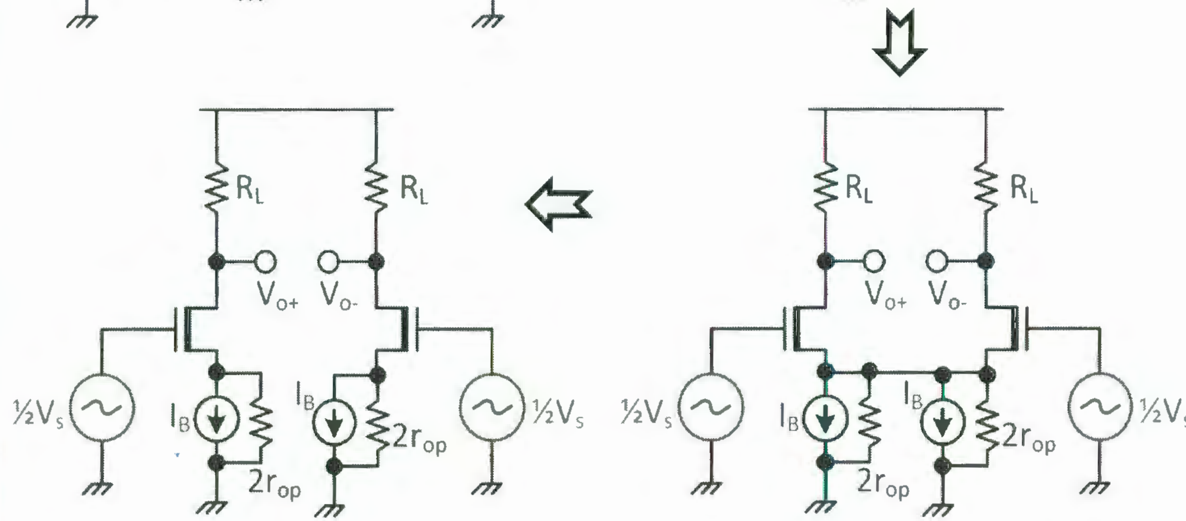
→ $\frac{(V_{o+}) - (V_{o-})}{V_s} = -g_m R_L$

Single-Ended vs. Differential Driving

- Topological equivalence in terms of common-mode driving

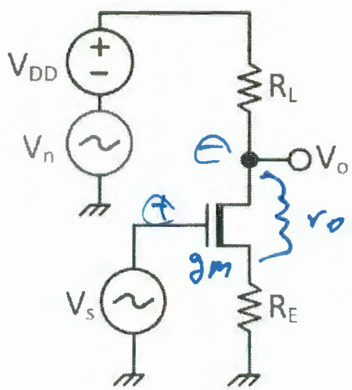


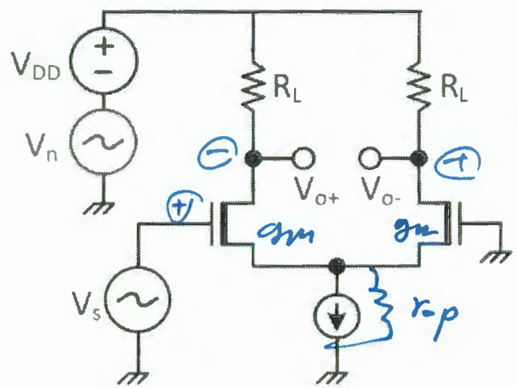




Power Supply Noise Rejection

- ❑ What's the benefit of differential topology?





$$A_{vs} = \frac{v_o}{v_s} = -\frac{g_m R_L}{1+g_m R_E}$$

$$A_{vn} = \frac{v_o}{v_n} = \frac{r_o(1+g_m R_E)}{R_L + r_o(1+g_m R_E)} \approx 1$$

(*) power supply rejection ratio (PSRR)

$$= \left|\frac{A_{vs}}{A_{vn}}\right| = \frac{g_m R_L}{1+g_m R_E}$$

$$A_{vs} = \frac{v_o}{v_s} = \frac{v_{o+}-v_{o-}}{v_s} = -g_m R_L$$

$$\Rightarrow \frac{v_{o+}}{v_s} = -\frac{1}{2} g_m R_L$$

$$\Rightarrow \frac{v_{o-}}{v_s} = \frac{1}{2} g_m R_L$$

$A_{vn} = 0 \longrightarrow v_n \Rightarrow$ common-mode signal

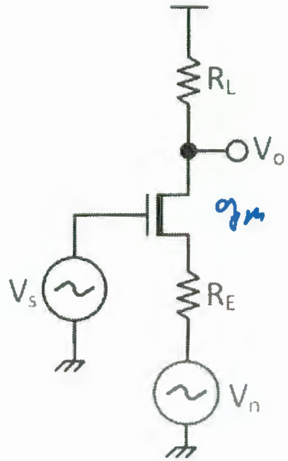
$$\frac{v_{o+}}{v_n} = \frac{r_o(1+2g_m r_{op})}{R_L + r_o(1+2g_m r_{op})}$$

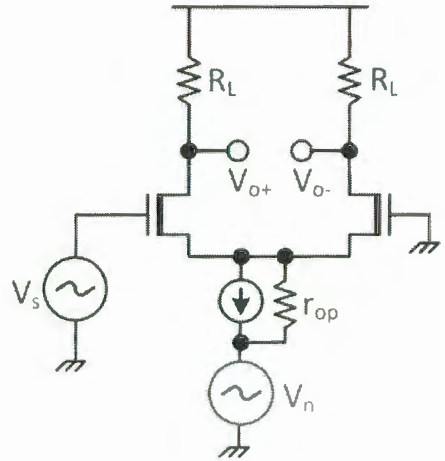
$$\frac{v_{o-}}{v_n} = \frac{r_o(1+2g_m r_{op})}{R_L + r_o(1+2g_m r_{op})}$$

$\Rightarrow$ PSRR $= \infty$

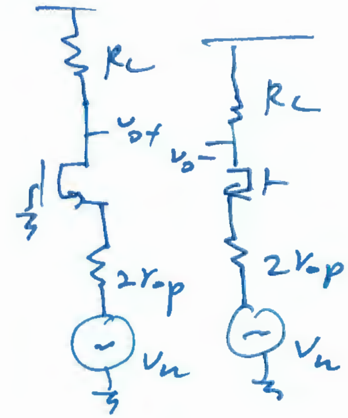
Ground Noise Rejection

- What's the benefit of differential topology ?





$\Rightarrow$



$$A_{vs} = \frac{V_o}{V_s} = -\frac{g_m R_L}{1+g_m R_E}$$

$$A_{vn} = \frac{V_o}{V_n} = \frac{g_m R_L}{1+g_m R_E}$$

⊛ Ground supply rejection ratio (GSRR)

$$= \left|\frac{A_{vs}}{A_{vn}}\right| = 1$$

$$\frac{V_{on+}}{V_n} = \frac{g_m R_L}{1+2g_m r_{op}}$$

$$\frac{V_{on-}}{V_n} = \frac{g_m R_L}{1+2g_m r_{op}}$$

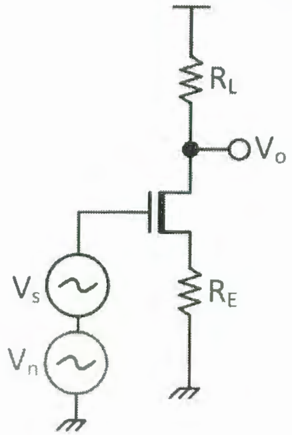
$\rightarrow \dfrac{V_{on+} - V_{on-}}{V_n} = 0$

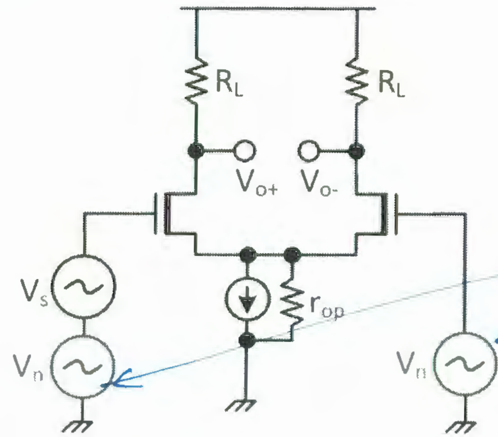
$\rightarrow V_n \Rightarrow$ common-mode signal

$\rightarrow GSRR = \infty$

Common-Mode Noise Rejection

- ❑ **What's the benefit of differential topology ?**





$$A_{vs} = \frac{V_o}{V_s} = -\frac{g_m R_L}{1+g_m R_E}$$

$$A_{vn} = \frac{V_o}{V_n} = \frac{-g_m R_L}{1+g_m R_E}$$

$CMRR \propto g_m \cdot r_{op}$

$$A_{vs} = \frac{V_o}{V_s} = \frac{V_{o+}-V_{o-}}{V_s} = -g_m R_L$$

$$A_{vn} = 0$$

$$\frac{V_{o+}}{V_n} = \frac{-g_m R_L}{1+2g_m r_{op}}$$

$$\frac{V_{o-}}{V_n} = -\frac{g_m R_L}{1+2g_m r_{op}}$$

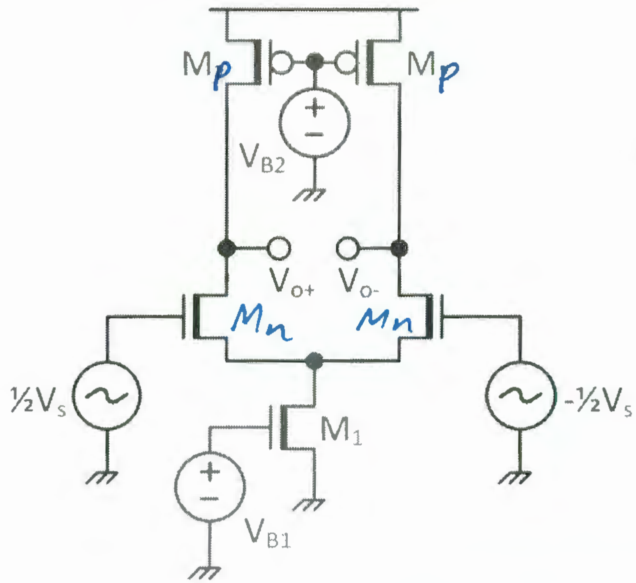
(*) common-mode rejection ratio

$$= \frac{\text{differential gain}}{\text{single-ended gain of common-mode signal}} = \frac{g_m R_L}{\frac{g_m R_L}{1+2g_m r_{op}}} = 1+2g_m r_{op} \approx 2g_m r_{op}$$

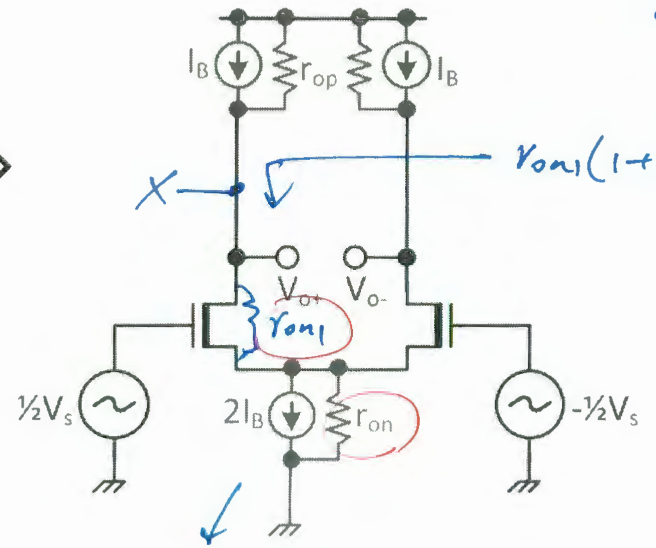
DC Stability (1)

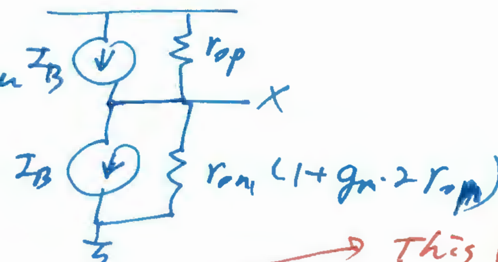
- What if NMOS and PMOS bias currents are not matched ?

DC is a common-mode signal

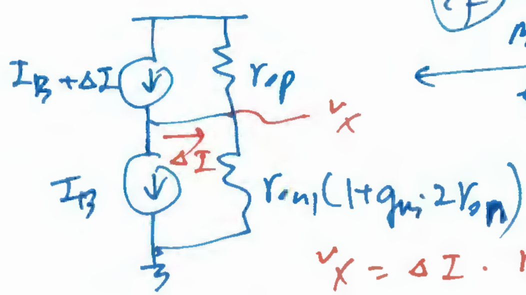


⇨





If there is a mismatch between two current sources



$v_X = \Delta I \cdot r_{op} // (r_{on1}(1+g_m \cdot 2r_{op}))$

$\simeq \Delta I \cdot r_{op}$ → can be very large value.

ex $\Delta I = 0.1\,mA$, $r_{op} = 10k\Omega$ } $v_X = 1V$

→ This large voltage change could force either Mn or Mp into deep triod region

→ deep triod region ⇒ r_o ↓ ⇒ gain ↓