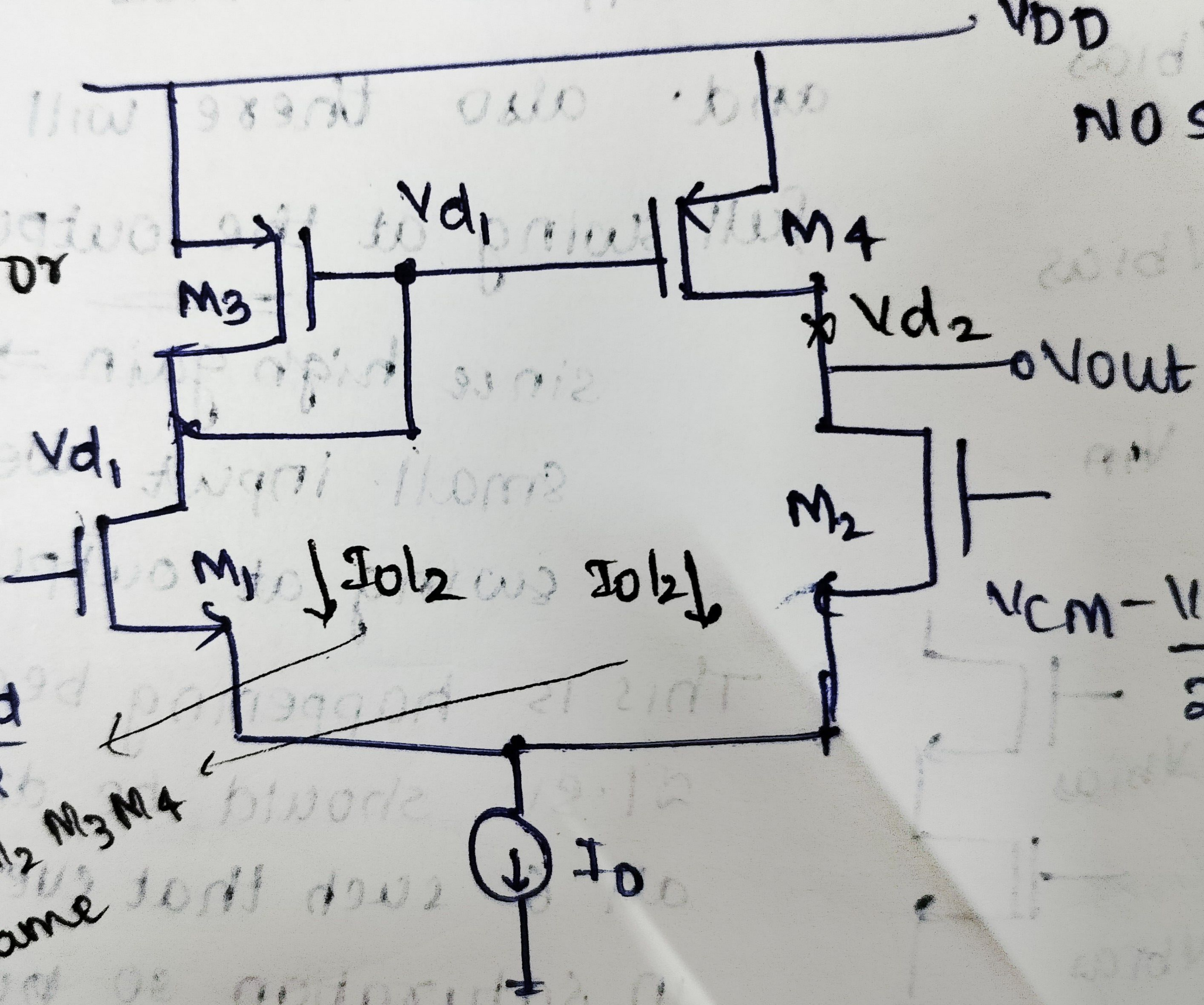
e get $I_o/2$ because $M_1 \equiv M_2 \equiv M_3 \equiv M_4$

→

NO symm

with
rent mirror
d.



∴ All $M_1 M_2 M_3 M_4$ same

3 ⇒ V_{SG}

suppose $V_{d_2} = V_{d_1} + \Delta V$.

Assume channel length modulation

so compare M_1 & M_2 → $(I_D)_{M_2} > (I_D)_{M_1}$ — $(1+\lambda V_{SD})$ — 3 same D of — $M_4 > M_3$ ∵ current r

In PMOS → because of V_{d_2}, M_3 current > M_4. (∵ M_4 has lower V_{SD} current)

But this argument can't be made ∵ I in M_3, M_1 same & in M_2, M_4 so

∴ $V_{d_2} = V_{d_1}$

Equivalent g_m → $\frac{I_{out}}{V_{in}}$

so if we calculate, $(g_m)_{eq} R_{eq}$ → $\underline{\underline{\text{Gain}}}$

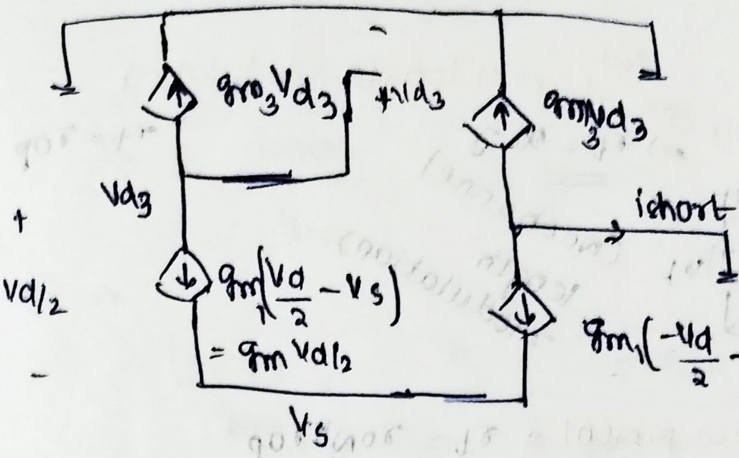
To find $\frac{I_{out}}{V_{in}}$ → Norton's [short circuit] → To make small signal short, but no DC changes.

small signal

→ we can put V source at V_{d_2}

→  $V = \underline{V_{d_2} = V_{d_1}}$

Small signal of stage-1



$g_{m_1}\left(\frac{-V_d}{2} - V_s\right) = -\frac{g_m V_d}{2}$

$\Downarrow = 0 \because \dfrac{\frac{V_d}{2} + \left(\frac{-V_d}{2}\right)}{2} = 0 \Rightarrow \frac{V_A + V_B}{2}$ (avg)

$\cancel{V_{d_3} = g_m\left(\frac{V_d}{2}\right)}$

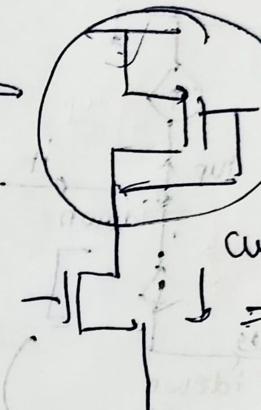
KCL:

$g_{m_3} V_{d_3} + g_{m_1} \frac{V_d}{2} = 0$

$$\boxed{V_{d_3} = \frac{-g_{m_1} V_d}{2 g_{m_3}}}$$

$\Downarrow$

same setup as left one in actual circuit $\Leftarrow$



acts as resistor $1/g_{m_3}$.

current $\Downarrow$ $\Rightarrow g_m \frac{V_d}{2}$

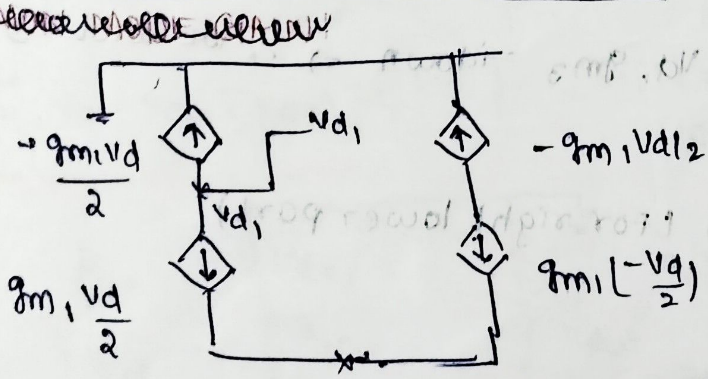
$\Rightarrow -V_{d_3} = \frac{g_{m_1} V_d}{2} \cdot \frac{1}{g_{m_3}}$

$g_{m_3} V_{d_3} = \cancel{g_{m_3}} \cdot \frac{-g_{m_1}}{2 \cancel{g_{m_3}}} V_d$

NOW $\boxed{i_{short} = g_{m_1} V_d}$ (KCL right side)

It is not only mirroring DC values but also ac mirroring.

$$\boxed{g_m \text{ equivalent} = g_{m_1}}$$



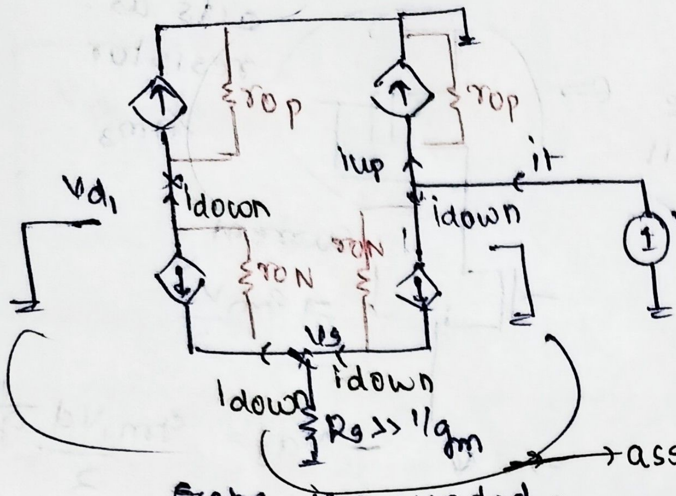
$V_s = 0$ ($\because$ current source is ideal) → so that's why we can completely open current source so there is no path for $g_{m_1}\frac{V_d}{2}$, $-g_{m_1}\frac{V_d}{2}$

$\therefore V_s = 0$ (KCL)

open → if r_{ON} is also present ⇒ $r_t = r_{ON} \| r_{OP}$

↗ when I_0 (b) is not ideal, R_{SS} is present.

$i_t = i_{up} + i_{down}$



$i_{up} \simeq i_{down} + \frac{V_t}{r_{op}}$ — (1)

we know that the downward current is going to get mirrored

→ assume no current through R_S ∵ $R_S >> 1/g_m$

Gate is grounded (∵ we are finding r_{out}).

$V_{d_1} = i_{down} \times \frac{1}{g_{m_3}}$ (ignore r_{op}) ∵ $(1/g_{m_3} \| r_{op})$ but $r_{op} >> 1/g_{m_3}$

then right top corner current ⇒ $V_{d_1} g_{m_3} = i_{down}$ ⇒ ∴ we wrote (1) in current source.

$i_{down} = \frac{V_t - V_S}{r_{ON}} + g_m(-V_S)$ (KCL) (for right lower part)

$i_{down} r_{ON} = V_t - V_S - g_m r_{ON} V_S$

$V_S(1 + g_m r_{ON}) = V_t - i_{down} r_{ON}$

$V_S = \frac{V_t - i_{down} r_{ON}}{1 + g_m r_{ON}}$ — (2)

$$i_{down} = \frac{V_s - V_{d_1}}{r_{ON}} + g_m V_s \quad \rightarrow i_{down}/g_{m_3}$$ (For Lower Left part)

$$i_{down}\, r_{ON} = V_s - V_{d_1} + r_{ON}\, g_m V_s$$

$$V_s(1 + g_m r_{ON}) = i_{down}\, r_{ON} + V_{d_1}$$

$$V_s = \frac{i_{down}\left[r_{ON} + 1/g_{m_3}\right]}{1 + g_{m_1} r_{ON}} = \frac{i_{down}\left[1 + \frac{1}{g_{m_3} r_{ON}}\right]}{\frac{1}{r_{ON}} + g_{m_1}}$$

smaller than 1

small

$$V_s \approx \frac{i_{down}}{g_{m_1}} \quad \text{--- (3)}$$

sub in (2) ⇒

$$\frac{i_{down}}{g_{m_1}} = \frac{V_t - i_{down} r_{ON}}{1 + g_m r_{ON}}$$

$$V_t = i_{down}\left[\frac{1 + g_m r_{ON}}{g_{m_1}} + r_{ON}\right]$$

$$\cancel{\frac{V_t}{i_t} = \frac{i_{down}\left[\frac{1 + g_m r_{ON}}{g_{m_1}} + r_{ON}\right]}{i_{down}}}$$

ignore

$$V_t = i_{down} \cdot r_{ON}\left[\frac{1/r_{ON} + g_m}{g_m} + 1\right]$$

$$\cancel{i_t = 2 i_{down} + \frac{V_t}{r_{op}}}$$

$$V_t = i_{down} \cdot r_{ON} \cdot (2)$$

$$i_{down} = \frac{V_t}{2 r_{ON}}$$

(1) ⇒

$$i_t = \frac{\cancel{2} V_t}{\cancel{2} r_{ON}} + \frac{V_t}{r_{op}}$$

$$\frac{V_t}{i_t} = (r_{ON} \parallel r_{op})$$

$$A_d \simeq g_m (r_{ON} \parallel r_{op})$$ (+ve) (Differential gain)

KCL at V_s Node