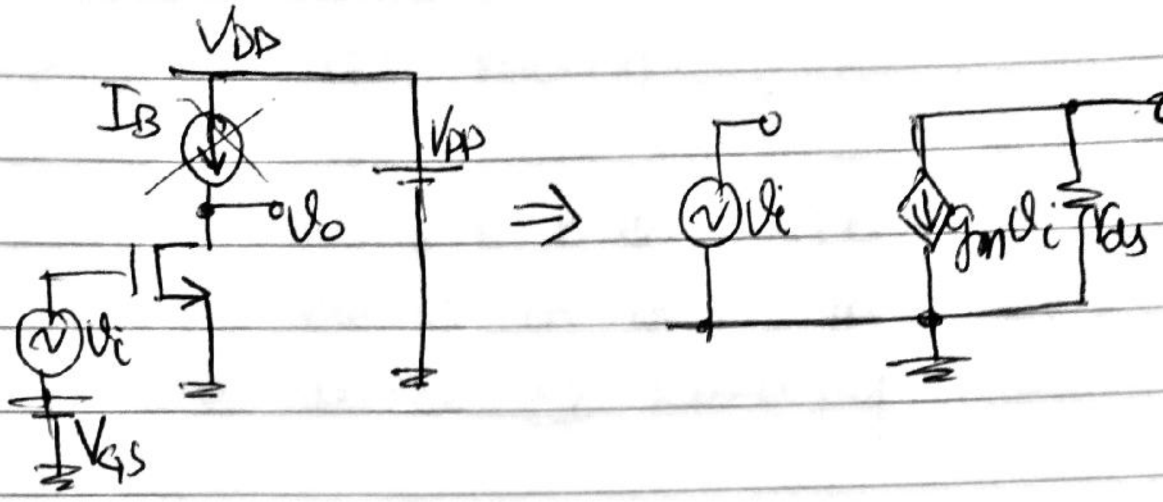
RECAP : SMALL-SIGNAL MODELING



→ Set all AC (small-signal) independent sources to zero ; v → open, i → short

→ Find the DC operating point (g_m, g_s, r_o

→ Set all the DC (Bias) independent sources to zer

→ Replace all non-linear elements with their small-signal equivalent.

→ Calculate the small-signal respon.

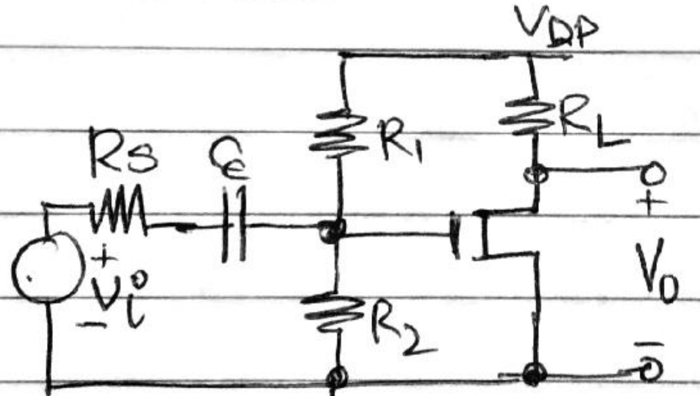
CURRENT MIRRORS

Why current mirrors ?

→ Provide bias current for multiple blocks in an IC from one single pristine source eg. Bandgap reference.

→ Active load for amplifiers.

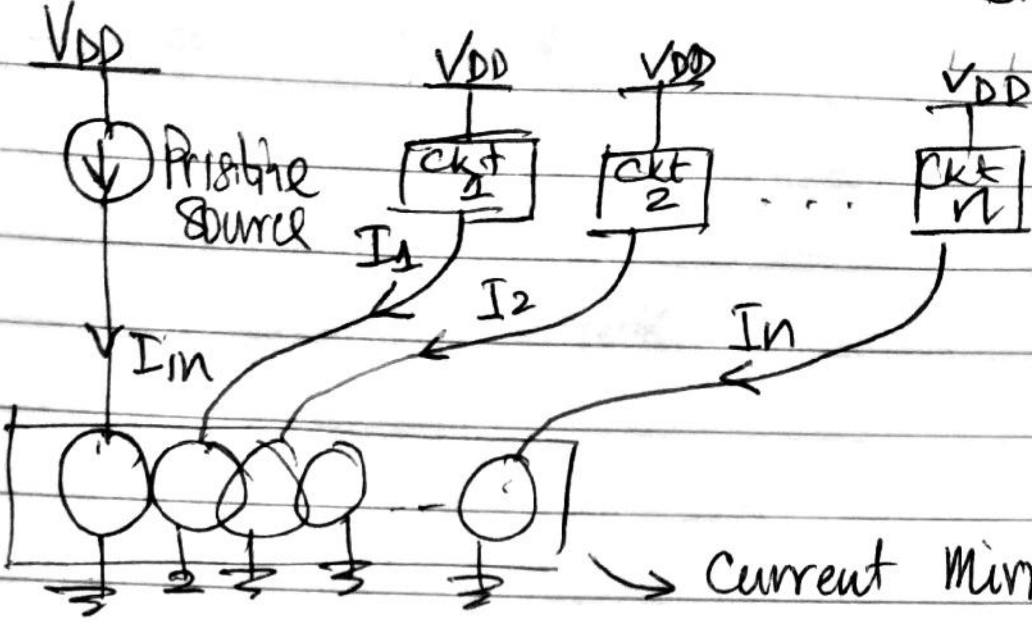
BIAS CIRCUIT FOR DISCRETE MOS



Not suitable for IC :

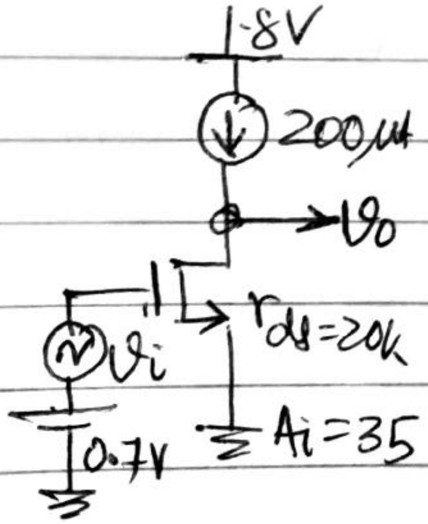
- Resistors consume big area.
- C_C also big area
- Bias current variations huge.

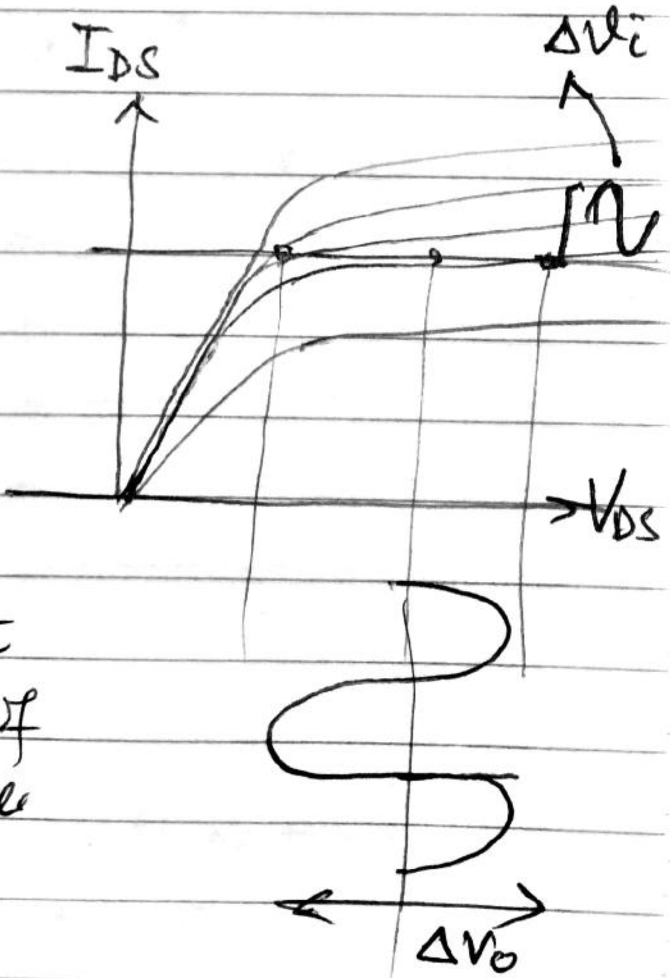
Current Mirrors as bias currents



Why Active Load?

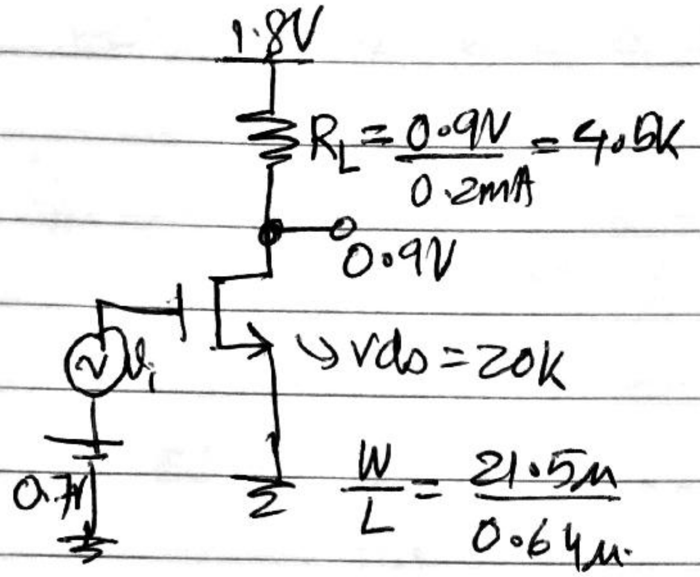
P 1.19



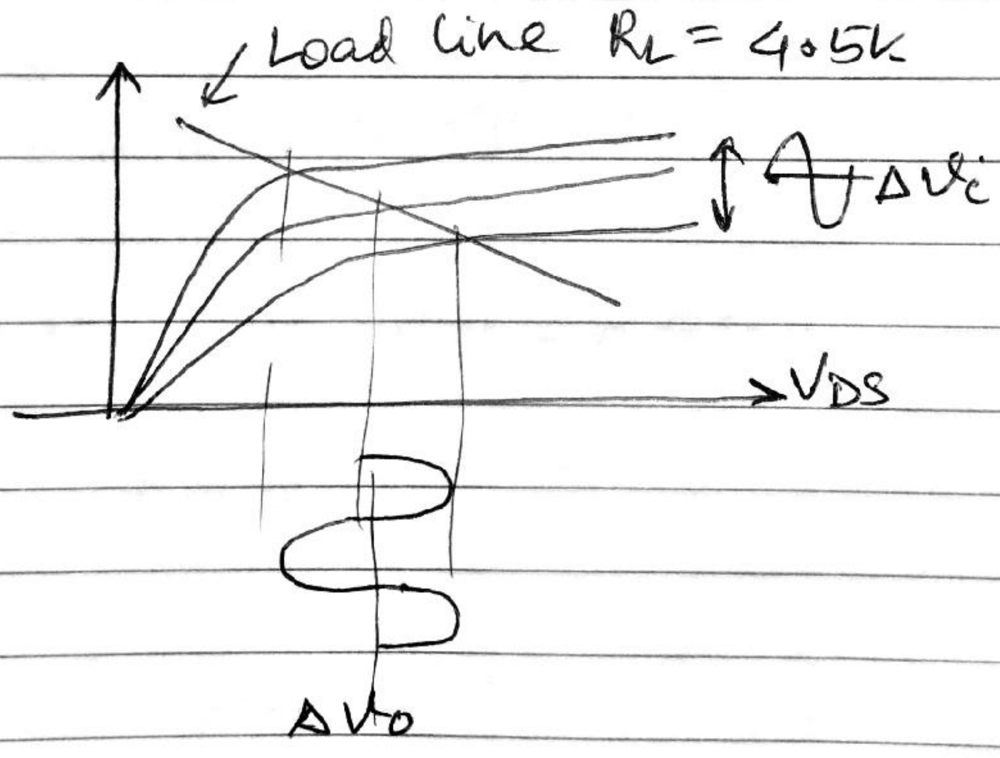


→ Key: Bias current is independent of output impedance

Resistive Load.



$$A = g_m \times (r_{ds} \parallel R_L) \cong g_m R_L = 28.$$



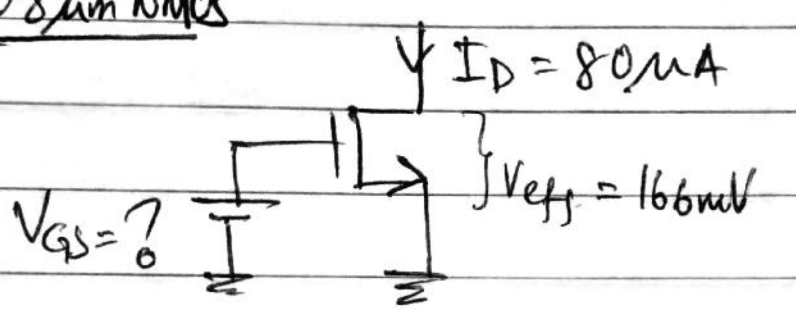
Bias current and output impedance are <u>NOT</u> independant.

How to Create Current Mirrors.

Let's say we want 80μA.

Eg. NMOS biased in saturation is a current mirror.

0.8μm NMOS



$\beta = \mu_n C_{ox} = 92 \frac{\mu A}{V^2}$

$V_{tn} = 0.8V$

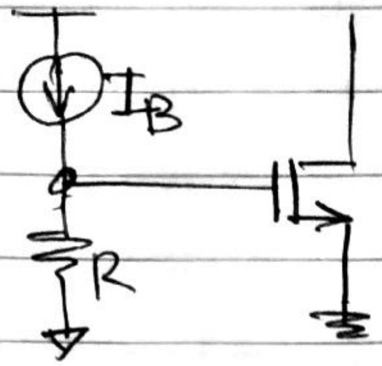
$\frac{W}{L} = \frac{100\mu}{1.6\mu}$

$$I_D = \frac{\mu_n C_{ox}}{2} \cdot \frac{W}{L} V_{eff}^2 \Rightarrow V_{eff} = \sqrt{\frac{2I_D}{\mu_n C_{ox} W/L}} = \underline{0.166V}$$

$\therefore V_{GS} = V_T + V_{eff} = 0.966V$

& $V_{DS} > V_{eff}$.

How to generate 0.966V from the 80μA



$$80\mu A \cdot R = 0.966V$$

$$\Rightarrow R = \frac{0.966V}{80\mu A} \cong 12k\Omega$$

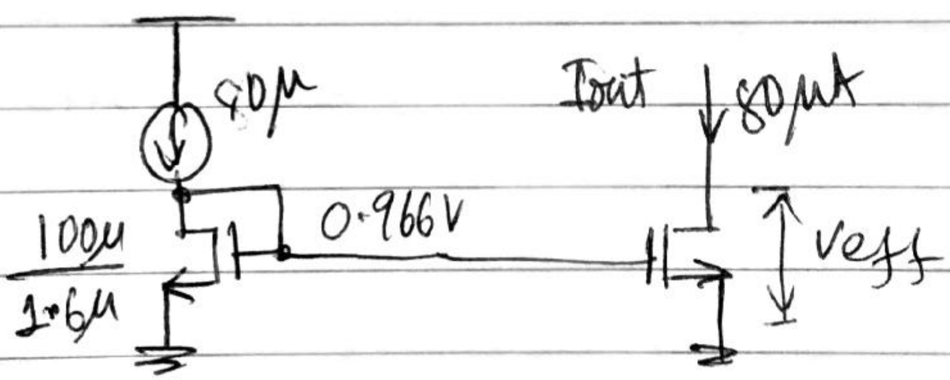
$I_B \cdot R = V_{GS}$?

Two reasons this not preferable

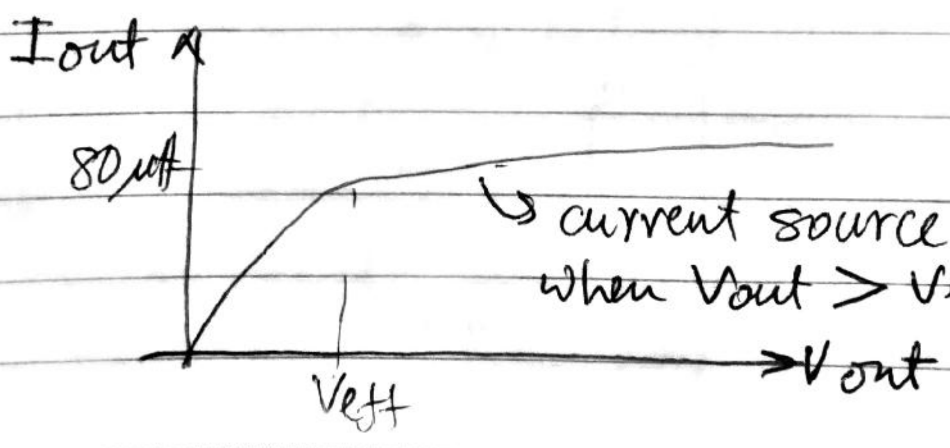
(1) Large area for the resistor

(2) Large variation due to Process, Temp

<u>Better way:</u>

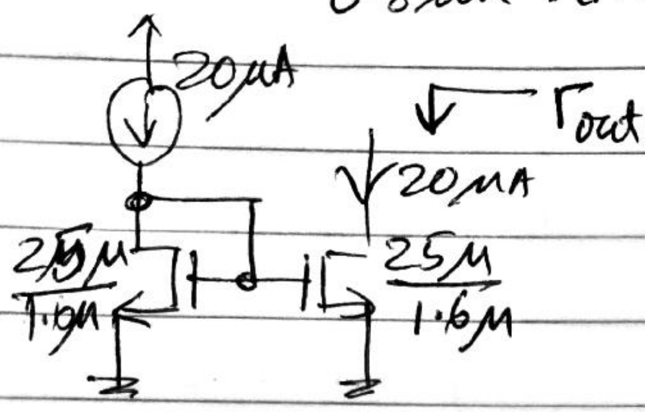


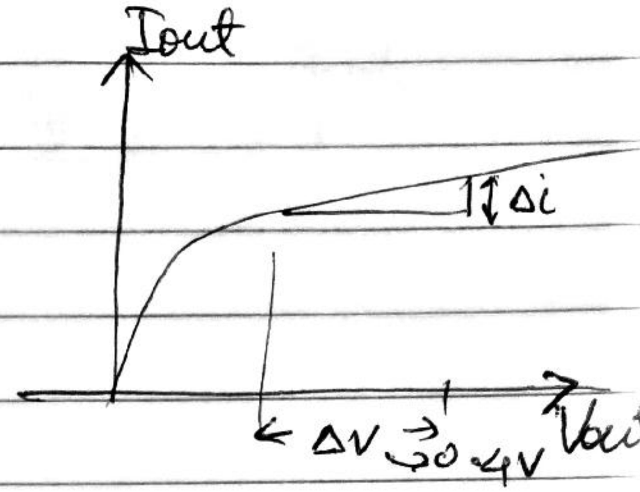
<u>Voltage Compliance</u>



Error in Output current due to finite out impedance.

0.8 µm nMOS



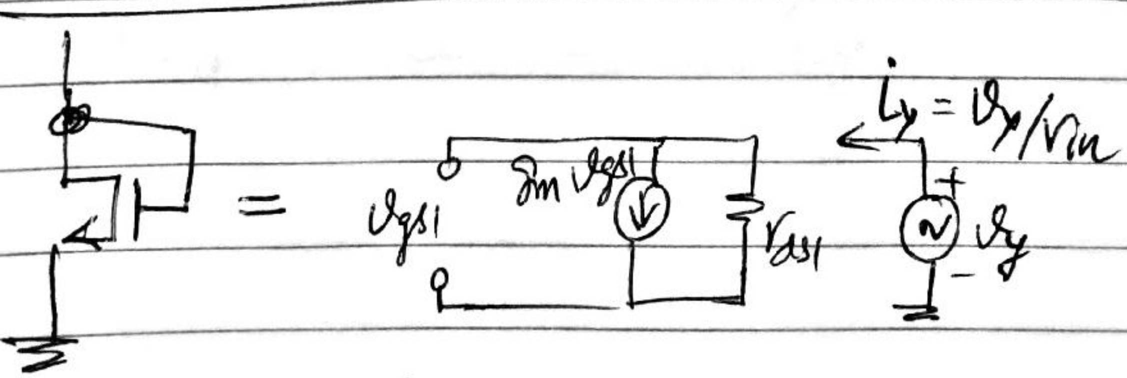


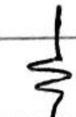
$\lambda \cdot L = 0.12\,\mu m/V$ $\quad r_{ds} \simeq \dfrac{1}{\lambda I_d} = 666\,k\Omega$

$$\Delta i = \frac{\Delta v}{r_{ds}} = \frac{0.4}{666\,k\Omega} = 0.77\,\mu A$$

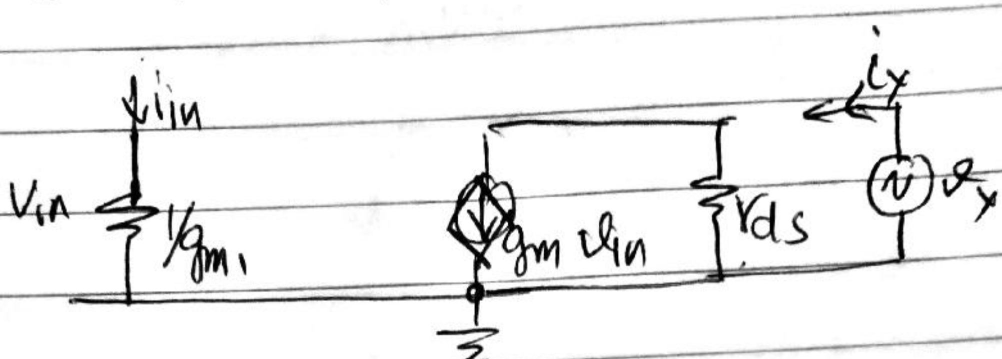
$$\text{Error } \% = \frac{0.77\,\mu A}{20\,\mu A} = \underline{\underline{3.8\,\%}}$$

Small-signal Analysis of Diode connected Transistor



$\Rightarrow$  $r_{in} = 1/g_{m1}$

Output Impedance



$\boxed{r_{out} = r_{ds}.}$

To find output impedance

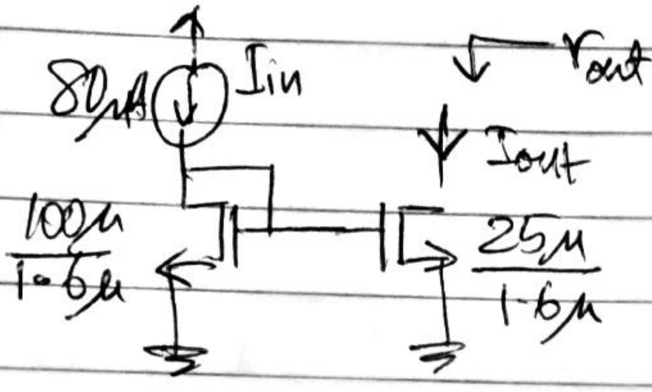
* Turn off all independent sources (AC, DC) ~~to~~ zero.

* Apply a test voltage (v_x) to the port of interest & measure current i_x

* Impedance $= v_x / i_x$

Problem 3.1

0.8 μm nMOS



$\mu_n C_{ox} = 92\ \mu A/V^2$

$V_{tn} = 0.8V$

$\lambda \cdot L = 0.12\ \mu m/V$

Find ① nominal o/p current
② rout
③ Output voltage compliance

① Nominal o/p current = 20 μA

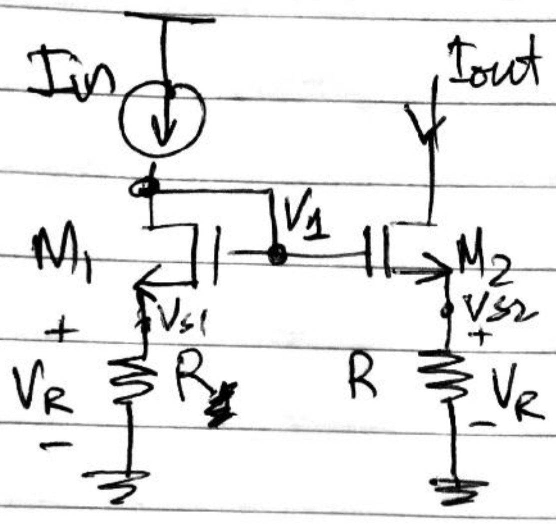
② rout = 666 kΩ

③ $V_{eff} = 0.166V$

previously calculated.

Source degenerated Current Mirror:

$M_1 = M_2$



$V_1 = I_{in} \cdot R + V_{GS}$

$I_{out} = \frac{\mu_n C_{ox}}{2} \frac{W_2}{L_2} (V_1 - V_{S2} - V_T)^2$

$\therefore V_1 = I_{in} \cdot R + V_{GS1}$

or $I_{out} = \frac{\mu_n C_{ox}}{2} \frac{W_2}{L_2} \left[(I_{in} - I_{out}) R + V_{GS1} - V_T \right]^2$

$\therefore M_1 = M_2$, only soln is $I_{in} = I_{out}$

Another way to prove it:

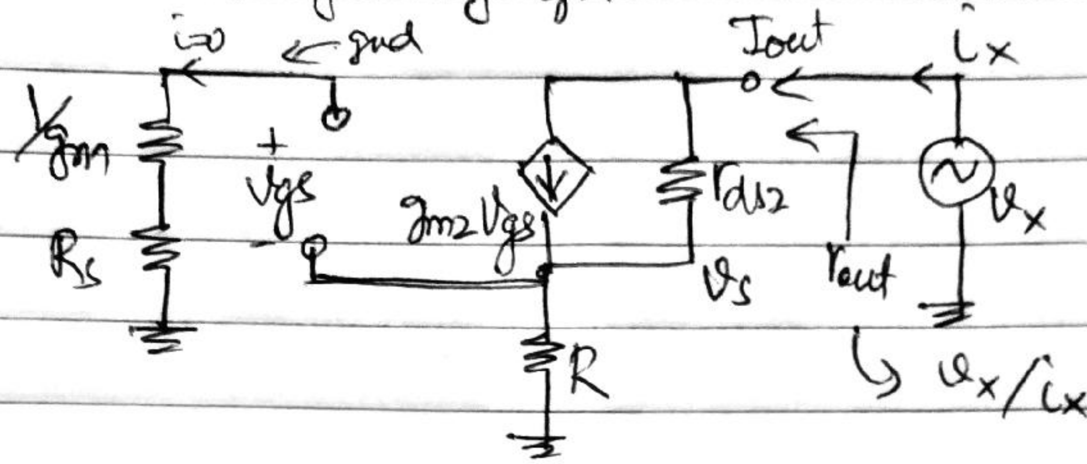
① If $I_{out} > I_{in} \Rightarrow V_{GS2} < V_{GS1}$
& $\therefore I_{DS2} < I_R$ ← not possible.

② If $I_{out} < I_{in} \Rightarrow V_{GS2} > V_{GS1}$
$\therefore I_{DS2} > I_R$ ← again not possible

$\therefore \boxed{I_{out} = I_{in}}$

Output Impedance : Source degen CM.

Neglecting g_{mb}



KCL @ node Iout

$$i_x = -g_{m2}v_s + (v_x - v_s)g_{ds} \quad \text{— (1)}$$

KCL @ node v_s

$$v_s = i_x \cdot R \quad \text{— (2)}$$

On substituting (2) in (1) we get

$$r_{out} = \frac{v_x}{i_x} = r_{ds2}\left[1 + (g_{m2} + g_{ds2})R\right]$$

Typically $g_{m2} \gg g_{ds2}$

$$\therefore \boxed{r_{out} \cong r_{ds2}\left[1 + g_{m2}R\right]}$$