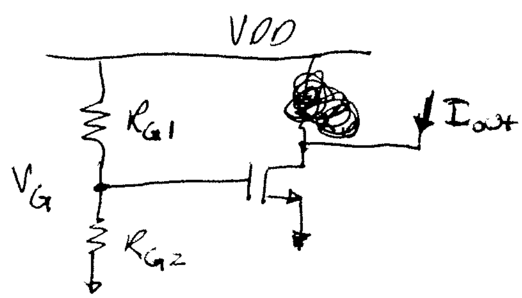
Single Stage Amplifier Comparison

	CS	CG	CD
Input/Output Phase	180°	0°	0°
R_{in}	High	Low	High
R_{OUT}	High	High	Low
A_V	Medium	Medium	<1
Application	Voltage Amp	I-V Amp (TIA)	Buffer

Current Mirrors / DC Biasing

* Resistive Biasing



Assuming Saturation

$$I_{OUT} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_G - V_{TN})^2$$

$$= \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(\frac{R_{G2}}{R_{G1}+R_{G2}}V_{DD} - V_{TN}\right)^2$$

I_{out} is sensitive to:

Supply : V_{DD}

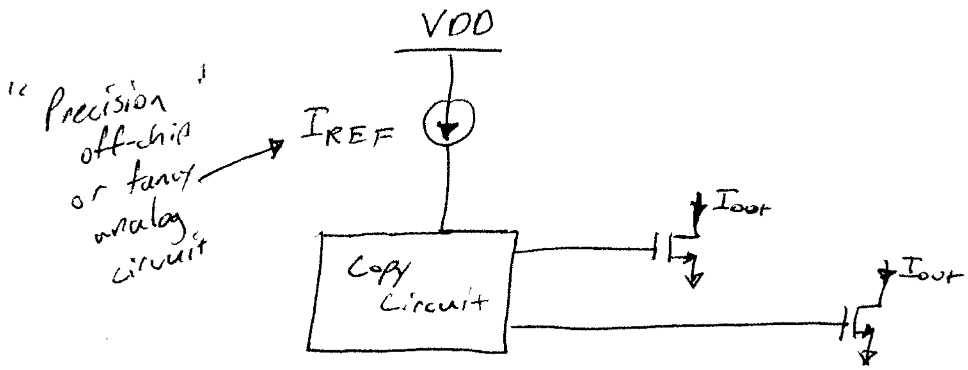
Process : V_T can vary by ~ 100mV from wafer to wafer

β $(\mu_n C_{ox}\frac{W}{L})$ can vary by ~ 5-15%

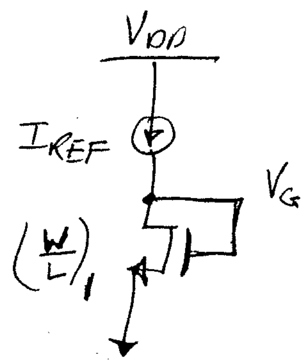
Temperature : μ_n and V_T sensitive to temp

* Current Mirrors

In ~~Eh~~ IC design we assume that we have one precise current source and we copy its value to our circuits.



* Basic Current Mirror

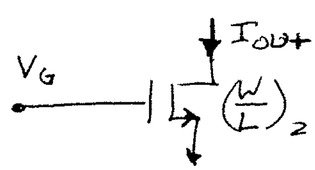


What is V_G?

$$I_D = \frac{KP_N}{2}\left(\frac{W}{L}\right)_1 (V_G - V_{TN})^2$$

$$V_G = \sqrt{\frac{2I_{REF}}{KP_N\left(\frac{W}{L}\right)_1}} + V_{TN}$$

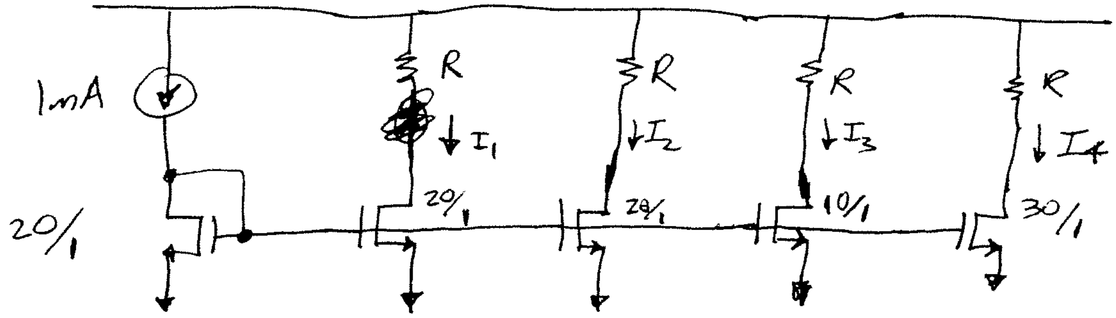
If I apply this V_G to another transistor



$$I_{out} = \frac{KP_N}{2}\left(\frac{W}{L}\right)_2 \left(\sqrt{\frac{2I_{REF}}{KP_N\left(\frac{W}{L}\right)_1}} + V_{TN} - V_{TN}\right)^2$$

$$\boxed{I_{out} = \frac{\left(W/L\right)_2}{\left(W/L\right)_1} I_{REF}}$$

Example



$I_1 = 1mA$

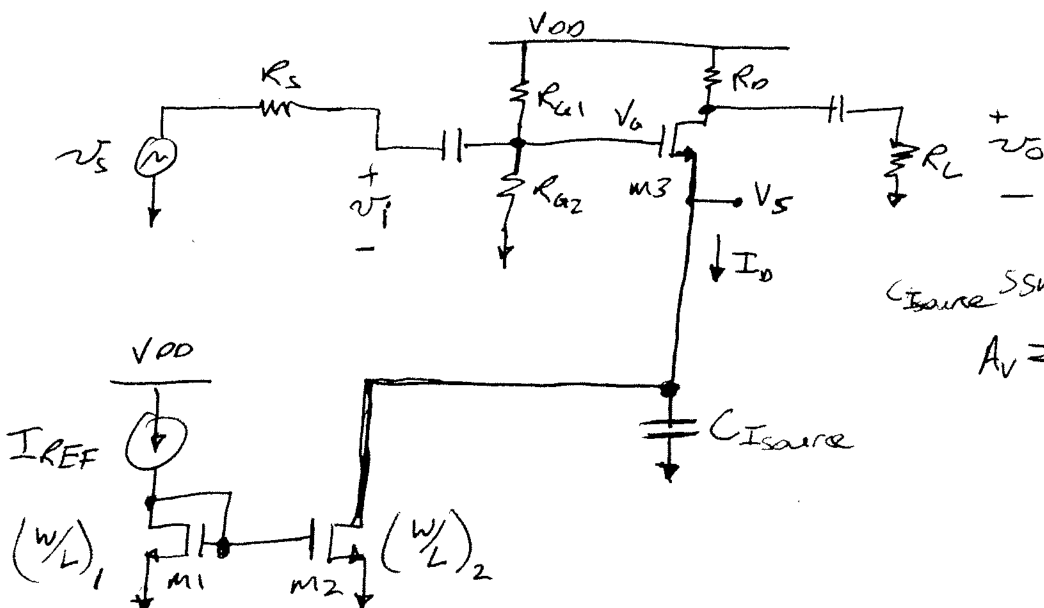
$I_2 = 1mA$

$I_3 = 0.5mA$

$I_4 = 1.5mA$

This bias scheme reduces sensitivity to PVT.

Common-Source Amp W/ Current Source



Assuming large $C_{Isource}$ SSM is same

$$A_V = -g_{m3}(R_D \| R_L)$$

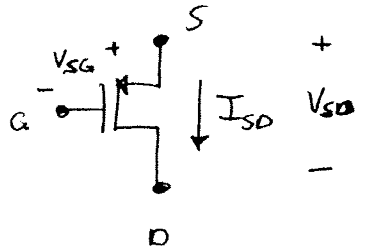
$$V_S = V_G - (VOO + V_{TN})$$

$$I_D = \frac{(W/L)_2}{(W/L)_1} I_{REF}$$

$$V_S = \left(\frac{R_{G2}}{R_{G1} + R_{G2}}\right) V_{DD} - \left(\sqrt{\frac{2 I_D}{KP_N \left(\frac{W}{L}\right)}} + V_{TN}\right)$$

Check that current source M2 is sat.

PMOS Review / SSM



For Saturation: $V_{SD} \geq V_{SG} - |V_{TP}|$

$$I_{SD} = \frac{1}{2} KP_p \frac{W}{L} \left(V_{SG} - |V_{TP}|\right)^2 \left(1 + \lambda_p V_{SD}\right)$$

For AC Small-Signal Analysis

$$i_{sd} = \underbrace{\frac{\partial I_{SD}}{\partial V_{SG}}}_{g_m} v_{sg} + \underbrace{\frac{\partial I_{SD}}{\partial V_{SD}}}_{g_o} v_{sd}$$

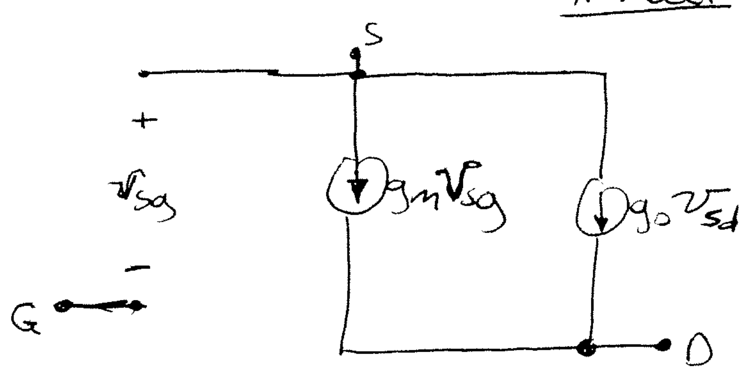
$$g_m = \left.\frac{\partial I_{SD}}{\partial V_{SG}}\right|_Q = KP_p \frac{W}{L}\left(V_{SG} - |V_{TP}|\right) \qquad \left(\text{neglect } 1+\lambda_p V_{SD} \text{ here}\right)$$

$$g_o = \left.\frac{\partial I_{SD}}{\partial V_{SD}}\right|_Q = \lambda_p \frac{1}{2} KP_p \frac{W}{L}\left(V_{SG} - |V_{TP}|^2\right) = \lambda_p I_D$$

(where I_D is w/o $1 + \lambda_p V_{SD}$ term)

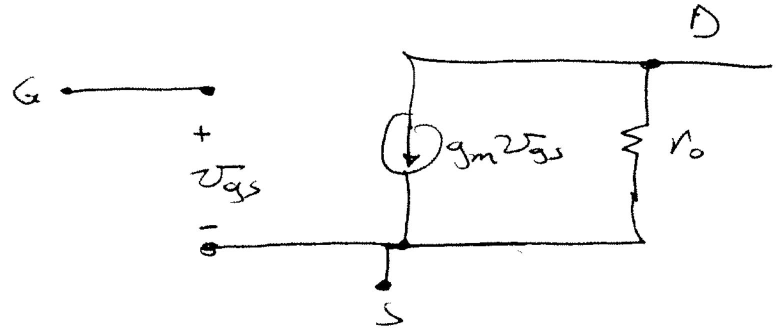
Formal SSM

π-model



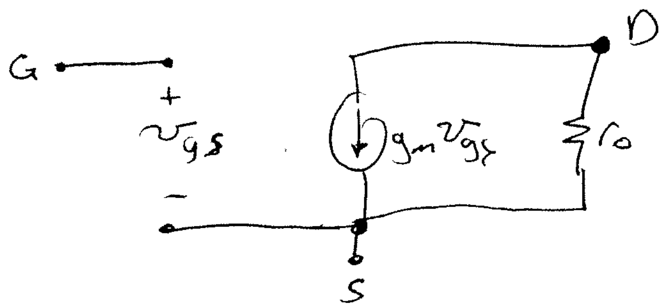
$$\Rightarrow r_o = \frac{v_{sd}}{g_o v_{sd}} = \frac{1}{g_o}$$

If we use v_{gs} instead of v_{sg}

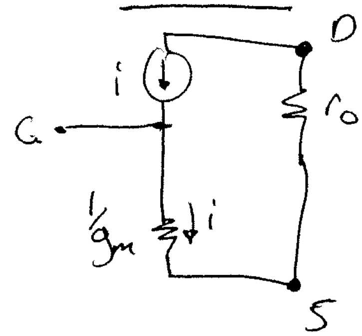


$\Rightarrow$ Same model as NMOS

<u>Π-model</u>



<u>T-model</u>



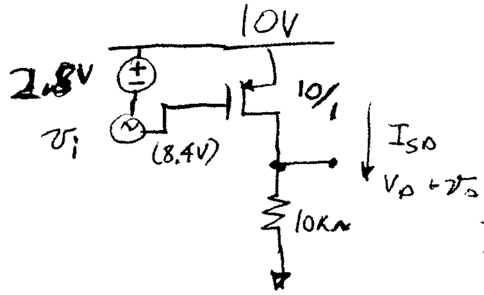
NMOS: $g_m = \dfrac{\partial I_{DS}}{\partial V_{GS}} = KP_N \dfrac{W}{L}(V_{GS} - V_{TN}) = KP_N \dfrac{W}{L} \, VOD$

$g_o = \dfrac{\partial I_{DS}}{\partial V_{DS}} = \lambda_N I_D$

PMOS: $g_m = \dfrac{\partial I_{SD}}{\partial V_{SG}} = KP_P \dfrac{W}{L}\left(V_{SG} - |V_{TP}|\right) = KP_P \dfrac{W}{L} \, VOD$

$g_o = \dfrac{\partial I_{SD}}{\partial V_{SD}} = \lambda_P I_D$

Example



$KP_p = 30\ \mu A/V^2 \qquad V_{TP} = -1V \qquad \lambda = 0.02V^{-1}$

$$I_{SD} = \frac{1}{2} KP_p \frac{W}{L} \left(V_{SG} - |V_{TP}| \right)^2$$

$$I_{SD} = \frac{1}{2} (30\ \mu A/V^2)(10)(2.8 - 1)^2$$

$$= 0.486\ mA$$

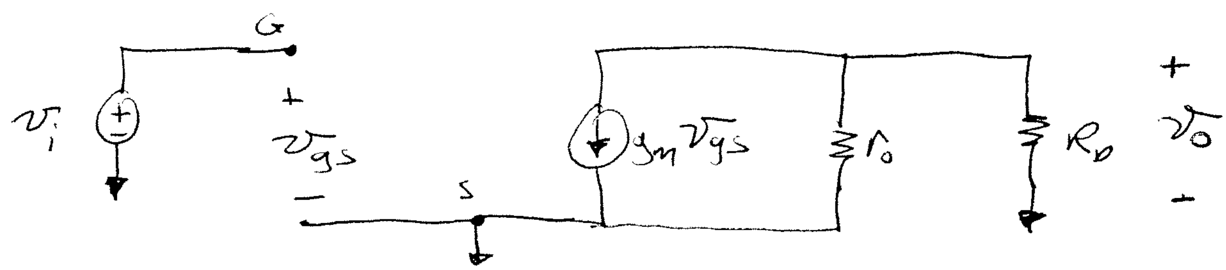
$$V_D = 4.86\ V \Rightarrow V_{SD} = 5.14V$$

$$\geq V_{SG} - |V_{TP}| = 1.8V$$

(sat) ✓

$$g_m = \frac{\partial I_{SD}}{\partial v_{SG}} = KP_p \frac{W}{L} \left(V_{SG} - |V_{TP}| \right) = (30\ \mu A/V^2)(10)(2.8 - 1) = 540\ \mu A/V$$

$$g_o = \lambda I_D = 0.02V^{-1}(0.486 mA) = 9.76\ \mu A/V \Rightarrow r_o = 103K\Omega$$



$$A_v = -g_m (R_D \| r_o) = -540\ \mu A/V \left(10K\Omega \| 103K\Omega \right)$$

$$\boxed{A_v = -4.92\ V/V}$$