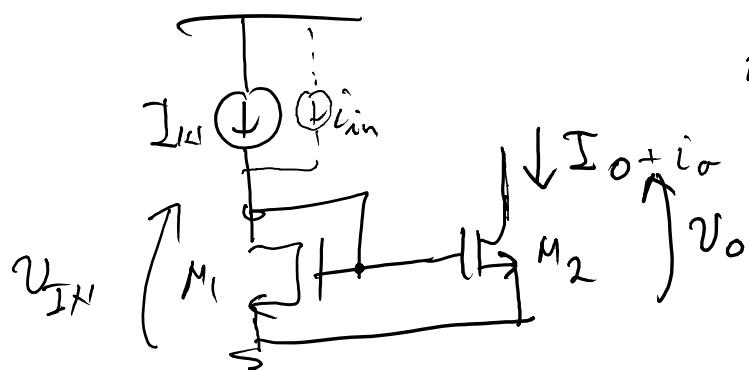


① Simplest current mirrors

Assume M_2 is in saturation

$$a) \lambda = 0; \quad V_{GS1} = V_{GS2}$$

$$\text{If } \left(\frac{w}{L}\right)_1 = \left(\frac{w}{L}\right)_2 \Rightarrow I_{D1} = I_{D2} = I_{IN} \Rightarrow I_o = I_{IN}$$

at low frequency : $i_o = i_{IN}$

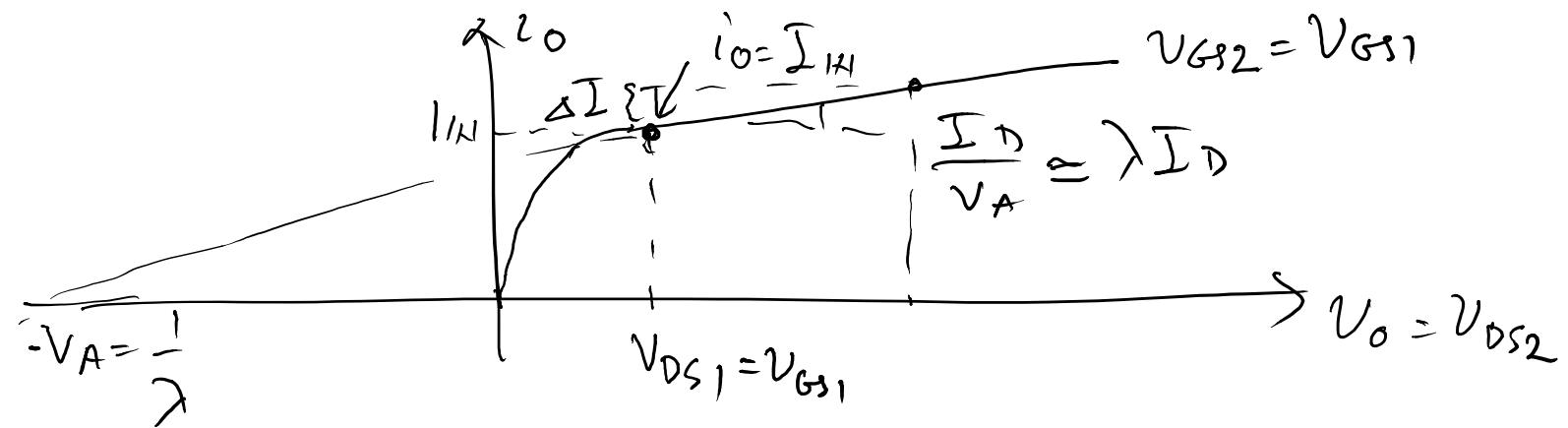
at high frequency : $i_o \neq i_{IN}$

$$\text{If } \left(\frac{w}{L}\right)_1 \neq \left(\frac{w}{L}\right)_2 : \quad V_{GS1} = V_{GS2} = V_{th} + \sqrt{\frac{2i_{IN}}{k'(\frac{w}{L})_1}}$$

$$I_o = \frac{k'}{2} \left(\frac{w}{L}\right)_2 \cdot (V_{GS2} - V_{th})^2 =$$

$$= \frac{k'}{2} \left(\frac{w}{L}\right)_2 \cdot \left(\frac{2i_{IN}}{k'(\frac{w}{L})_1} \right) = \frac{\left(\frac{w}{L}\right)_2}{\left(\frac{w}{L}\right)_1} \cdot i_{IN}$$

b) $\lambda \neq 0$; if $(\frac{w}{l})_1 = (\frac{w}{l})_2$



DC: $I_{IN} = \frac{k'}{2} \left(\frac{w}{l} \right)_1 \cdot (V_{GS1} - V_{th})^2 (1 + \lambda V_{DS1})$

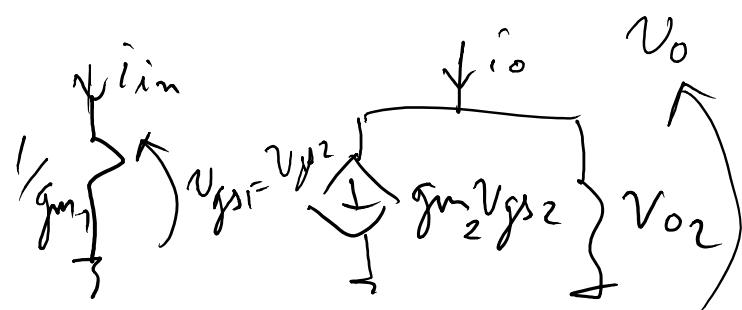
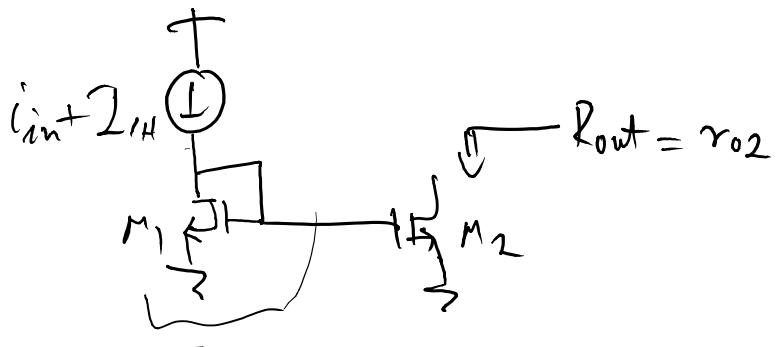
$$I_O = \frac{k'}{2} \left(\frac{w}{l} \right)_2 \cdot (V_{GS2} - V_{th})^2 (1 + \lambda V_{DS2})$$

$$\frac{I_O}{I_{IN}} = \frac{\left(\frac{w}{l} \right)_2}{\left(\frac{w}{l} \right)_1} \cdot \frac{1 + \lambda V_{DS2}}{1 + \lambda V_{DS1}} = \frac{(1 + \lambda V_{DS2})(1 + \lambda V_{DS1})^{-1}}{(1 - \lambda V_{DS1})}$$

$$I_O = \frac{\left(\frac{w}{l} \right)_2}{\left(\frac{w}{l} \right)_1} I_{IN} \cdot \underbrace{(1 + \lambda(V_{DS2} - V_{DS1}))}_{\text{systematic gain error}} = 1 + \lambda(V_{DS2} - V_{DS1})$$

Lecture 11 - Current Mirrors

EE140 Spring 2014
Vladimir Stojanović



$$R_{out} \gg r_o$$

$$i_o = g_{m2}v_{gs2} + \frac{v_o}{r_{o2}}$$

$$i_o = \underbrace{g_{m2} - \frac{1}{g_{m1}} \cdot i_{in}}_{\frac{(w/L)_2}{(w/L)_1}} + \frac{v_o}{r_{o2}}$$

Practical notes: Pick the right $\left(\frac{w}{L}\right)$

$$w_2 = M \cdot w_1$$

$$\boxed{L_1 = L_2}$$

$$x_d = 0$$

$$L_d$$

$$L_{eff} = L - 2L_d - x_d$$

$$L_1 = 1 \mu m$$

$$L_d = 0.1 \mu m$$

$$w = 200 \mu m$$

$$L_2 = 2 \mu m$$

$$x_d = 0$$

$$M \cdot \frac{200}{1 - 0.2} \neq \frac{200}{2 - 0.2}$$

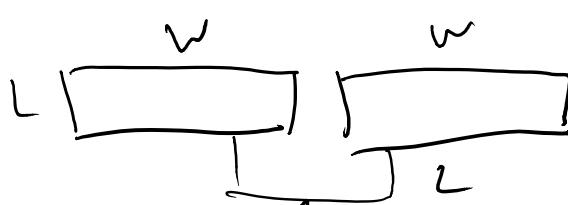
↑
integer = 2

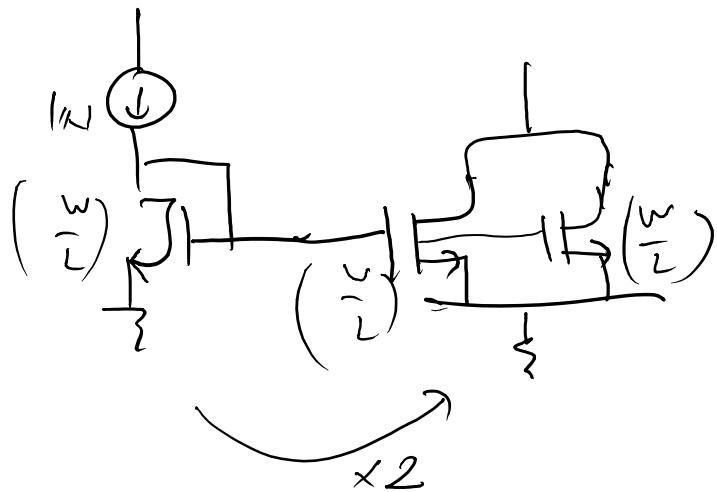
$$w_2 = 2w_1, \quad L_1 = L_2$$

$$\left(\frac{w}{L_{eff}}\right)_2 = 2 \cdot \left(\frac{w}{L_{eff}}\right)_1$$

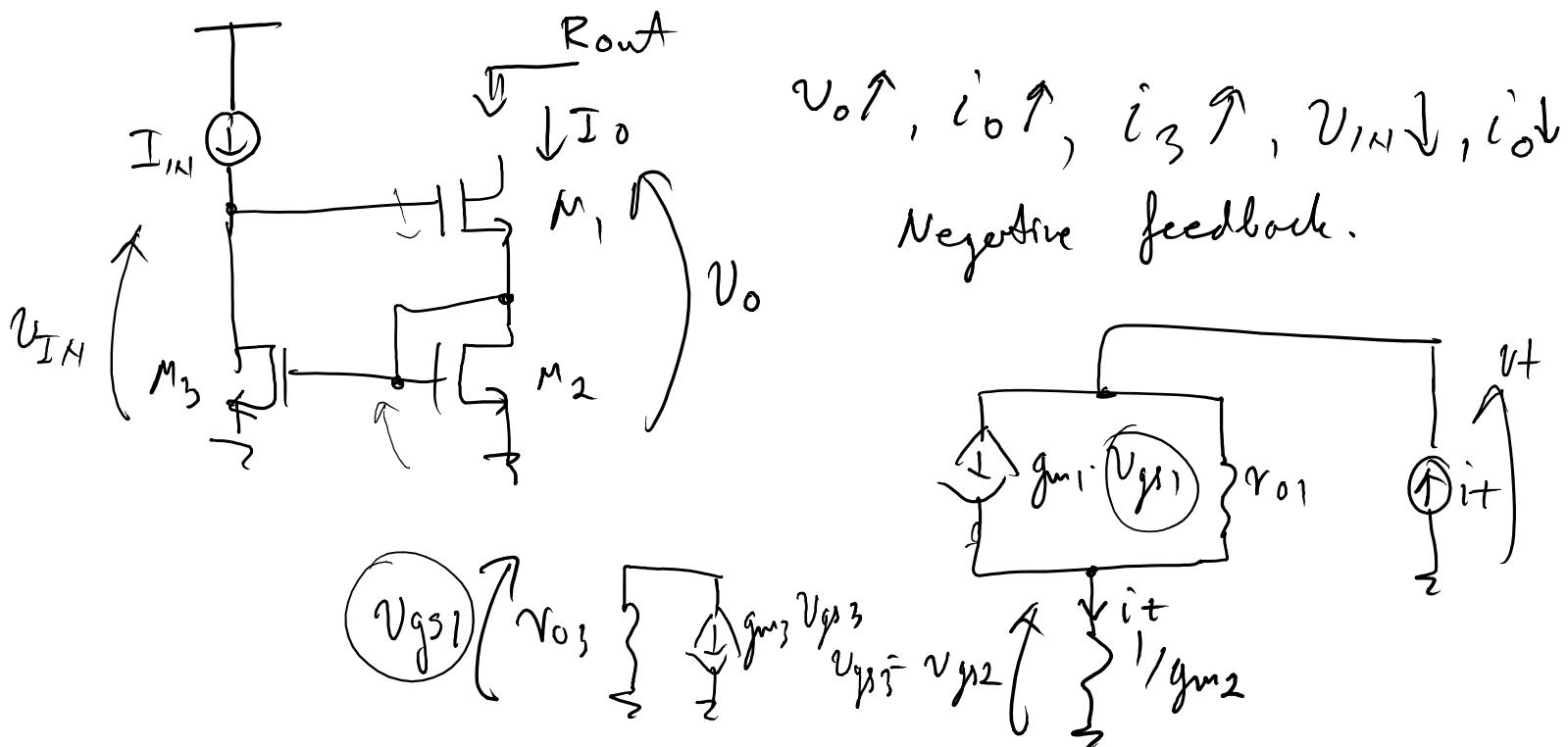


$$2 \cdot (w_1 - 2\Delta) \neq 2w_1 - 2\Delta$$





② Wilson current mirror:

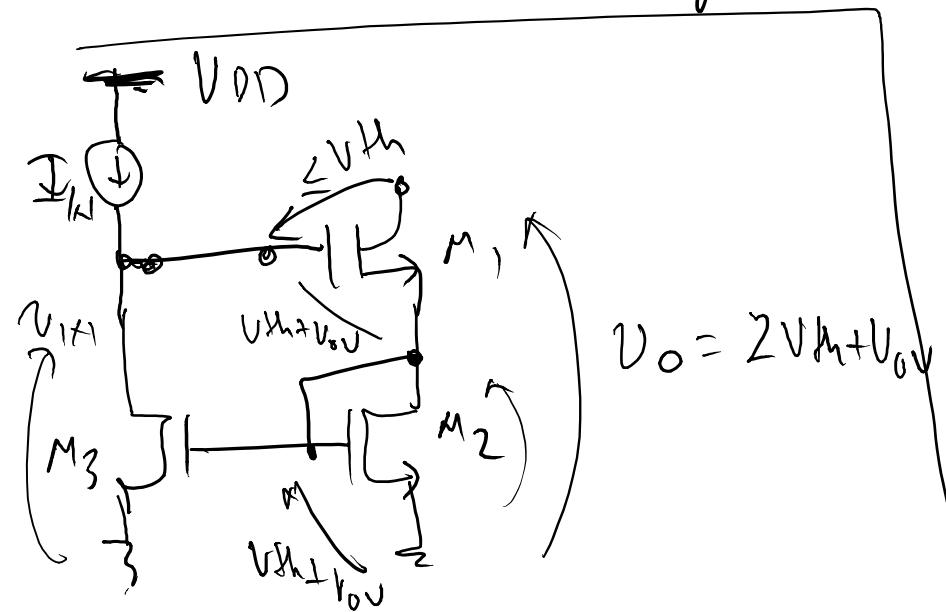


$$V_{gs3} = V_{gs2} = \frac{i_t}{g_{m2}} ; \quad V_{gs1} = -g_{m3} r_{o3} \cdot \frac{i_t}{g_{m2}}$$

$$V_t = \frac{i_t}{g_{m2}} + R_{o1} \cdot \left(i_t - g_{m1} \cdot (-g_{m3} r_{o3} \frac{i_t}{g_{m2}}) \right)$$

$$vt = \frac{it}{g_{m2}} + r_{01} \left(it + g_{m1} \cdot \frac{g_{m3}}{g_{m2}} \cdot v_{03} \cdot it \right)$$

$$R_{out} = \frac{Vt}{it} = \frac{1}{gm_2} + r_{o1} + \frac{g_{m1} g_{m3}}{g_{m2}} r_{o1} r_{o3}$$



$$V_o = 2V_{th} + U_{av}$$

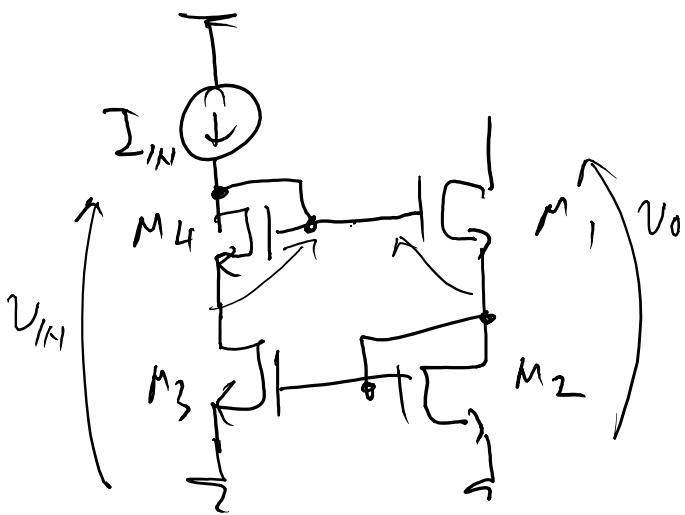
$$\sim g_m \cdot r_0^2$$

$$\frac{(g_m - r_0)}{g_m} = r_0$$

$$V_{omin} = \underbrace{V_{GS2}}_{V_{th} + V_{ov}} + \underbrace{V_{GS1}}_{V_{th} + V_{ov}} - \underbrace{V_{GDI}}_{V_{th} + 2V_{ov}} = V_{th} + 2V_{ov}$$

$$V_{I\min} = 2 V_{fh} + 2 V_{ou}$$

$$\text{Systematic gain error} \approx \lambda (V_{DS2} - V_{DS3}) = -\lambda V_{GS1}$$

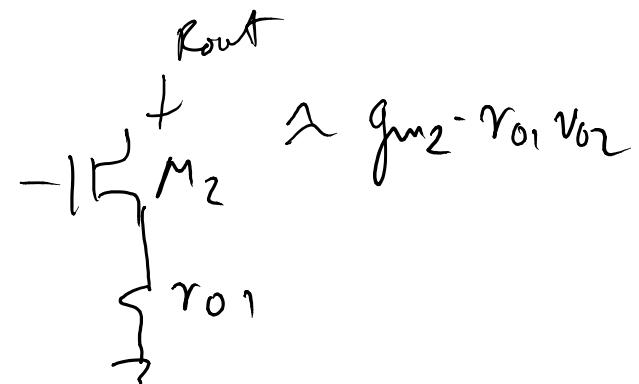
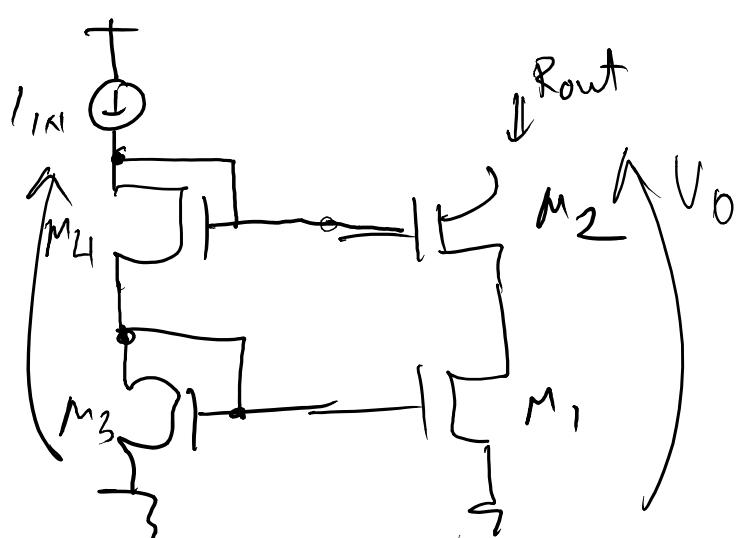
(3) Improved Wilson:

$$\text{Synthesis error: } \lambda (V_{DS2} - V_{DS3}) \\ \Rightarrow (V_{GS2} - V_{GS1}) \approx 0$$

$$V_{IN} = \underbrace{V_{GS2}}_{V_{th} + V_{ov}} + V_{th} + V_{ov} = 2V_{th} + 2V_{ov}$$

$$V_{min} = V_{th} + 2V_{ov}$$

(4) Cascade current mirror:



$$V_{IN} = 2V_{ov} + 2V_{th}$$

$$V_{min} = V_{th} + 2V_{ov}$$

$$\text{Synthesis gain error: } \lambda (V_{DS1} - V_{DS3}) \xrightarrow{=} 0$$