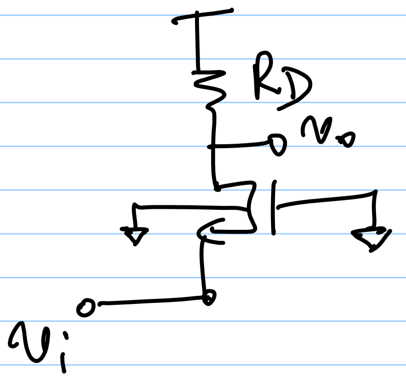
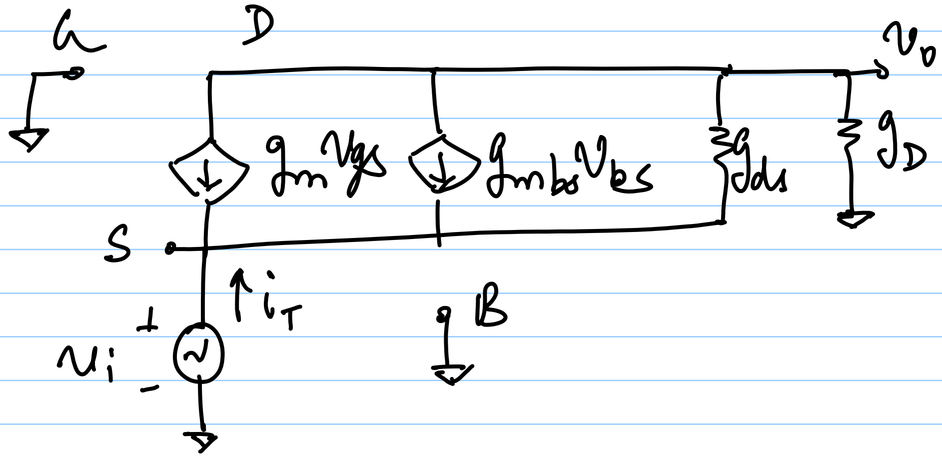
6/1/12 Lec 4

C.G. amplifier





$$v_{gs} = -v_i$$

$$v_{bs} = -v_i$$

KCL @ D : $g_m v_{gs} + g_{mbs} v_{bs} + g_{ds}(v_o - v_i) + g_D v_o = 0$

$$-g_m v_i - g_{mbs} v_i - g_{ds} v_i + g_{ds} v_o + g_D v_o = 0$$

$$a_v = \frac{v_o}{v_i} = \frac{g_m + g_{mbs} + g_{ds}}{g_{ds} + g_D}$$

$$R_{out} = 1/(g_{ds} + g_D)$$

$R_{in} = ?$

KCL @ S ...

or note that

$$i_T = v_o \cdot g_D = \frac{(g_m + g_{mbs} + g_{ds}) g_D}{g_{ds} + g_D} \cdot v_i$$

$$R_{in} = \frac{v_i}{i_T}$$

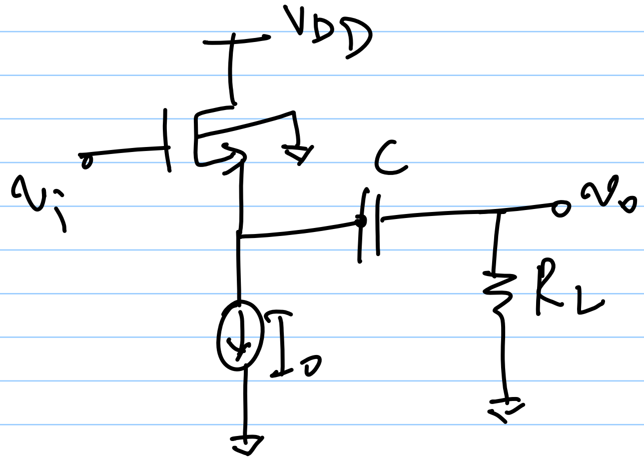
$$= \frac{g_{ds} + g_D}{g_D(g_m + g_{mbs} + g_{ds})}$$

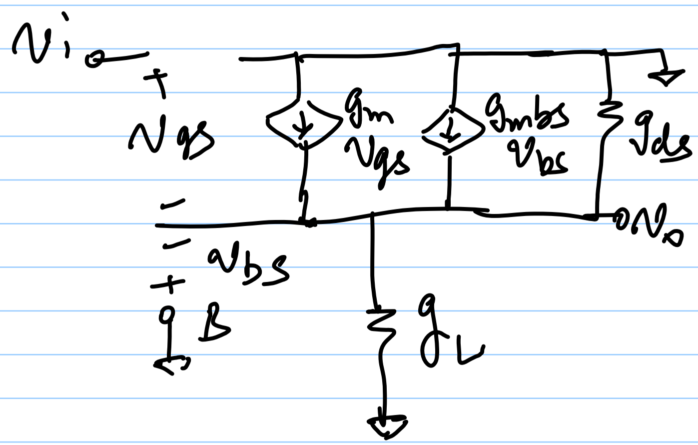
valid approx. $\Rightarrow g_m >> g_{mbs}, g_{ds}$

$$\Rightarrow R_{in} \approx \frac{g_{ds} + g_D}{g_D \cdot g_m} = \frac{1}{g_m} + \frac{g_{ds}}{g_D g_m}$$

If $r_{ds} >> R_D \Rightarrow g_{ds} << g_D \Rightarrow R_{in} \approx \frac{1}{g_m}$

C.D. Amp. (source follower)





$$v_{gs} = v_i - v_o$$

$$v_{bs} = v_b - v_s = -v_o$$

KCL @ S :

$$g_m v_{gs} + g_{mbs} v_{bs} = (g_L + g_{ds}) v_o$$

$$g_m(v_i - v_o) - g_{mbs} v_o = (g_L + g_{ds}) v_o$$

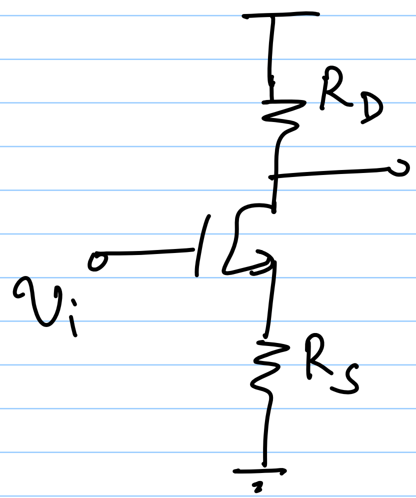
$$\Rightarrow \quad g_m v_i = (g_m + g_{mbs} + g_{ds} + g_L) \cdot v_o$$

$$a_v = \frac{v_o}{v_i} = \frac{g_m}{g_m + g_{mbs} + g_{ds} + g_L}$$

$$\approx 1 \quad \text{if} \quad g_m \gg g_{mbs}, g_{ds}, g_L$$

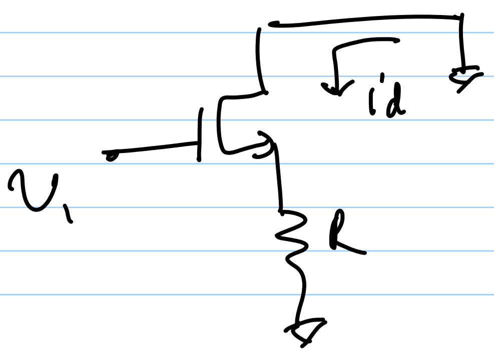
$$g_{out} = g_m + g_{mbs} + g_{ds} + g_L$$

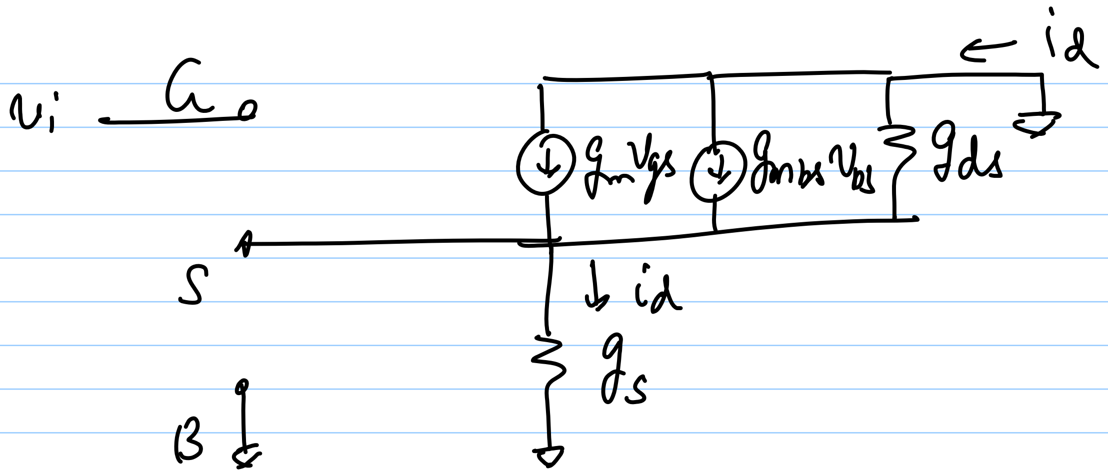
C.S. w/ degeneration



→ determine effective transconductance G_m

⇒ short ckt o/p terminal in signal picture





$$v_s = i_d / g_s$$

$$v_{gs} = v_i - v_s = v_i - i_d / g_s$$

$$v_{bs} = - v_s = - i_d / g_s$$

KCL @ S :

$$i_d = g_m v_{gs} + g_{mbs} v_{bs} + g_{ds} (- v_s)$$

$$= g_m (v_i - i_d / g_s) - g_{mbs} \cdot \frac{i_d}{g_s} - g_{ds} \cdot \frac{i_d}{g_s}$$

$$= g_m v_i - \left(\frac{g_m}{g_s} + \frac{g_{mbs}}{g_s} + \frac{g_{ds}}{g_s} \right) i_d$$

$$\Rightarrow \quad G_m = \frac{i_d}{v_i} = \frac{g_m}{1 + (g_m + g_{mbs} + g_{ds}) g_s}$$

$$G_m = \frac{g_m}{1 + (g_m + g_{mbs} + g_{ds}) R_s}$$

$$g_m >> g_{mbs} >> g_{ds}$$

$$G_m = \frac{g_m}{1 + g_m R_s}$$

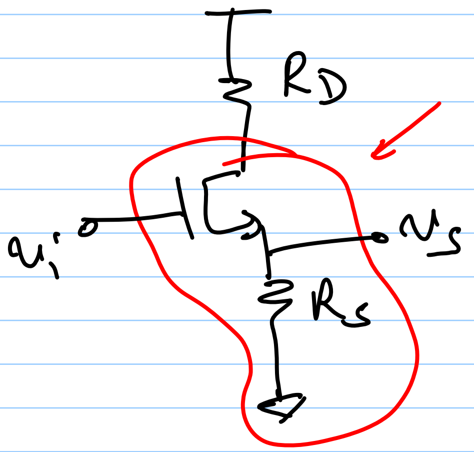
If $g_m R_s >> 1$ $\{$ i.e. $R_s >> 1/g_m \}$

$$G_m \approx \frac{1}{R_s} \quad //$$

$g_m >> G_m$!

$\Rightarrow$ Source degeneration reduces transconductance

Intuitively:



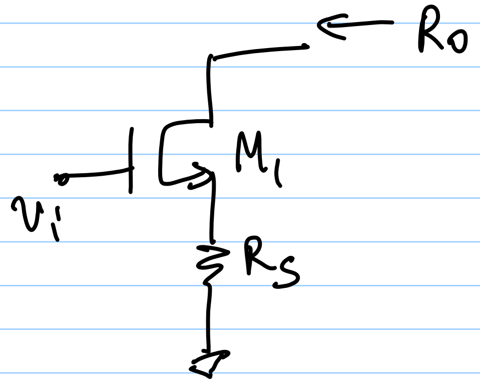
source follower

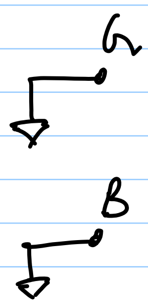
$$\frac{v_i}{v_s} \approx 1 \Rightarrow v_i \approx v_s$$

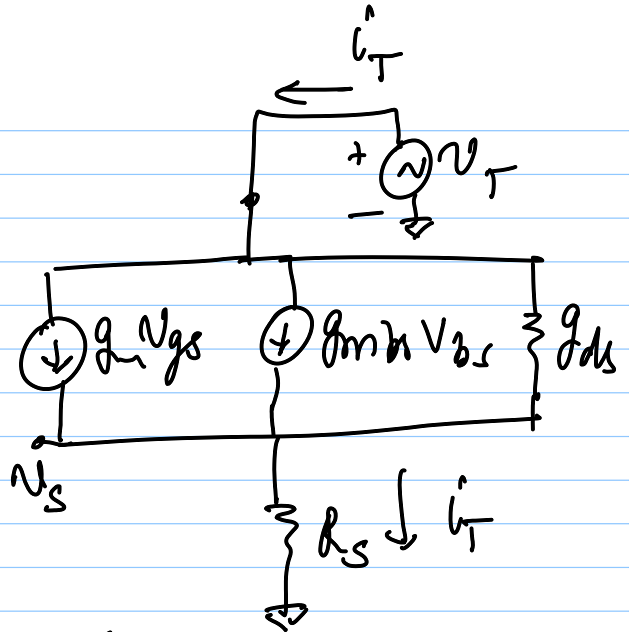
$$i_d = \frac{v_s}{R_s} \approx \frac{v_i}{R_s}$$

$$\Rightarrow G_m \approx \frac{i_d}{v_i} \approx \frac{1}{R_s}$$

$R_{out} = ?$







$$i_T = g_m v_{gs} + g_{mbs} v_{bs} + (v_T - v_s)\, g_{ds}$$

$$v_s = i_T / g_s \; ; \quad v_{gs} = -i_T/g_s \; ; \quad v_{bs} = -i_T/g_s$$

$$i_T = -(g_m + g_{mbs} + g_{ds}) \cdot \frac{i_T}{g_s} + g_{ds} \cdot v_T$$

$$R_o = \frac{v_T}{i_T} = \frac{g_m + g_{mbs} + g_{ds} + g_s}{g_{ds}\, g_s}$$

$$= r_{ds}\left[1 + (g_m + g_{mbs} + g_{ds}) \cdot R_s\right]$$

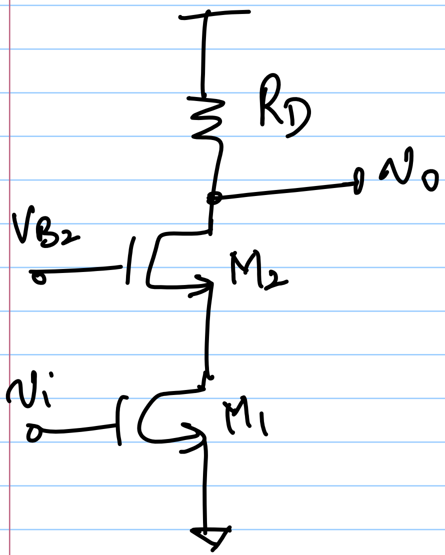
$$\approx \underbrace{(g_m r_{ds})}_{\text{self-gain of } M_1} \cdot R_s \qquad \left\{ g_m \gg g_{mbs} \gg g_{ds} \text{ and } g_m R_s \gg 1 \right\}$$

$$a_v = -G_m \cdot (R_o \| R_D)$$

$$\simeq -\frac{1}{R_S} \cdot (g_m r_{ds} \cdot R_S \| R_D)$$

$$\simeq -\frac{R_D}{R_S}$$

Cascode C.S. amp. (very important)



by inspection:

$$G_m = g_{m1}$$

$$R_o = R_L \| (g_{m2} r_{ds2} \cdot r_{ds1})$$

$$a_v = -G_m R_o$$

$$= -\frac{g_{m1} g_{m2} r_{ds1} r_{ds2} R_L}{g_{m2} r_{ds2} r_{ds1} + R_L}$$

$$= -\frac{g_{m1} g_{m2} r_{ds1} r_{ds2}}{1 + \frac{g_{m2} r_{ds2} r_{ds1}}{R_L}}$$

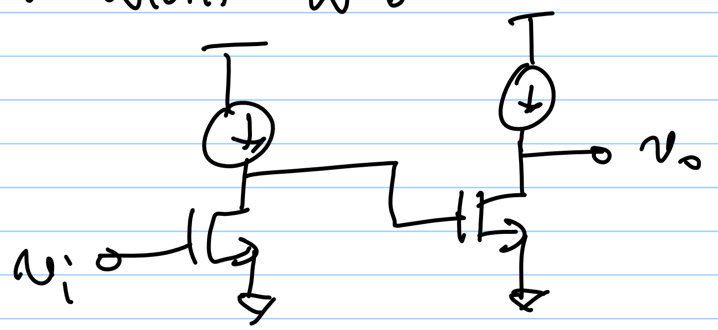
* $R_L \to \infty$ (e.g. ideal current source)

$\Rightarrow a_v \to -(g_{m_1} r_{ds_1}) \cdot (g_{m_2} r_{ds_2})$

self-gain of M_1

self-gain of M_2

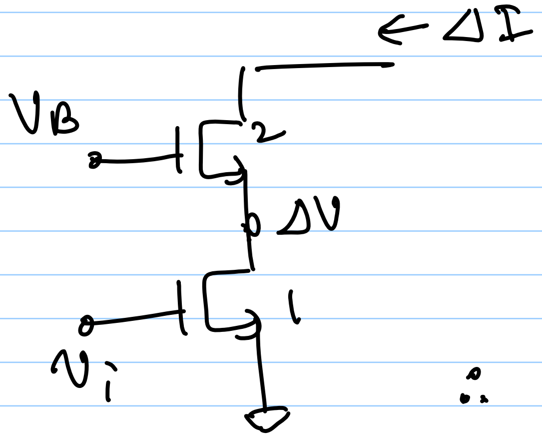
equivalent to:



$|a_v| = g_{m_1} r_{ds_1} \cdot g_{m_2} r_{ds_2}$

* high gain in 1 stage
* good stability (one stage)
* current reuse = power efficiency

Intuitively:



* pump in ΔI

$\to \Delta V = \Delta I \cdot r_{ds_1}$

$\to V_{GS_2}' = V_{GS_2} - \Delta I \cdot r_{ds_1}$ (decreases)

$\therefore$ negative f.b. acts to reduce i_{d_2} $\Rightarrow$ large R_{out}