Summary of Single transistor amplifiers

CS (No body effect)

$$A_v = -g_m (r_o \parallel R_D)$$

$$R_{in} = \infty$$

$$R_{out} = r_o \parallel R_D$$

CS (with Source deg)

$$A_v = \frac{-g_m R_D}{1 + g_m R_S \left(1 + \frac{g_{mb}}{g_m}\right)}$$

$$R_{in} = \infty$$

$$R_{out} = r_o + R_S + (g_m + g_{mb}) r_o R_S$$

CD

$$A_v = \frac{R_S}{r_m + R_S(1+\chi)} \approx \frac{R_S \parallel r_{mb} \parallel r_o}{(r_o \parallel R_S \parallel r_{mb}) + r_m}$$

$$R_{in} = \infty$$

$$R_{out} = R_S \parallel r_m \parallel r_{mb} \parallel r_o$$

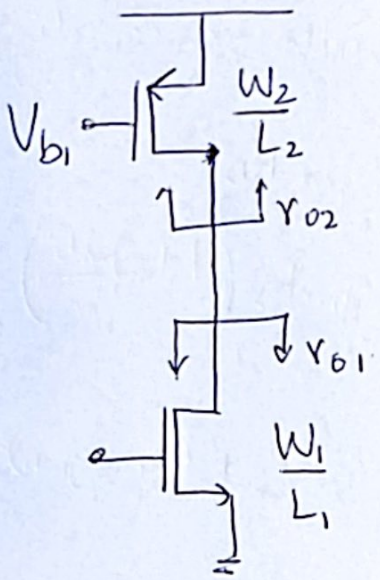
CG

$$A_v = \frac{R_D \parallel r_o}{r_o \parallel r_m \parallel r_{mb}}$$

$$R_{out} = R_D \parallel r_o$$

$$R_{in} = r_m \parallel r_{mb} \parallel r_o$$

Cascode



$\mu_n C_{ox} = 50\,\mu A/V^2$

$\mu_p C_{ox} = 25\,\mu A/V^2$

$\left(\frac{dX_d}{dV_{DS}}\right)_N = 0.1\,\frac{\mu}{V}$

$\left(\frac{dX_d}{dV_{DS}}\right)_P = 0.05\,\frac{\mu}{V}$

$I_D = 100\,\mu A$

$\frac{W}{L} = \frac{100\mu}{1\mu}$

$g_{m1} = \sqrt{2\mu_n C_{ox}\frac{W_1}{L_1} I_D} = 1\,mS$

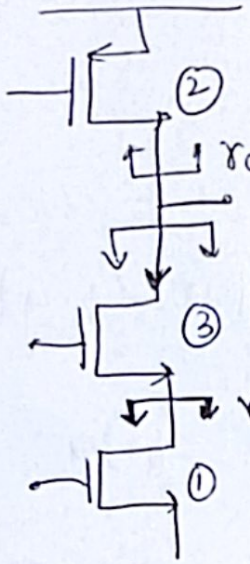
$g_{m2} = 0.7\,mS$

$r_{on} = \frac{L}{I_D}\left(\frac{dX_d}{dV_{DS}}\right)^{-1} = \frac{1\,\mu m}{100\mu A}\cdot\frac{V}{0.1\mu} \simeq 100k\Omega$

$r_{op} \simeq 200k\Omega.$

$A_V = -g_m(r_{o1}\,||\,r_{o2}) = -1\,mS\,(100k\,||\,200k) \simeq -67$

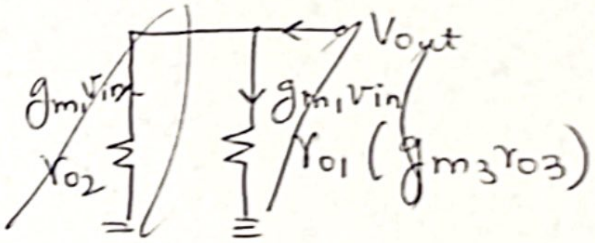
How can we increase r_{o1}?



$$r_{out} = r_{o2}\left(1 + g_{m3} r_{o1} (1 + \chi)\right) \quad \chi = \frac{g_{mb}}{g_m}$$

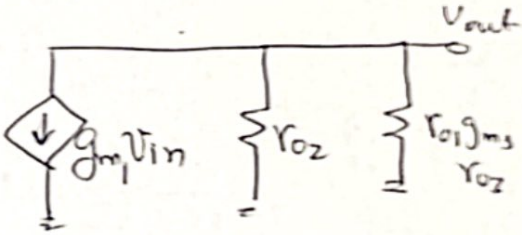
→ Source degen output resistance

$$\triangleq g_{m3} r_{o3} r_{o1}$$



$$R_{out} = g_{m3} r_{o3} r_{o1}$$

$A_v = ?$



$$i_{D3} = g_{m1} v_{in}$$

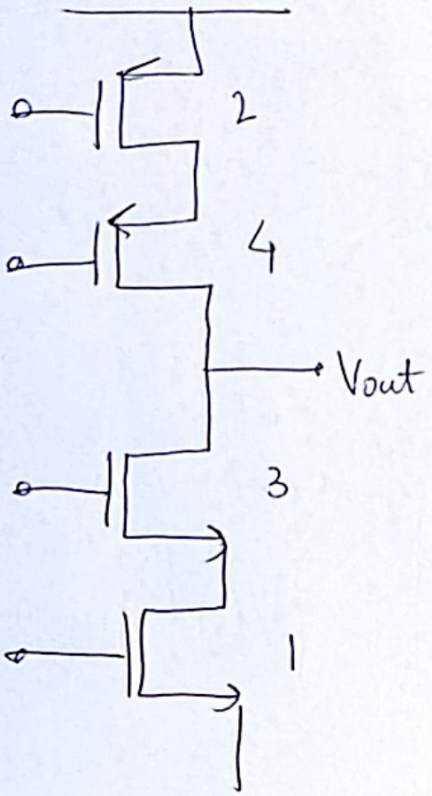
$$\Rightarrow V_{out} = g_{m1} v_{in} (R_{out})$$

$$\Rightarrow A_v = -g_{m1}\left(r_{o2} \parallel r_{o1} g_{m3} r_{o3}\right)$$

If $r_{o2} \to \infty$ ← This dominates!

$$A_v = -g_{m1} g_{m3} r_{o1} r_{o3} \rightarrow \text{CS followed by CG.}$$

- Cascode the PMOS too!



100K 1m 100k

$$A_v = g_{m1}\left(r_{o3} g_{m3} r_{o1} \| r_{o2} g_{m4} r_{o4}\right)$$

1ms $\quad$ 100 x 100k $\quad$ 10M

$$= 10M$$

$$= 5{,}000$$

> Triple Cascode? Another factor of 100?

> Biasing is a problem (Headroom)

> Currents become too small. & leakage currents start to dominate.

Folded Cascode

> CS feeding PMOS CG.