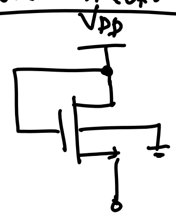
Lecture 8: Active Loads

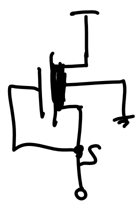
- **Announcements**:
  - No Prof. Nguyen Office Hours this coming Monday (on travel)
  - But there WILL BE lecture Tuesday
- **Lecture Topics**:
  - Types of Active (Transistor) Loads
  - Analysis of actively loaded circuits
  - Current Sources
- ---------------------------------------
- **Last Time**:

Diode-Connected Enhancement Loads



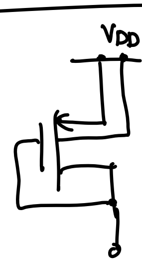
Depletion Load

ancient & we won't consider this

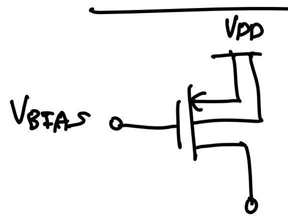


$V_{GS}=0 \rightarrow$ device is on

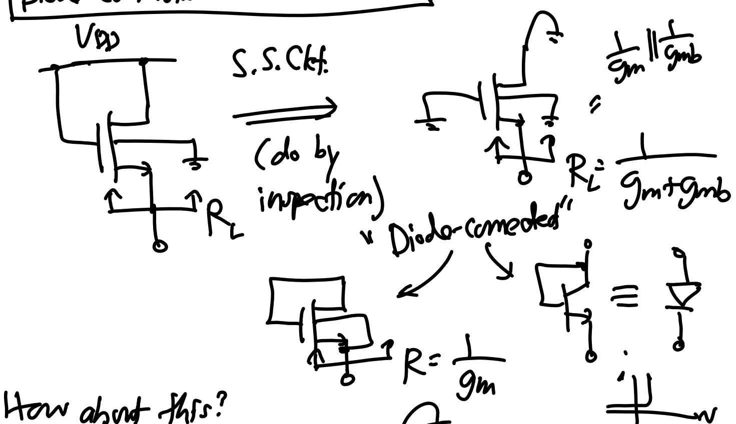
Diode-Connected PMOS Load:



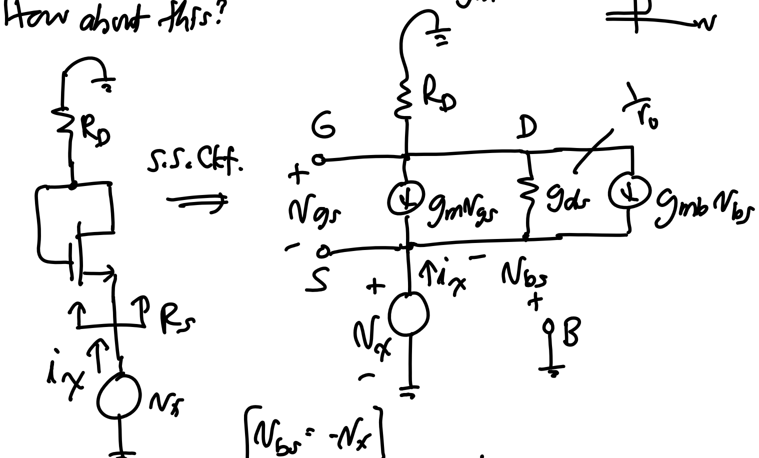
PMOS Current Source Load:



Diode-Connected Enhancement Load



How about this?



$[v_{bs} = -v_x]$

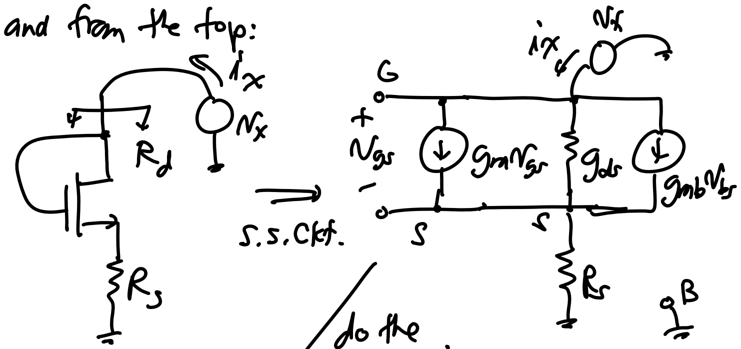
$$i_x = -g_m v_{gs} + \cancel{g_{ds}}(-v_{gs}) - g_{mb} v_{bs} \quad \text{neg!} \qquad \eta = \frac{g_{mb}}{g_m}$$

$$= g_m(v_x - i_x R_D) + g_{mb} v_x$$

$$R_s = \frac{v_x}{i_x} = \frac{1 + g_m R_D}{g_m + g_{mb}} = \frac{1}{g_m + g_{mb}} + \frac{R_D}{(1+\eta)}$$

$$R_s \cong \frac{\frac{1}{g_m} + R_D}{1+\eta}$$

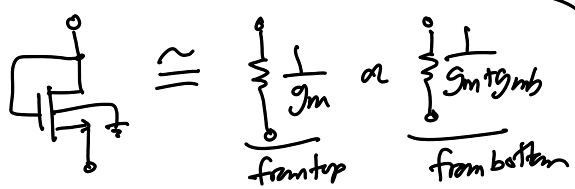
... and from the top:



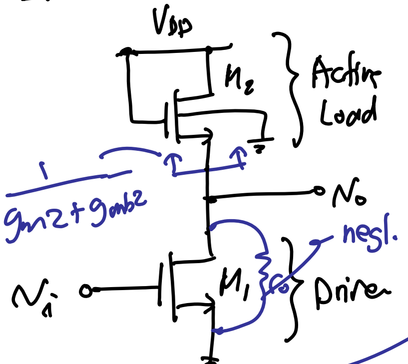
do the analysis

$$R_d = \frac{v_x}{i_x} = \frac{1}{g_m} + (1+\eta) R_s \approx \frac{1}{g_m} + R_s$$

Thus:



Apply to C.S. Ckt.

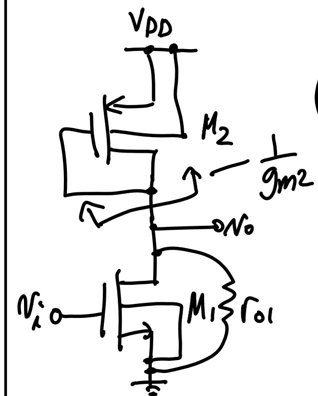


$$A_v = \frac{v_o}{v_i} = -\frac{g_{m1}}{g_{m2} + g_{mb2}}$$

$$= -\frac{1}{(\eta+1)} \frac{g_{m1}}{g_{m2}}$$

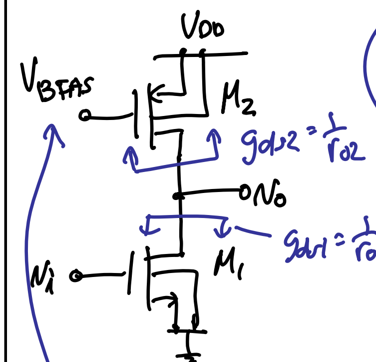
$$A_v = -\frac{1}{\eta+1} \frac{\sqrt{\cancel{2}\mu_n \cancel{C_{ox}} \left(\frac{W}{L}\right)_1 \cancel{I_D}}}{\sqrt{\cancel{2}\mu_n \cancel{C_{ox}} \left(\frac{W}{L}\right)_2 \cancel{I_D}}} = -\frac{1}{\eta+1} \sqrt{\frac{(W/L)_1}{(W/L)_2}} = A_v$$

Diode-Connected PMOS Load



$$A_v = -\frac{g_{m1}}{g_{m2}} = -\sqrt{\frac{\mu_n (W/L)_1}{\mu_p (W/L)_2}}$$

PMOS Current Source Load



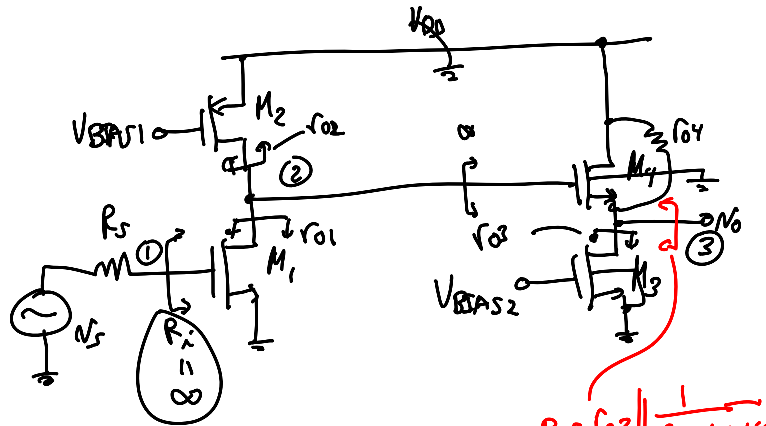
$$A_v = \frac{v_o}{v_i} = -\frac{g_{m1}}{g_{ds1} + g_{ds2}}$$

$$= -g_{m1} (r_{o1} \| r_{o2})$$

⇒ gain is huge! (r_o = huge)

⇒ but requires V_{BIAS}

Ex. Multi-Stage Actively-Loaded MOS Ckt.



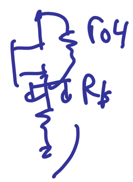
$R_o = r_{o3} \| \frac{1}{g_{m4}+g_{mb4}}$

$\boxed{R_o \approx \frac{1}{g_{m4}+g_{mb4}}}$

$$a_v = \frac{v_1}{v_s}\cdot\frac{v_2}{v_1}\cdot\frac{v_o}{v_2}$$

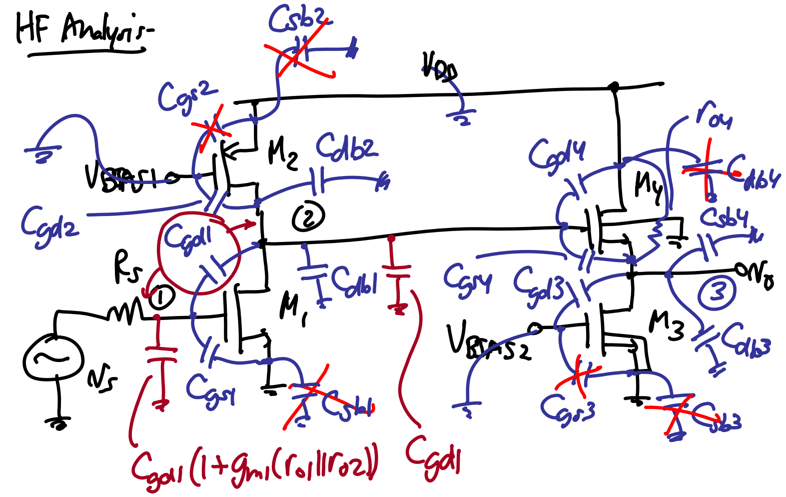
$$= (1)(-g_{m1}(r_{o1}\|r_{o2}))\cdot\frac{g_{m4}(\cancel{r_{o3}\|r_{o4}})}{\cancel{1}+(g_{m4}+g_{mb4})(\cancel{r_{o3}\|r_{o4}})}$$

$$\boxed{a_v = -g_{m1}(r_{o1}\|r_{o2})\left(\frac{g_{m4}}{g_{m4}+g_{mb4}}\right)}$$



$$\frac{g_m R_s}{1+(g_m+g_{mb})R_s}$$

HF Analysis



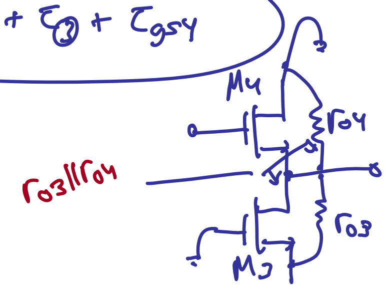
$$\tau_1 = [C_{gs1}+C_{gd1}(1+g_{m1}(r_{o1}\|r_{o2}))]R_s$$

$$\tau_2 = (C_{gd1}+C_{db1}+C_{db2}+C_{gd2}+C_{gd4})(r_{o1}\|r_{o2})$$

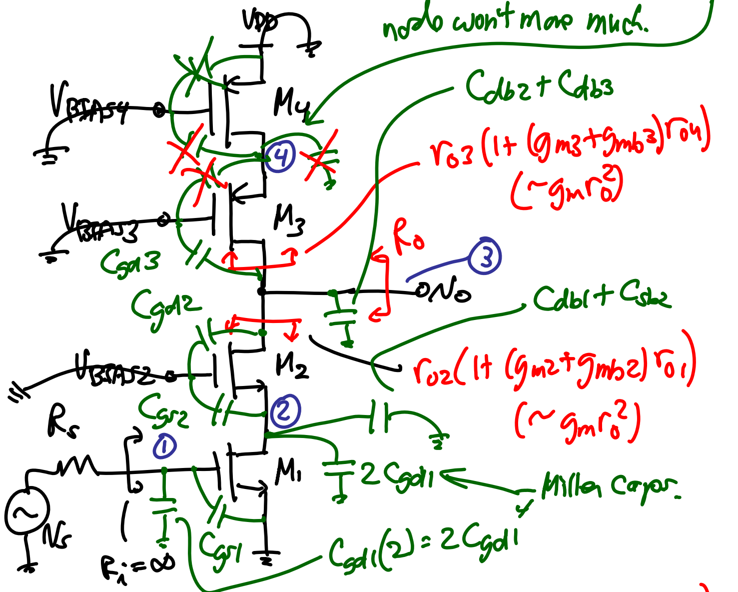
$$\tau_3 = (C_{gd3}+C_{db3}+C_{sb4})\left(\frac{1}{g_{m4}+g_{mb4}}\right)$$

$$\tau_{C_{gs4}} = C_{gs4}\left(\frac{(r_{o1}\|r_{o2})+(r_{o3}\|r_{o4})}{\cancel{1}+(g_{m4}+g_{mb4})(r_{o3}\|r_{o4})}\right) \approx \underbrace{C_{gs4}\left(\frac{2}{g_{m4}+g_{mb4}}\right)}_{\text{small}}$$

$$\boxed{\omega_H = \frac{1}{\tau_1+\tau_2+\tau_3+\tau_{gs4}}}$$



Ex. Cascode Drive + Load



$$R_o = r_{o2}(1+(g_{m2}+g_{mb2})r_{o1}) \,\|\, r_{o3}(1+(g_{m3}+g_{mb3})r_{o4})$$

$$A_v = \frac{v_1}{v_s}\cdot\frac{v_2}{v_1}\cdot\frac{v_o}{v_2}$$

$$= (1)\underbrace{\left(-g_{m1}\left(\frac{1}{\cancel{g_{m2}+g_{mb2}}}\right)\right)}_{\approx -1}\cancel{(g_{m2}+g_{mb2})}R_o$$

$$\therefore \boxed{A_v = -g_{m1}R_o}$$

Get the dominant pole: (use OCTC analysis)

$$\tau_1 = (2C_{gd1}+C_{gs1})R_s$$

$$\tau_2 = (2C_{gd1}+C_{gs2}+C_{db1}+C_{sb2})\left(\frac{1}{g_{m2}+g_{mb2}}\right)$$

$$\tau_3 = (C_{gd2}+C_{db2}+C_{db3}+C_{gd3})R_o \leftarrow \text{huge}$$

$$\omega_H = \frac{1}{\tau_1+\tau_2+\tau_3}$$

$\Rightarrow$ this is accurate enough… but… can we be a bit smarter?