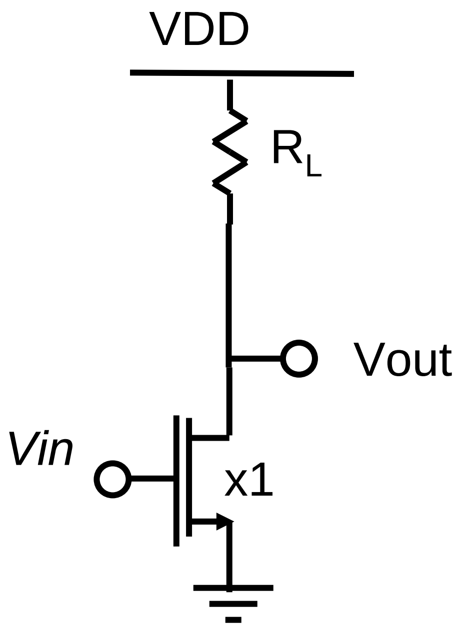
Lectures 11+12

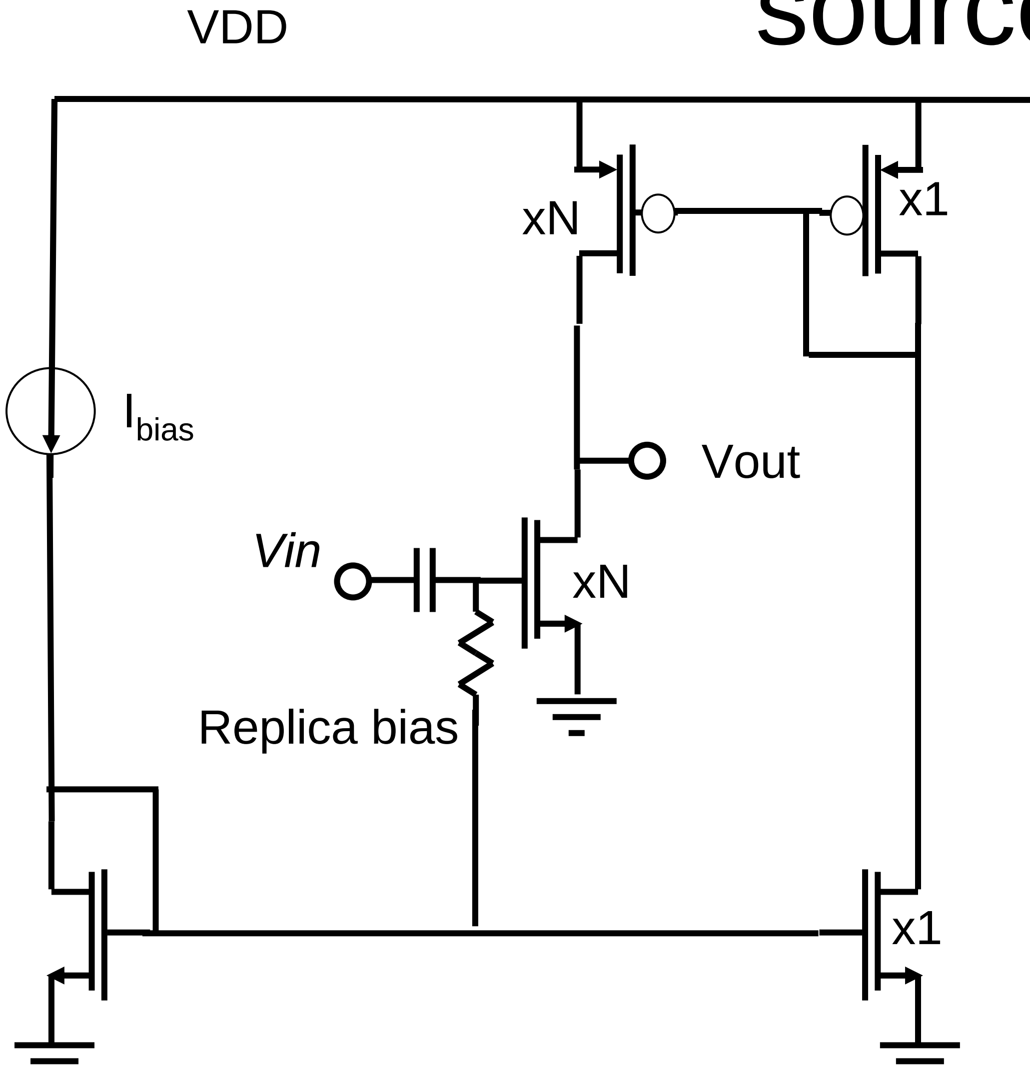
Much ado about current mirrors

Biasing limits gain for resistive loads



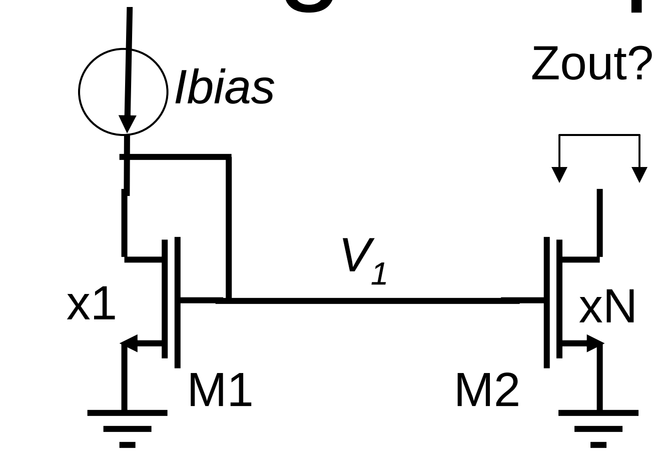
- R sets gain:
  - $Av = gmR_L$
  - $gm=2I_D/V_{od}$
  - $Av=2I_DR_L/V_{od}$
- But for saturation:
  - $I_DR_L<V_{DD}-V_{od}$
  - So $Av < 2V_{DD}/V_{od}-2$
- Example:
  - $V_{DD}=2.4V$
  - $V_{od}=0.2V$
  - $Av<22$

Using Current mirrors as active sources



- Replica bias sets Id = $N \cdot I_{bias}$
- PFET mirror set load
- $Av = gm_n(r_{on}||r_{op})$
- Bias: $V_{odn}+V_{odp}<V_{DD}$
- This is much easier to make high gain!
- Implies that mirror output impedance matters.

High-frequency analysis: Zout



- Start small signal

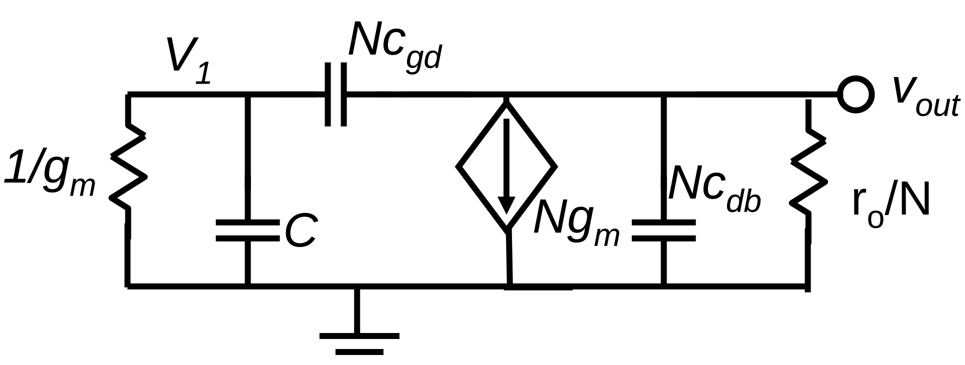
$$C = (1+N)C_{GS} + C_{DB}$$

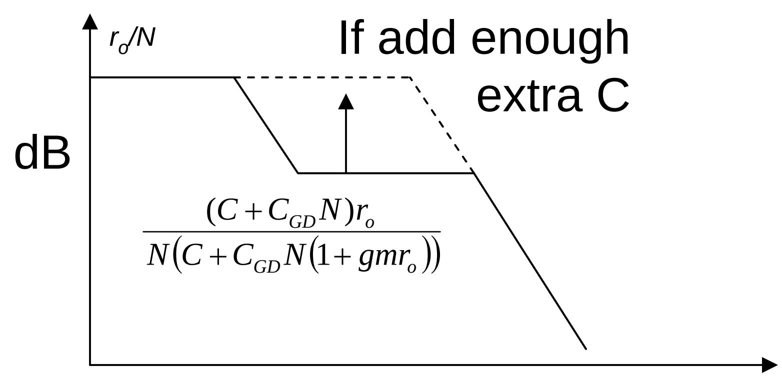
$$i_{out} = Nv_{out}\left(\frac{1}{r_o} + j\omega C_{DB}\right) + j\omega C_{GD}N\left(v_{out} - v_1\right) + v_1 Ngm$$

$$v_1 = v_{out}\,\frac{j\omega C_{GD}N}{gm + j\omega(C + C_{GD}N)}$$

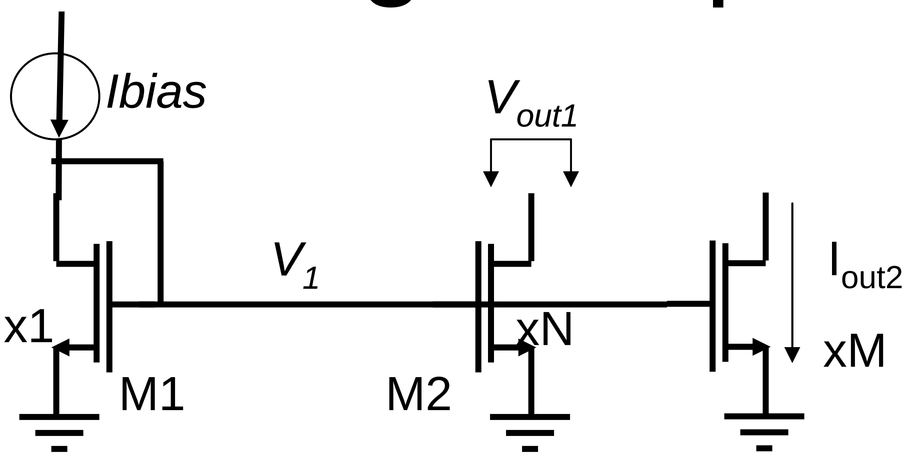
$$i_{out} = Nv_{out}\left(\frac{1}{r_o} + j\omega C_{DB} + j\omega C_{GD} + \frac{j\omega C_{GD}N\left(gm - j\omega C_{GD}\right)}{gm + j\omega(C + C_{GD}N)}\right)$$

$$Zout \approx \frac{gmr_o + j\omega(C + C_{GD}N)r_o}{N\left(gm + j\omega\left(C + C_{GD}N\left(1 + gmr_o\right)\right) - \omega^2\left(C + C_{GD}N\right)\left(C_{DB} + C_{GD}\right)r_o\right)}$$





High-frequency analysis

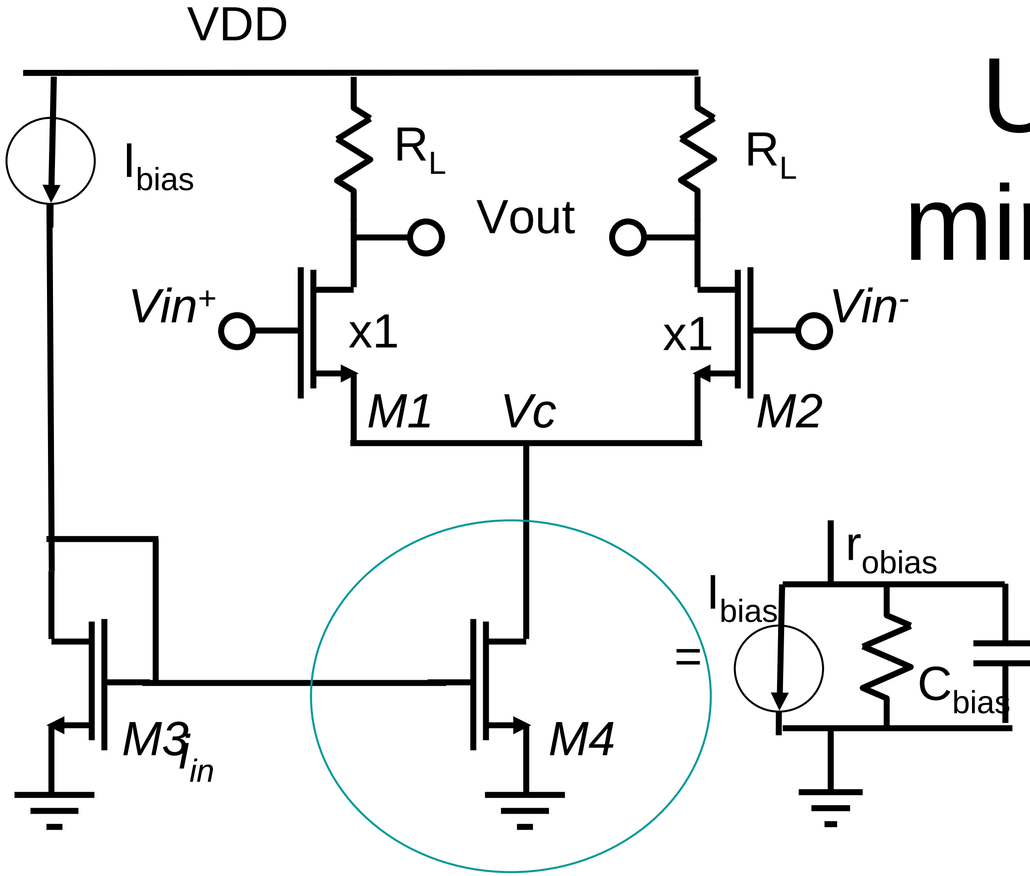


$$v_1 = v_{out1} \frac{j\omega C_{GD} N}{gm + j\omega(C + C_{GD} N)}$$

$$I_{out2} = Mgm \cdot v_1 = v_{out1} \frac{j\omega C_{GD} NM}{gm + j\omega(C + C_{GD} N)}$$

- Start small signal
- Can also get cross-talk
- All much better if add explicit Capacitor on gate
- Or if cascode everything (now need capacitor on cascode node)

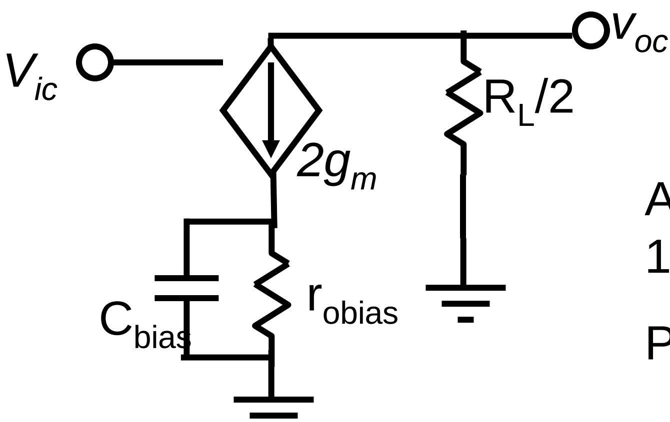
Using Current mirrors as biases



- This implies $Vc>V_{OD4}$
  - In general need to maintain headroom
- No effect on differential behavior:
  - Same half-circuit
- Affects common mode, however
  - Small signal
  - Low F: $Voc=Vic(g_mR_L/(1+2g_mr_{obias}))$
  - A_{VCM} = Voc/Vic ~ $R_L/2r_{obias}$
  - High F: replace r_{obias} with general Zc including ro, Cdb, and Csb of differential pair.

$$\frac{Voc}{Vic}=\frac{g_m R_L\left(1+j\omega r_{obias}C_{bias}\right)}{1+2g_m r_{obias}+j\omega r_{obias}C_{bias}}$$

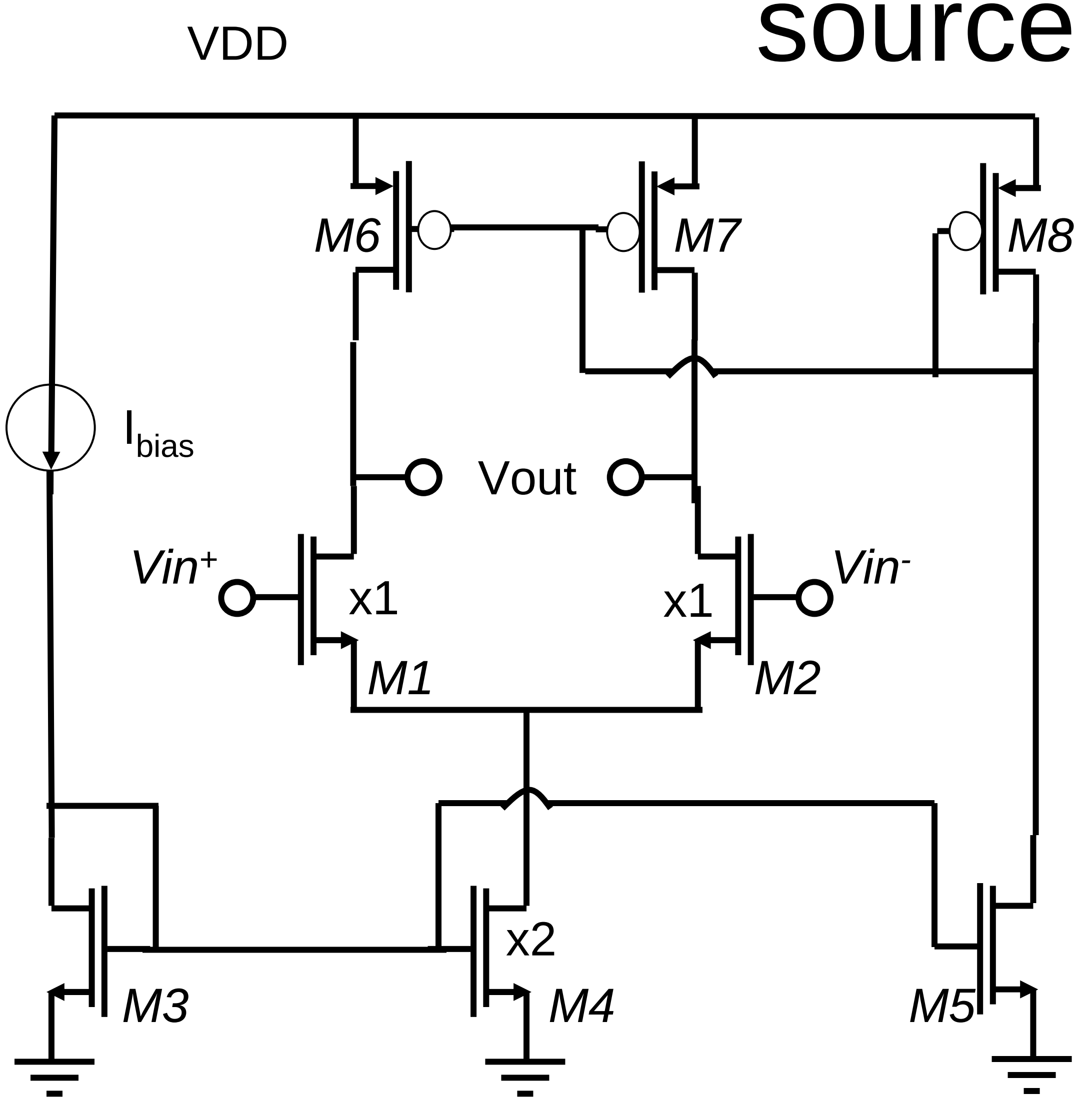
$$C_{bias}=C_{db4}+C_{sb1}+C_{sb2}$$



ACM: zero at $1/(r_{obias}C_{bias})$

Pole at $2gm/C_{bias}$

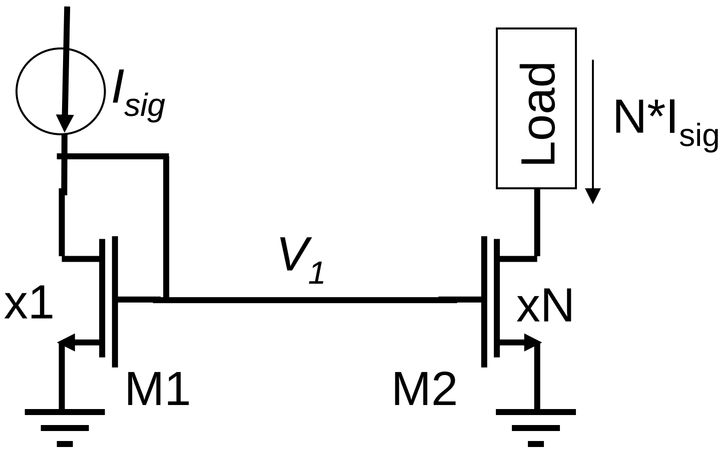
Using Current mirrors as active sources



- Use extra mirror (M6-M8) to source the current sunk by the diff. pair
- M6 and M7 act as load resistors ($R_L = r_{on}||r_{op}$)
- $A_{vdm} = gm_n(r_{on}||r_{op})$
- $A_{vcm} \sim (r_{on}||r_{op})/r_{obias}$

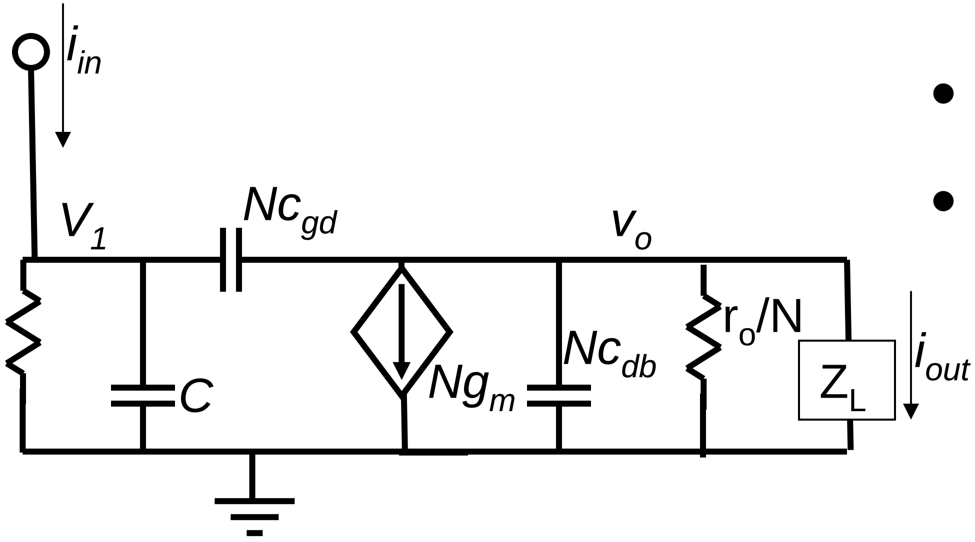
This is a sort of differential op amp (high gain)

Active mirror



- Mirror acts as current amplifier
  - Excellent dynamic range
  - Well defined gain (N)
  - Requires input always have one sign
- Can think of as:
  - a Common source amp
  - preceded by a pre-distorting load (the diode-connected device

Active mirror: HF



- Small signal model
- Model CS:

$$\frac{V_o}{V_1} = -Ng_m\left(Z_L \parallel \frac{r_o}{N}\right)\frac{1 - j\omega/z_{trans}}{1 + j\omega/p_{out}}$$

  - where

$$p_{out} = \frac{1}{\left(R_L \parallel \frac{r_o}{N}\right)\left(C_L + Nc_{db} + Nc_{gd}\right)} \quad z_{trans} = \frac{gm}{c_{gd}}$$

- Model input impedance

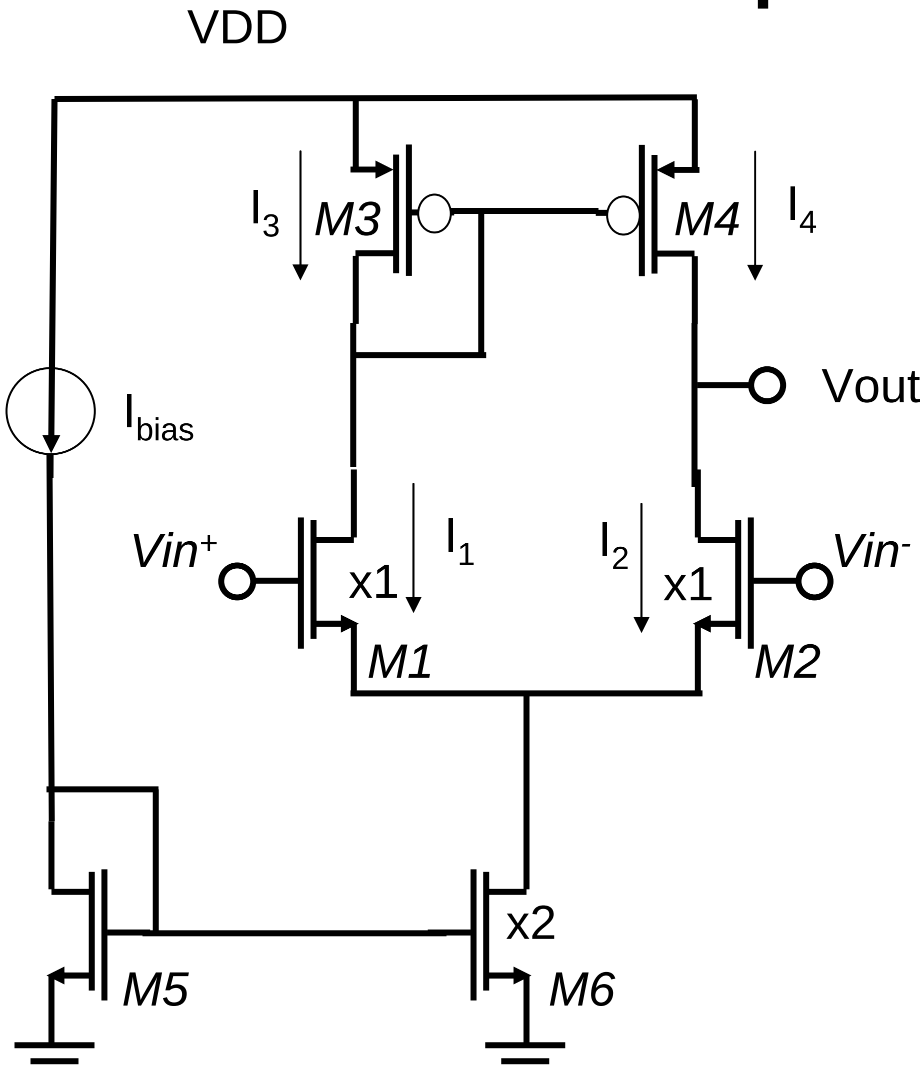
$$\frac{V_1}{i_{in}} = \frac{1}{g_m + j\omega C + j\omega NCgd(1-A)} = \frac{1}{g_m}\frac{1}{1 + j\omega/p_{in}}$$

$$p_{in} = {g_m}\Big/{C + NCgd(1-A)}$$

- Finally: $\frac{i_{out}}{V_0} = \frac{1}{Z_L}$

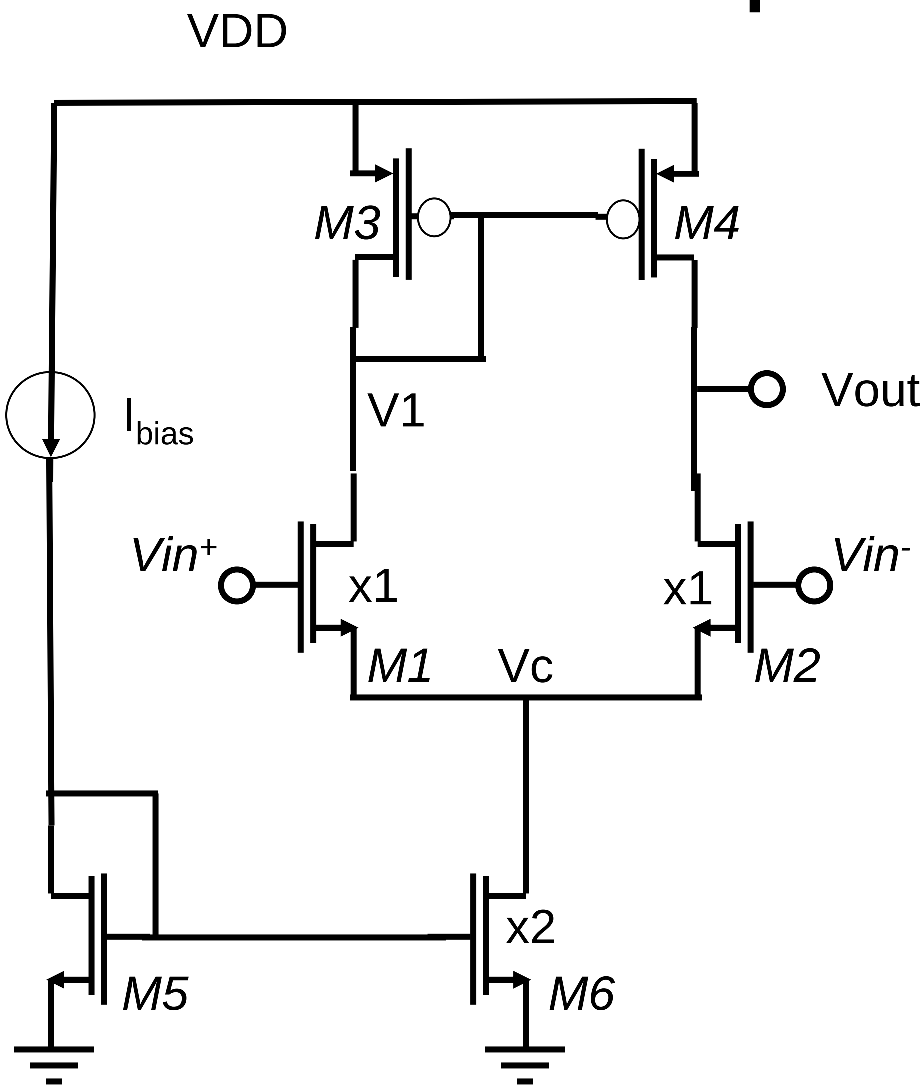
$$\frac{i_{out}}{i_{in}} = \frac{i_{out}}{V_o}\frac{V_o}{V_1}\frac{V_1}{i_{in}} = \frac{1}{Z_L}\left(-Ng_m\left(Z_L \parallel \frac{r_o}{N}\right)\frac{1 - j\omega/z_{trans}}{1 + j\omega/p_{out}}\right)\frac{1}{g_m}\frac{1}{1 + j\omega/p_{in}} = -N\frac{1 - j\omega/z_{trans}}{\left(1 + j\omega/p_{out}\right)\left(1 + j\omega/p_{in}\right)}\frac{r_o}{NZ_L + r_o}$$

Simple op-amp



- Uses PFET mirror to:
  - combine differential outputs as single-ended
  - $I1=I_{bias}+g_{mn}(V_{in}^{+}-V_{in}^{-})/2$
  - $I2=I_{bias}-g_{mn}(V_{in}^{+}-V_{in}^{-})/2$
  - I3=I1 (KCL)
  - I4=I3 (mirror)
- Iout = I4-I2
  - $Iout = g_{mn}(V_{in}^{+}-V_{in}^{-})$
- $Rout = (r_{on}||r_{op})$
- $A_{vdm}=g_{mn}(r_{on}||r_{op})$

Simple op-amp



- Claim:
  - Rout = (r_{on}||r_{op})
- Check:
  - Vary Vout,
  - set V_{in}^{+}-V_{in}^{-}=0,
  - check Iout

$$I_2 = -gmVc + \frac{Vout - Vc}{r_{on}}$$

$$I_1 = -gmVc + \frac{V_1 - Vc}{r_{on}} = \frac{Vc}{r_{ob}} - I_2$$

$$|Vout| >> |V_1|, gm >> \frac{1}{r_{ob}}, \frac{1}{r_{on}}$$

$$Vc \approx \frac{Vout}{2gmr_{on}}, I_2 = \frac{Vout}{2r_{on}} = -I_1 = -I_3$$

$$I4 = -\frac{Vout}{r_{op}} + I_3 = -\frac{Vout}{r_{op}} - \frac{Vout}{2r_{on}}$$

$$Iout = I4 - I2 = -\frac{Vout}{r_{op}} - \frac{Vout}{r_{on}} = -\frac{Vout}{r_{on} \| r_{op}}$$