Lecture 5

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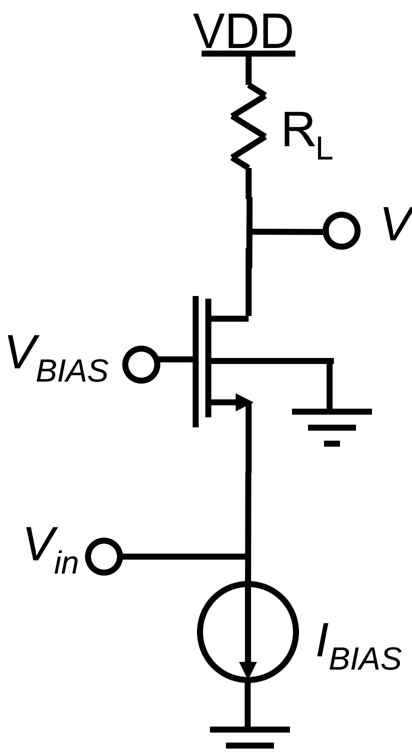
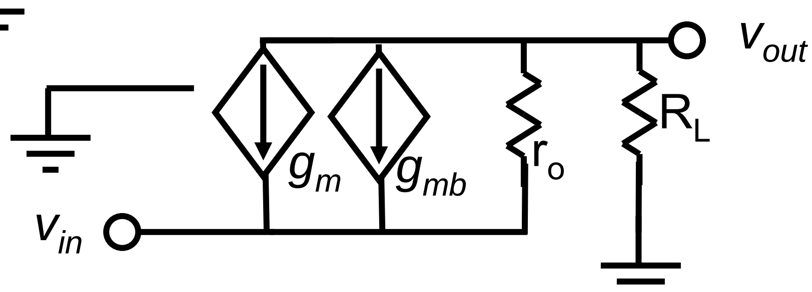
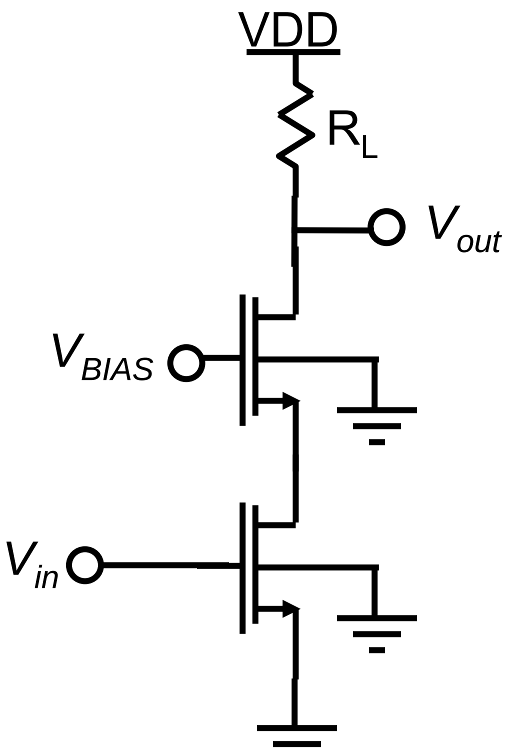
Common Gate Amplifier



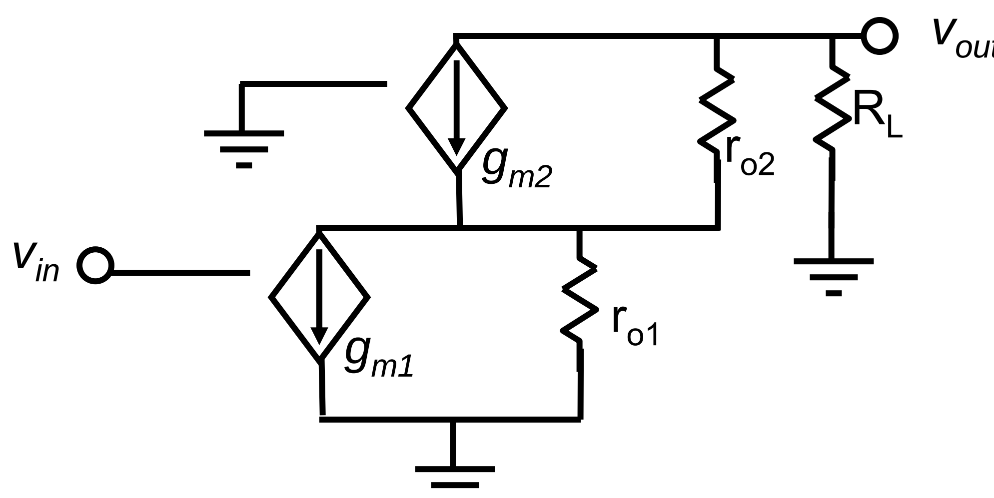
- Large signal (bias)
  - $V_{out} = VDD - R_L I_{BIAS}$
  - $V_{in} = V_{BIAS} - V_{GS} = V_{BIAS} - V_{TH} - (2I_D L)^{½}/(W\mu c_{ox})^{½}$
  - For saturation, $V_{BIAS} < VDD - R_L I_{BIAS} + V_{TH}$
- Small signal
  - Gain: $\frac{V_{out}}{V_{in}} = \frac{(g_m + g_{mb})r_o R_L + R_L}{r_o + R_L} \approx g_m (r_o \parallel R_L)$
  - Zout: $\frac{V_{out}}{I_{out}} = (r_o \parallel R_L)$
  - Zin: $\frac{V_{in}}{I_{in}} = \frac{1}{g_m + g_{mb} + \frac{1}{r_o} - g_m \frac{r_o \parallel R_L}{r_o}} \approx \frac{1}{g_m}$



Cascode amplifier



- Large signal (bias)
  - $I_{D1} = I_{D2} = W_1/L_1\mu c_{ox}/2(V_{in}-V_{TH})^2$
  - V_{out} = VDD-$R_L I_{D2}$
  - For M_2 saturation, V_{BIAS}<VDD-$R_L I_{D2}+V_{TH}$
  - For M_1 saturation, $V_{BIAS}>V_{TH}+V_{OD1}+V_{OD2}$



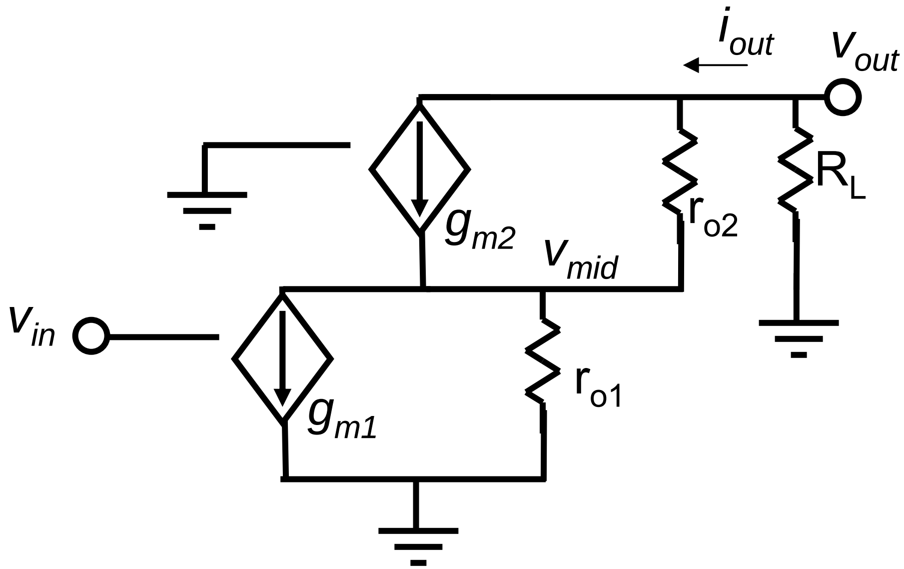
Cascode amplifier

- Want to find equivalent gm’, r_{out} for combined circuit
- Gm’ = i_{out}/v_{in} for $R_L = 0$
  - KCL for v_{mid}:

$$0 = v_{in} g_{m1} + \frac{v_{mid}}{r_{o1}} + \frac{v_{mid}}{r_{o2}} + v_{mid} g_{m2}$$

$$i_{out} = \frac{v_{mid}}{r_{o2}} + v_{mid} g_{m2} = v_{in} \frac{g_{m1} r_{o1}(1 + g_{m2} r_{o2})}{g_{m2} r_{o1} r_{o2} + r_{o1} + r_{o2}}$$

$$\boxed{g_m = \frac{g_{m1} r_{o1} r_{o2}(1 + g_{m2} r_{o2})}{g_{m2} r_{o1} r_{o2}^2 + r_{o1} r_{o2} + r_{o2}^2} \approx g_{m1}}$$



- $r_{out} = i_{out}/v_{out}$ for $v_{in} = 0$
  - KCL for v_{mid}:

$$0 = \frac{v_{mid}}{r_{o1}} + \frac{v_{mid} - v_{out}}{r_{o2}} + v_{mid} g_{m2}$$

$$I_{out} = \frac{v_{mid} - v_{out}}{r_{o2}} + v_{mid} g_{m2} = v_{out}\left(\frac{r_{o1}(1 + g_{m2} r_{o2})}{g_{m2} r_{o1} r_{o2}^2 + r_{o1} r_{o2} + r_{o2}^2} - \frac{1}{r_{o2}}\right)$$

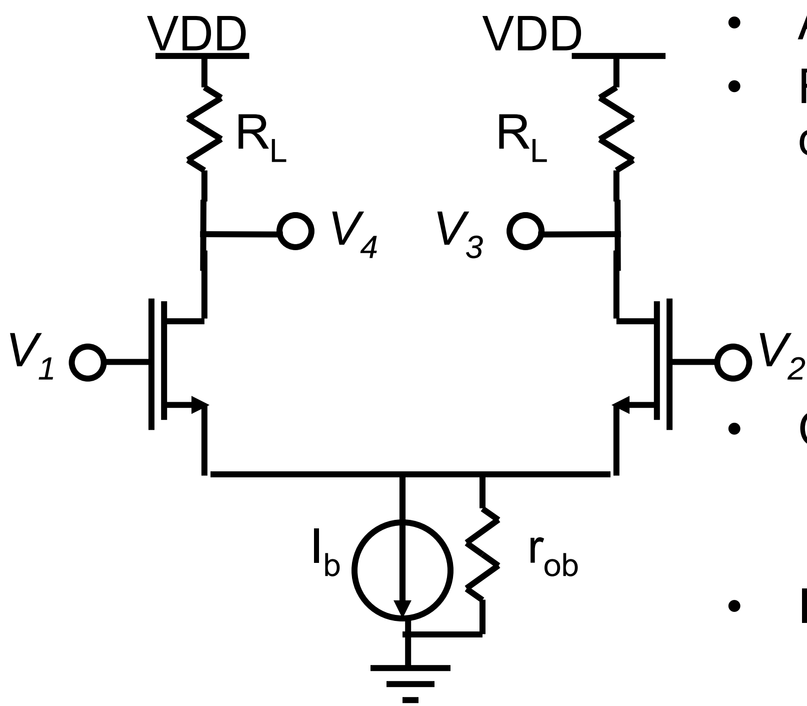
$$= v_{out}\left(\frac{r_{o1}(1 + g_{m2} r_{o2}) - (g_{m2} r_{o1} r_{o2} + r_{o1} + r_{o2})}{g_{m2} r_{o1} r_{o2}^2 + r_{o1} r_{o2} + r_{o2}^2}\right) = v_{out}\left(\frac{1}{g_{m2} r_{o1} r_{o2} + r_{o1} + r_{o2}}\right)$$

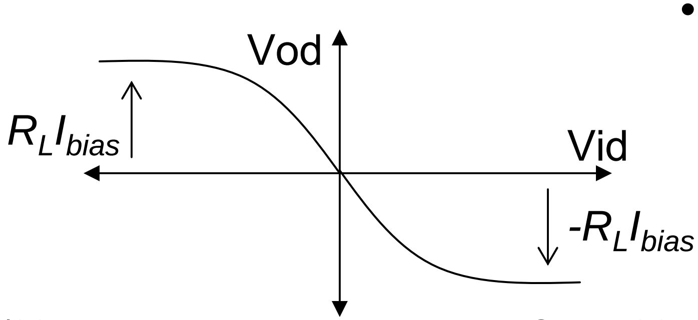
$$\boxed{r_{out} = \frac{v_{out}}{i_{out}} = g_{m2} r_{o1} r_{o2} + r_{o1} + r_{o2} \approx g_{m2} r_{o1} r_{o2}}$$

So, gain = $-g_m(r_{out}||R_L) \sim -g_{m1}((g_{m2} r_{o1} r_{o2})||R_L)$

Max gain = $-g_m r_{out} \sim -g_{m1} g_{m2} r_{o1} r_{o2}$

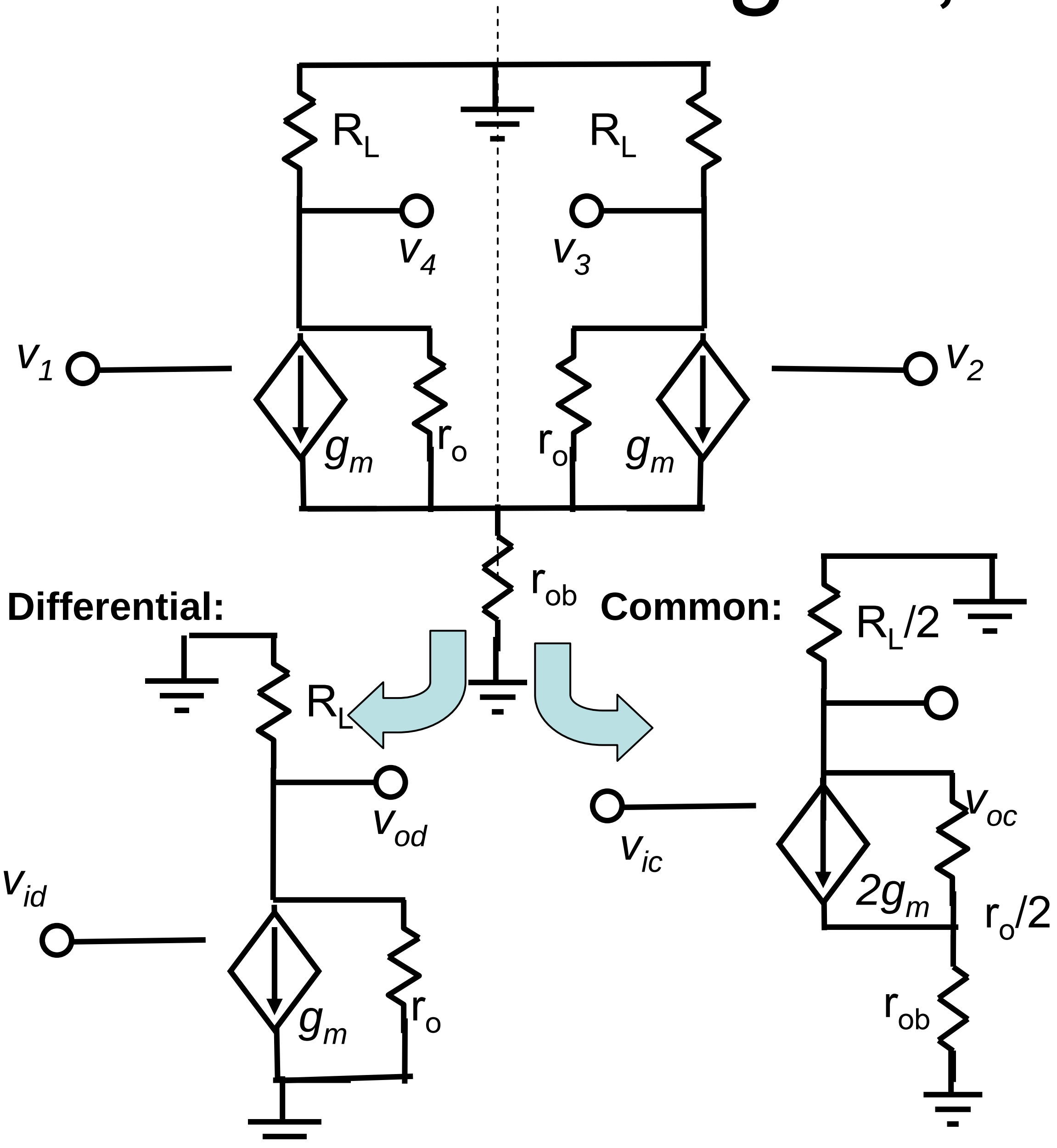
Differential pairs





- Assume the transistors are identical.
- Redefine inputs, outputs as differential, common mode:
  - Vid = V1-V2
  - Vic = (V1+V2)/2
  - Vod = V4-V3
  - Voc = (V4+V3)/2
- Can also do this for drain currents:
  - Idd=Id1-Id2
  - Idc=(Id1+Id2)/2=Ibias/2
- Implies output common mode~ constant:
  - Voc = VDD-R_LIbias/2
- To find Vod, solve for V_C too
  - $Ib=W/L\mu c_{ox}[(V_1-V_C-V_{TH})^2+(V_2-V_C-V_{TH})^2]$
  - $Vod = R_L \cdot W/L\mu c_{ox}[(V_1-V_C-V_{TH})^2-(V_2-V_C-V_{TH})^2]$

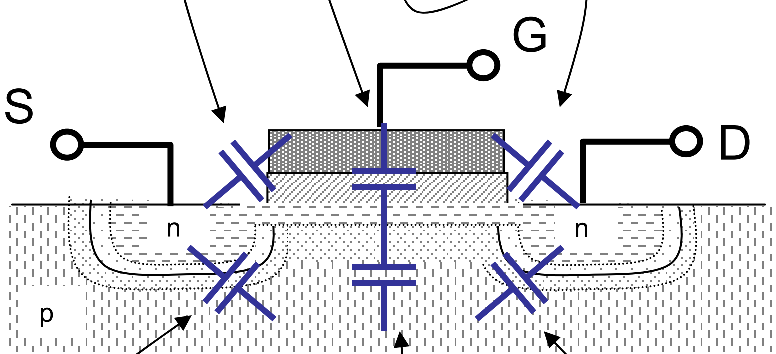
Small-Signal, Diff Pair



- Again define in terms of differential, common mode:
  - v_{id} = V1-V2
  - v_{ic} = (V1+V2)/2
  - v_{od} = V4-V3
  - v_{oc} = (V4+V3)/2
- Use half circuit analysis:
- Common mode, combine both sides in parallel
  - $v_{cs} \sim v_{ic}$ (if $2gm >> 1/r_{ob}$)
  - $i_b \sim v_{ic}/r_{ob}$, $v_{oc} = i_b R_L/2$
  - Gain: $A_c = v_{oc}/v_{ic} = R_L/2r_{ob}$
- Differential mode, insert “virtual grounds” at symmetry points
  - $A_d = v_{od}/v_{id} = (-gm(R_L||r_o))$
  - Differential mode just like a common-source amp!
- Common mode rejection:
  - $Ad/Ac \sim gm/2r_{ob}$

Accounting for device capacitance

$$C_{gch} = c_{ox} \cdot W \cdot L$$
$$C_{gs} = c_{ol} \cdot W$$
$$C_{gd} = c_{ol} \cdot W$$



$$C_{bch} = c_{depl} \cdot W \cdot L$$
$$C_{sb} = c_j\left(V_{SB}\right) \cdot W$$
$$C_{db} = c_j\left(V_{DB}\right) \cdot W$$

- Expect capacitance across oxide
  - from gate to channel:
  - to source
  - and to drain
- Expect depletion capacitance:
  - from bulk to channel,
  - to source
  - and to drain
- Where, c_{ox} is the unit oxide cap
  - c_{ox} = 4fF/μm^2-12fF/μm^2
- c_{ol} is the overlap capacitance
  - c_{ol} ~ 0.2fF/ μm
- c_{depl} is the unit depletion cap
  - c_{depl} ~ c_{ox}/5 (when in inversion)
- c_j is the reversed-biased junction cap
  - c_j(V) ~ 0.3fF/(1+V/0.7)$^{1/2}$

Complete small signal model

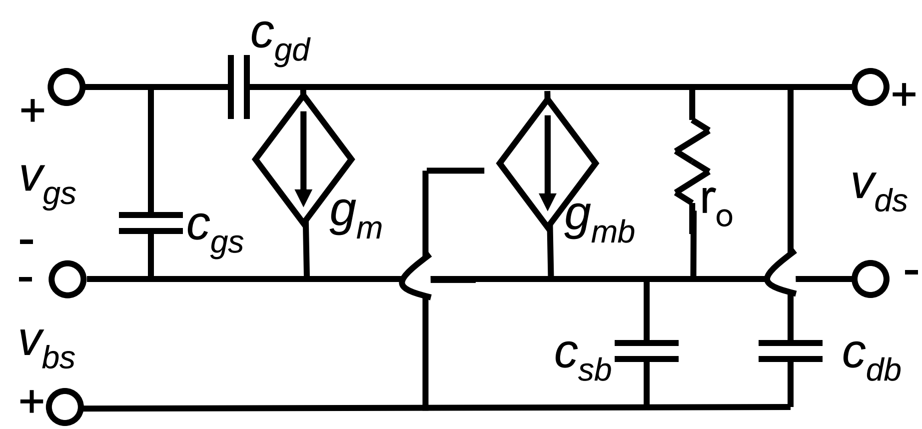
- Want to eliminate channel node:
  - Generally neglect c_{depl} unless in cut-off
- In triode ($V_{DS} = 0$)
  - Split C_{gch} between source, drain

$$c_{gs} = c_{ol} \cdot W + c_{ox} \cdot W \cdot L/2$$
$$c_{gd} = c_{ol} \cdot W + c_{ox} \cdot W \cdot L/2$$

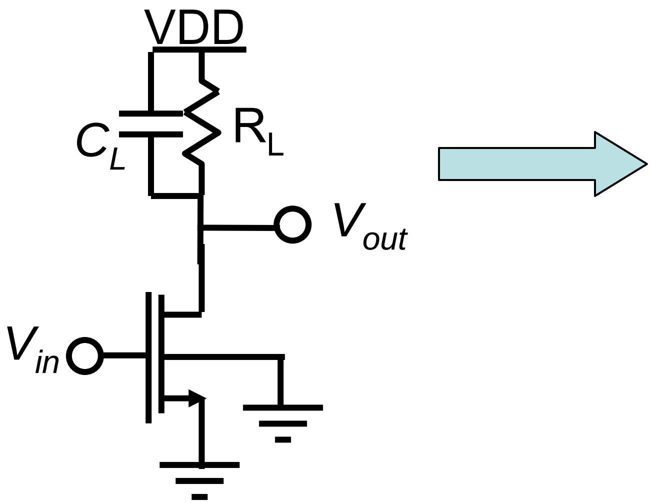
- In saturation
  - channel tied only to source,
  - but close to pinch off $V_{Gch} \rightarrow V_{TH}$ regardless of V_{GS}
  - So get partial coupling to source:

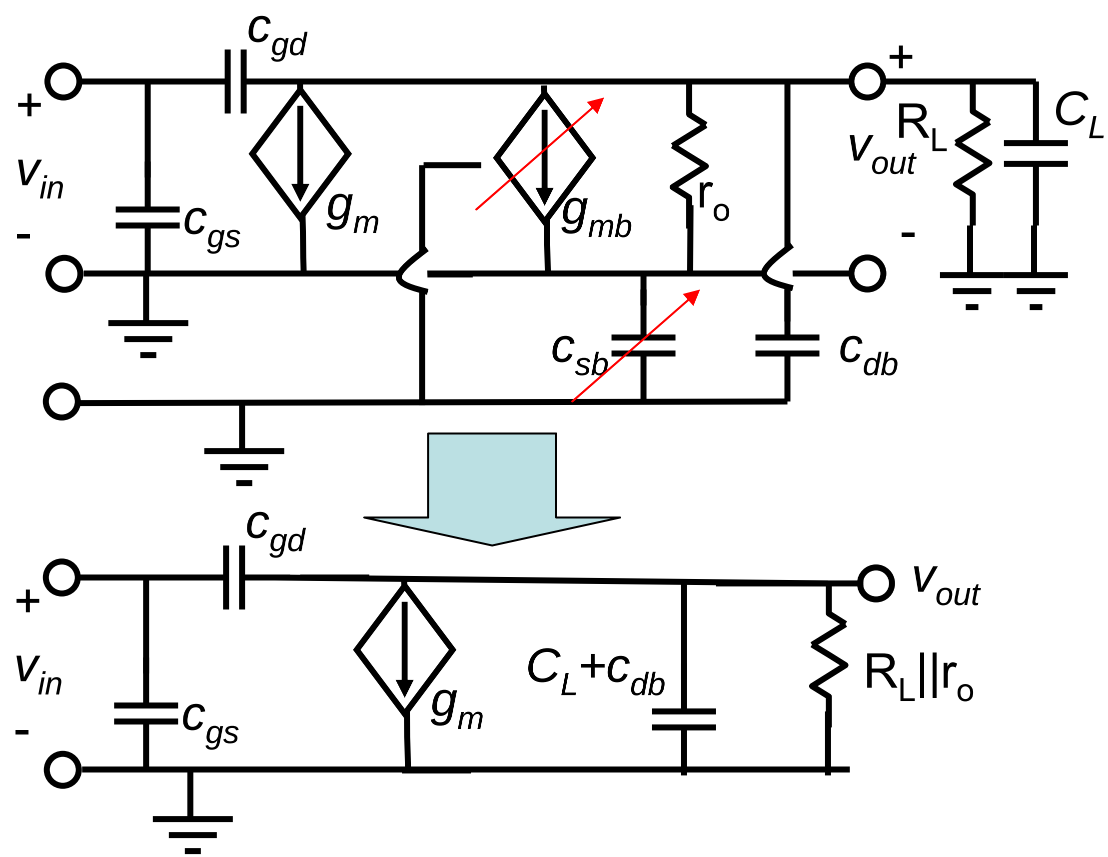
$$c_{gs} = c_{ol} \cdot W + c_{ox} \cdot W \cdot L \cdot 2/3$$
$$c_{gd} = c_{ol} \cdot W$$

- So get complete small signal model:



C.S. example





To find Zin, Zout, account for c_{gd} with Miller effect (or ignore it)

$$A \approx \frac{-g_m\left(\frac{R_L}{1+g_{ds}R_L}\right)}{1+j\omega(c_{db}+c_{gd})\left(\frac{R_L}{1+g_{ds}R_L}\right)} \approx \frac{-g_m R_L}{1+g_{ds}R_L+j\omega(c_{db}+c_{gd})R_L}$$

$$Zin = \frac{1}{j\omega(c_{gs}+(1-A)c_{gd})} \approx \frac{1}{j\omega(c_{gs}+(1+g_m R_L)c_{gd})}$$

$$Zout = \frac{\left(\frac{R_L}{1+g_{ds}R_L}\right)}{1+j\omega\left(c_{db}+\left(\frac{1-A}{-A}\right)c_{gd}\right)\left(\frac{R_L}{1+g_{ds}R_L}\right)} \approx \frac{R_L}{1+g_{ds}R_L+j\omega(c_{db}+c_{gd})R_L}$$