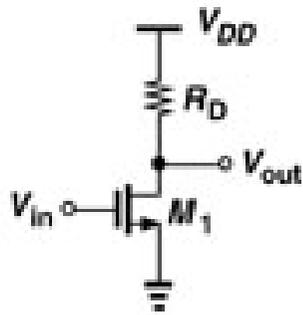


## Lecture 2

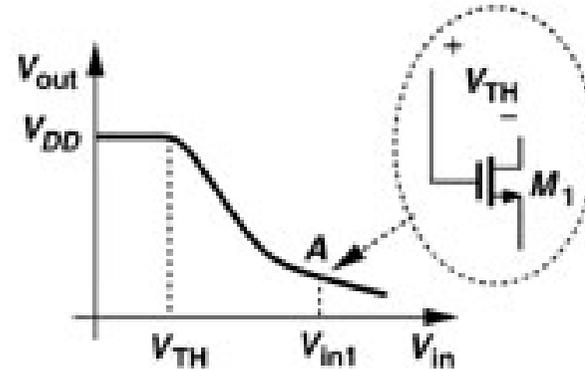
# IL2218 Analog electronics, advanced course

- Chapter 3      Single stage amplifiers
- CS-stage
  - different loadings
  - source degeneration
- CD-stage, source follower
- CG-stage
- Example 3.20a

# CS-stage, common source



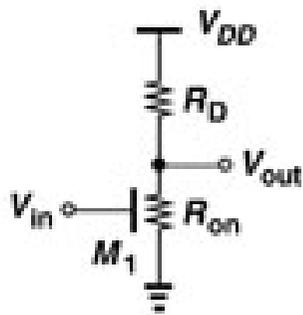
(a)



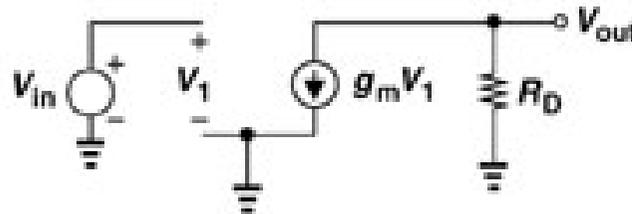
(b)

Saturation if

$$V_{DS} > V_{GS} - V_{TH}$$



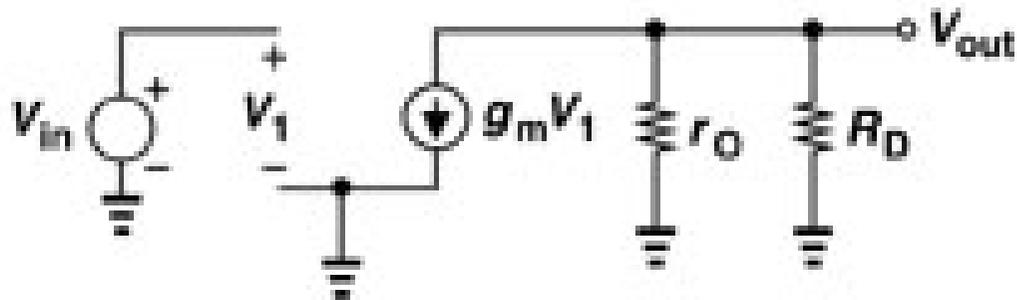
(c)



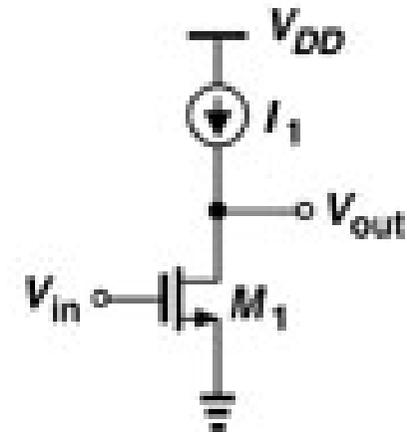
(d)

$$A_v = -g_m R_D$$

# CS - Intrinsic gain



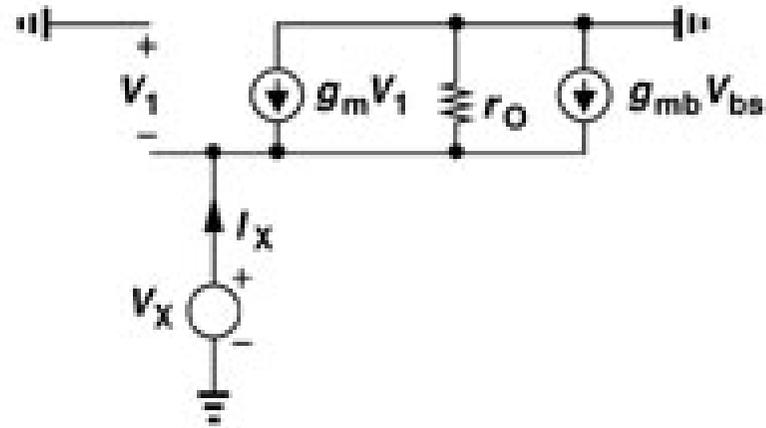
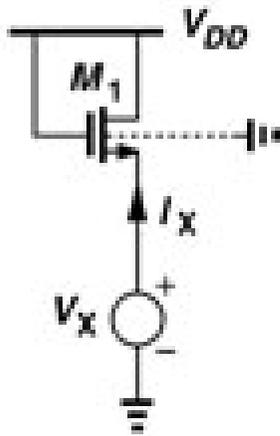
$$A_v = -g_m (r_o // R_D)$$



$$A_v = -g_m r_o$$

Intrinsic gain, max gain  
from one transistor

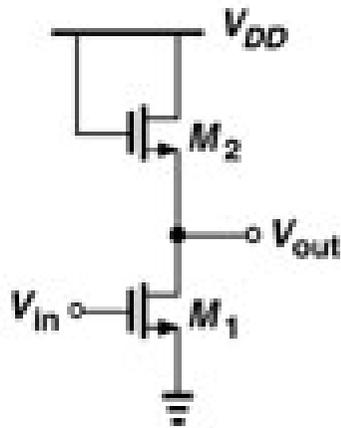
# CS – diode connected load



$$(g_m + g_{mb})V_x + \frac{V_x}{r_o} = I_x$$

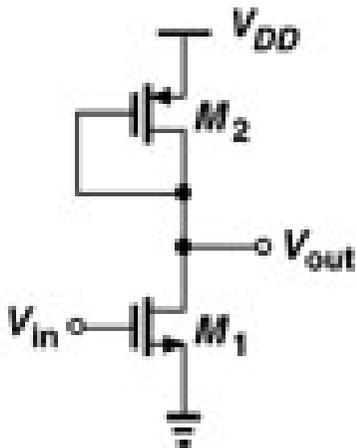
$$\frac{V_x}{I_x} = \frac{1}{g_m + g_{mb}} // r_o \approx \frac{1}{g_m + g_{mb}}$$

# CS – diode connected load



$$A_v = -g_{m1} \frac{1}{g_{m2} + g_{mb2}} = -\frac{g_{m1}}{g_{m2}} \frac{1}{1 + \eta}$$

$$A_v = -\sqrt{\frac{(W/L)_1}{(W/L)_2}} \frac{1}{1 + \eta}$$

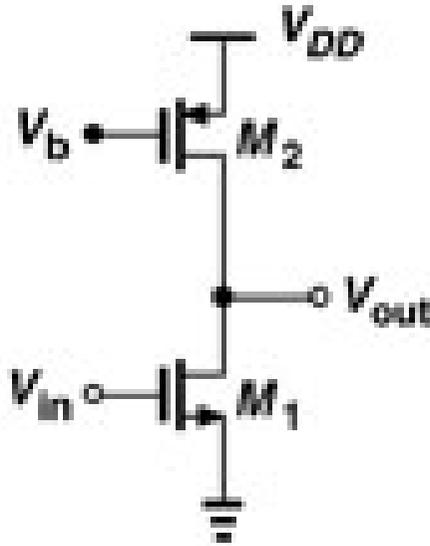


$$A_v = -\sqrt{\frac{\mu_n (W/L)_1}{\mu_p (W/L)_2}} = -\frac{|V_{GS2} - V_{TH2}|}{V_{GS1} - V_{TH1}}$$

Gain is independent of bias current!

High gain  $\Rightarrow$  Wide load transistor, limited output swing

# CS – current source load



$$A_v = -g_{m1} (r_{o1} // r_{o2})$$

Assuming  $r_{o2}$  large, intrinsic gain

$$A_v = -g_{m1} r_{o1} = \sqrt{2 \left( \frac{W}{L} \right)_1 \mu_n C_{ox} I_D} \cdot \frac{1}{\lambda I_D}$$

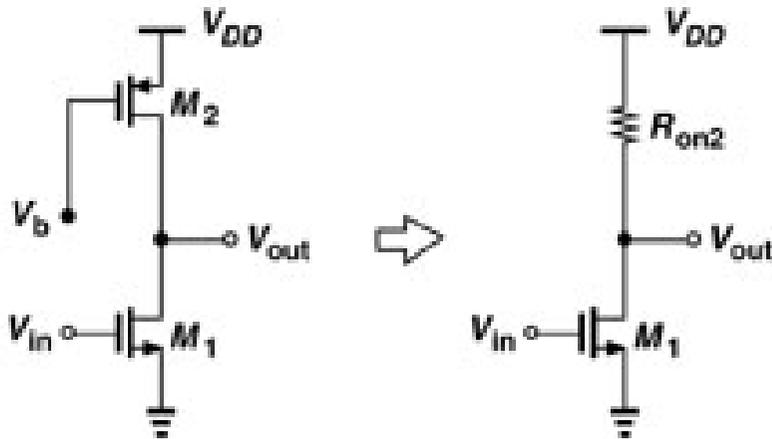
What happens with gain if

$L_1$  increases?

$L_2$  increases?

$I_D$  increases?

# CS – triode load

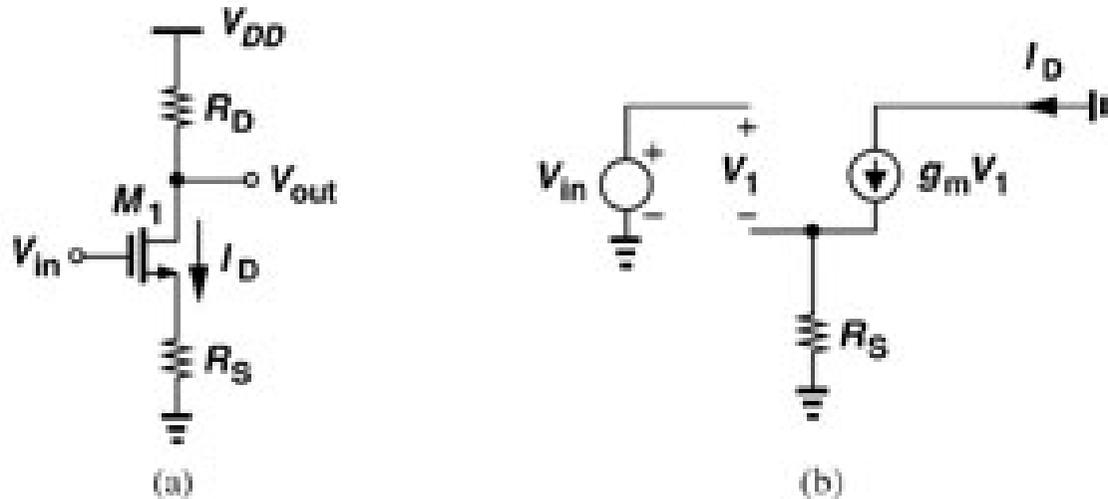


$$A_v = -g_m R_{ON2}$$

$$R_{ON2} = \frac{1}{\mu_n C_{ox} \left(\frac{W}{L}\right)_2 (V_{DD} - V_b - |V_{THP}|)}$$

Gain dependent on process parameters

# CS – source degeneration



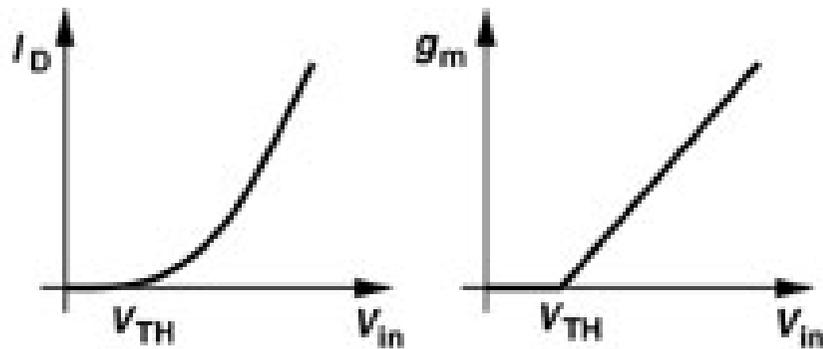
$$G_m = \frac{g_m}{1 + g_m R_S} \quad A_v = -G_m R_D \quad A_v = \frac{-g_m R_D}{1 + g_m R_S}$$

Feedback, increases linearity

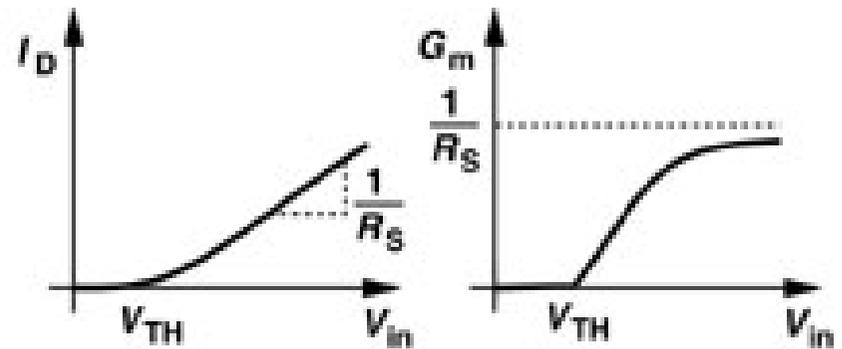
# CS – source degeneration



$$A_v = \frac{-g_m R_D}{1 + g_m R_S} = -\frac{R_D}{1/g_m + R_S}$$

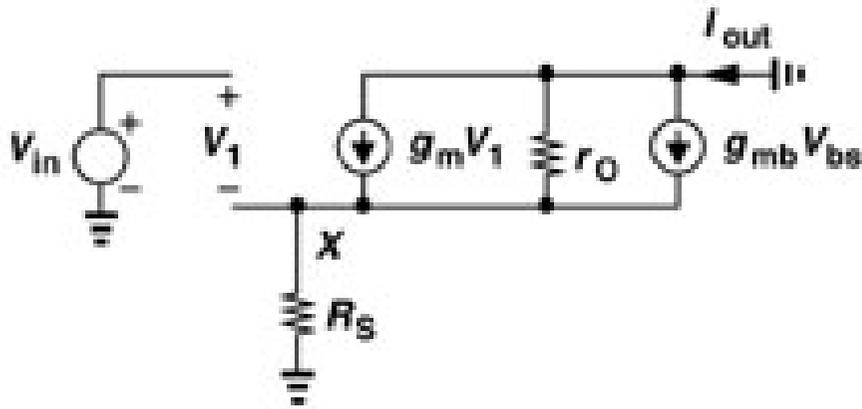


(a)



(b)

# CS – source degeneration including output resistance and body effect



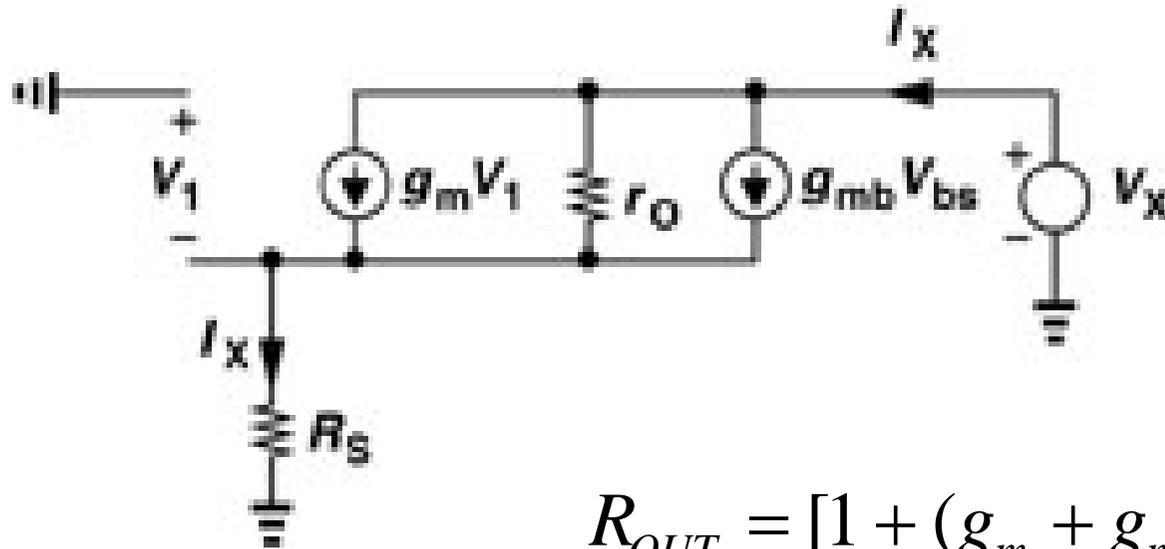
$$G_m = \frac{g_m r_o}{R_S + [1 + (g_m + g_{mb}) R_S] r_o}$$

$$G_m = \frac{g_m}{\frac{R_S}{r_o} + [1 + (g_m + g_{mb}) R_S]}$$

$$A_v = -G_m (R_D // R_{OUT})$$

$R_{OUT} ??$

# CS –output resistance

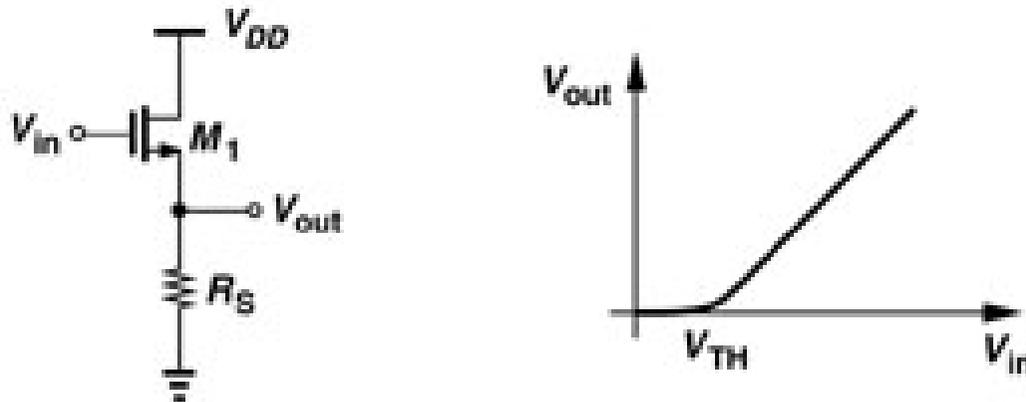


$$R_{OUT} = [1 + (g_m + g_{mb})r_o]R_S + r_o$$

$$R_{OUT} = r_o' \approx r_o [1 + (g_m + g_{mb})R_S]$$

$$A_v = -G_m R_D \parallel r_o'$$

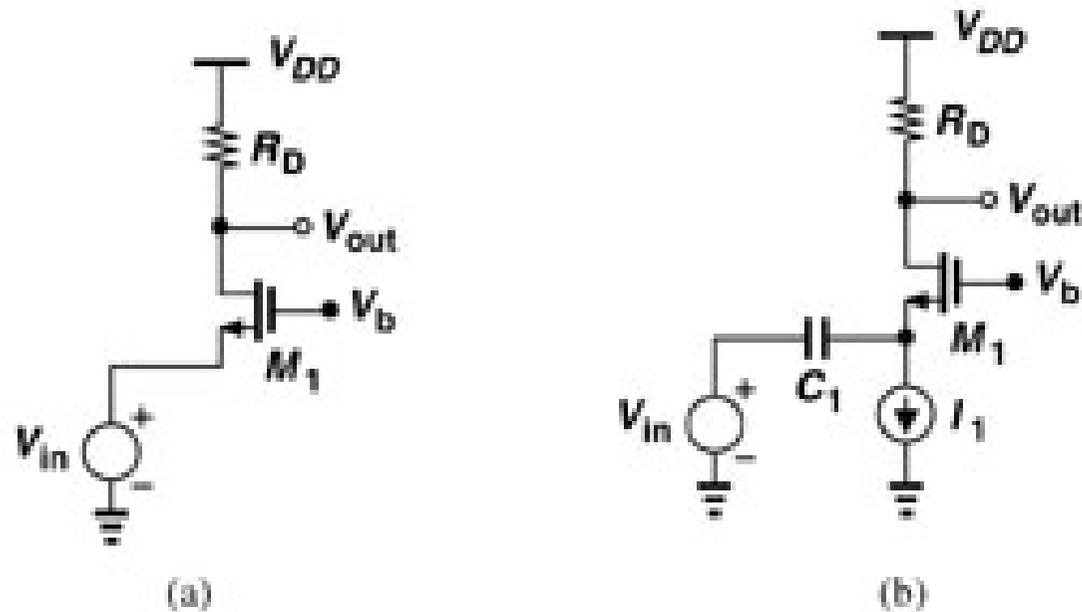
# CD – source follower, common drain



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

$$R_{out} = \frac{1}{g_m} // \frac{1}{g_{mb}} = \frac{1}{g_m + g_{mb}}$$

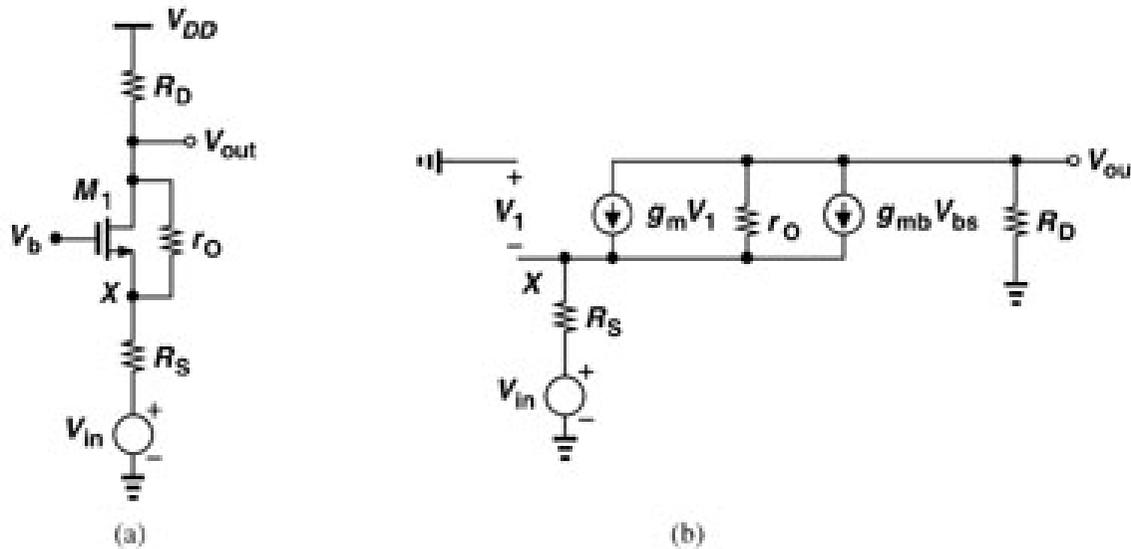
# CG – common gate



$$A_v = (g_m + g_{mb})R_D = g_m(1 + \eta)R_D$$

$$R_{out} = \{ [1 + (g_m + g_{mb})r_o]R_S + r_o \} // R_D$$

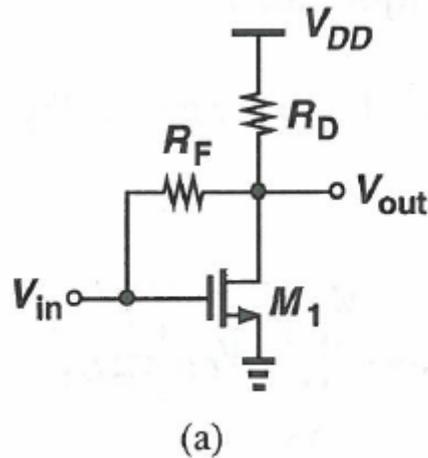
# CG – common gate



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

$$R_{in} = \frac{R_D + r_o}{1 + (g_m + g_{mb})r_o} \approx \frac{R_D}{(g_m + g_{mb})r_o} + \frac{1}{g_m + g_{mb}}$$

# Problem 3.20 a



Assuming MOSFET is in saturation, calculate the small signal gain.

$$\lambda \neq 0, \quad \gamma = 0$$

Solution handed out is an example how to do the documentation from your simulations in labs.