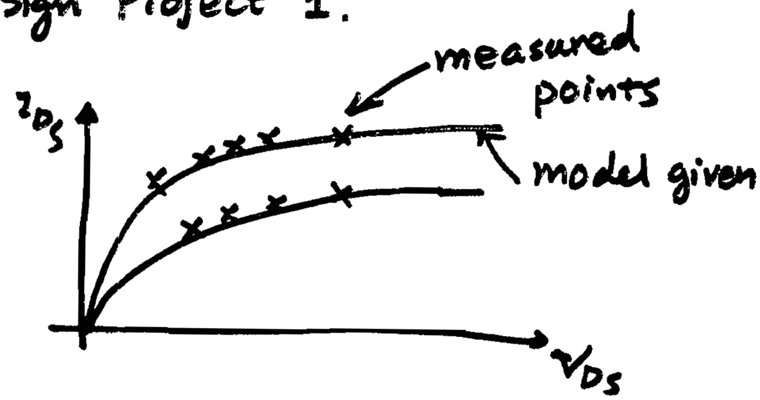
design Project 1.



level 1 : does not have subthreshold

level 2 : does.

Keep in mind. your measured points may be off from your model

This is the reason you have 10% off is fine!

The state of art is BSIM 5. 200 equations

you should also understand corners.

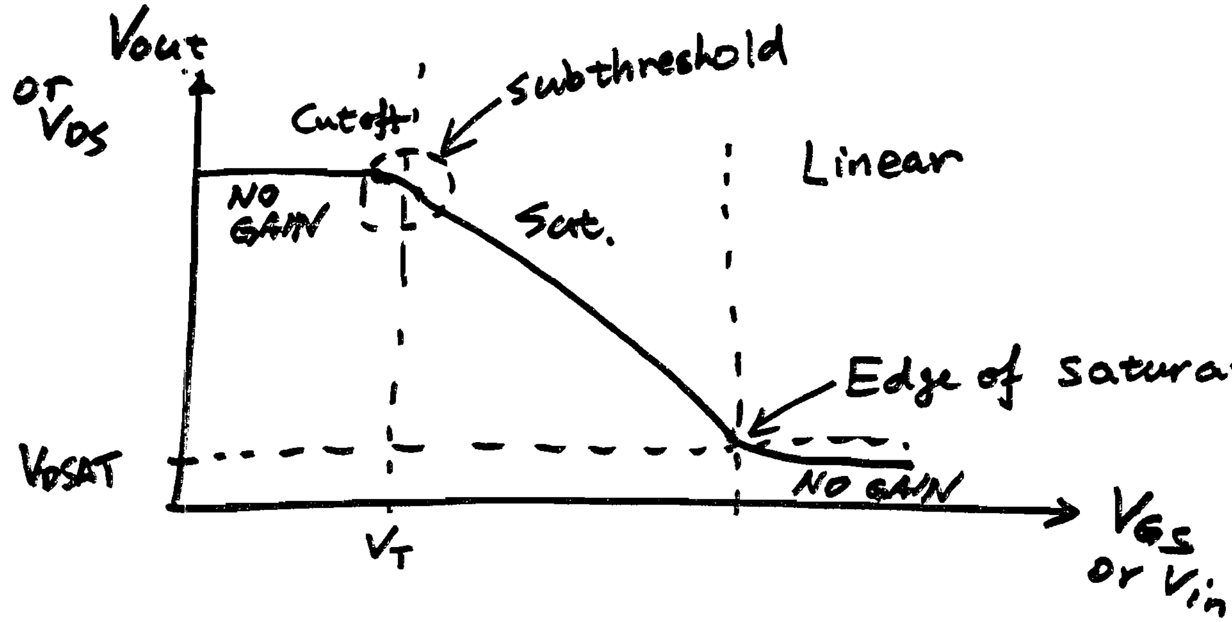
Common Source:

high Gain : $A_v = 100 \sim 1000$

(moderate gain : 5, 10

low gain : 1, 2 ...)

Rout : $\begin{cases} \text{High} : \text{10s of M}\Omega \\ \text{moderate Rout} : \text{10s of k}\Omega\text{, k}\Omega \\ \text{low Rout} : \text{10s }\Omega < 100\Omega \end{cases}$

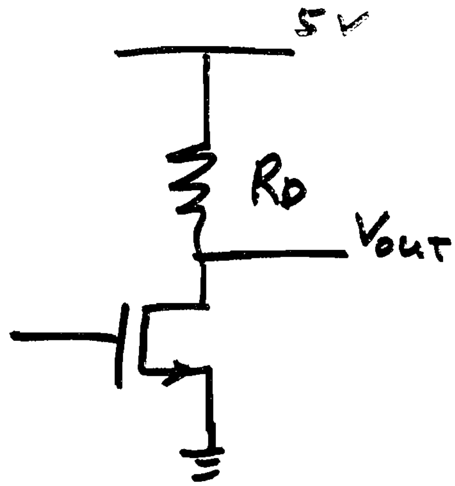


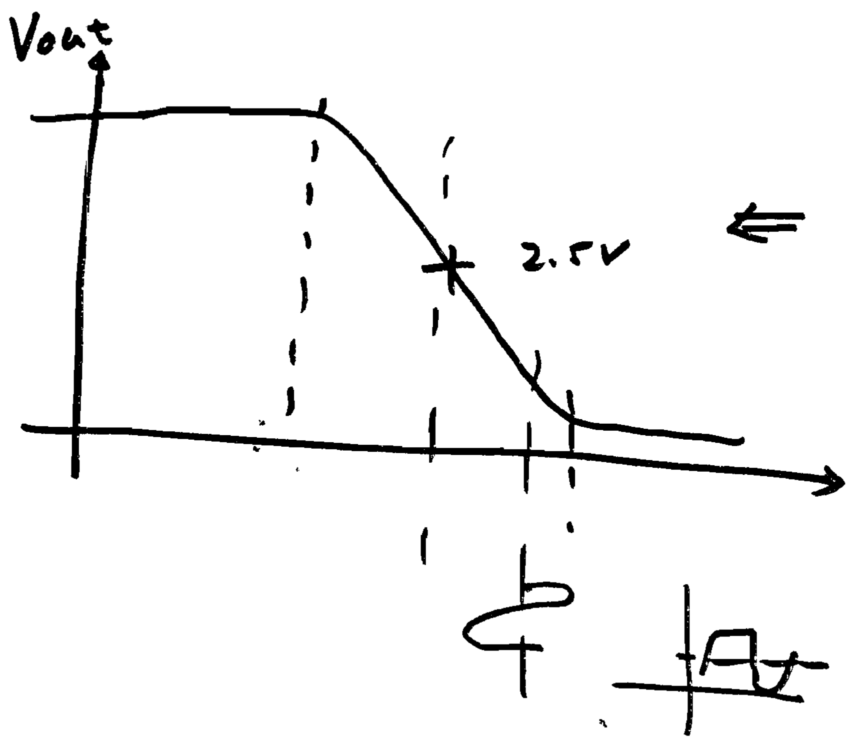
No Body effect $V_{SB}=0$

$V_{out} = V_{DD} - I_{DS} R_D$

$I_{DS} = 0$ at cutoff, $I_{DS}\uparrow$ $V_{DS}\downarrow$

$V_{DS} > V_{DSAT} = \left(\dfrac{2 I_{DS}}{k' \frac{W}{L}}\right)^{\frac{1}{2}}$





⇐ you put your DC bias point in the middle to avoid clipping

$R_D = 1k\Omega$

V_{out} wish to be 2.5V.

$\Rightarrow I_{DS} = \frac{2.5V}{1k\Omega} = 2.5mA$ ← you want I_{DS} to be this

$\Rightarrow V_{DSAT} = \left(\frac{2I_{DS}}{K'W/L}\right)^{\frac{1}{2}} \doteq 2.08\ V.$

$$\hookrightarrow I_{DS} = \frac{K'}{2}\frac{W}{L}(\underbrace{V_{in}-V_t}_{V_{DSAT}})^2(1+\underbrace{\overset{0.01}{\lambda}\,\overset{2.5V}{V_{DS}}}_{0.025} \le 10\% * 1V)$$

So you can forget $(1+\lambda V_{DS})$

$$\Rightarrow \quad I_{DS} \doteq \frac{k'}{2}\frac{W}{L}(\underbrace{V_{IN}-V_T}_{V_{DSAT}})^2$$

$$\Rightarrow \quad V_{DSAT} = \left(\frac{2 I_{DS}}{k'\frac{W}{L}}\right)^{1/2} = 3.08$$

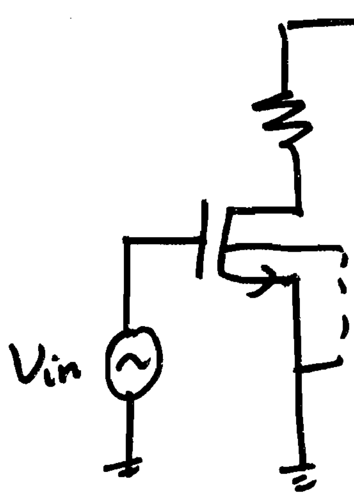
$$\Rightarrow \because V_{GS} - V_T = V_{DSAT}$$

$$\Rightarrow \quad V_{GS} = V_{DSAT} + V_T = 4.08\,V.$$

or $V_{in} = 4.08\,V.$

$\Rightarrow$ $V_{in} \doteq 4V$! it is possible

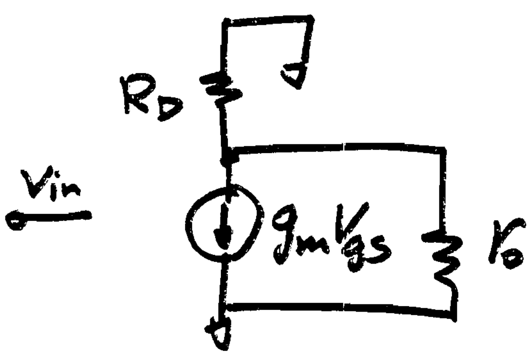
Small signal analysis:



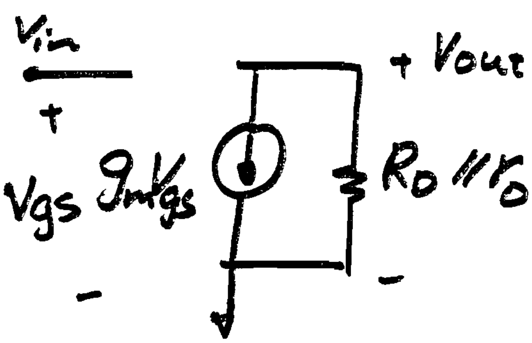
$V_{BS} = 0$

So: $g_m = \sqrt{2k' \frac{W}{L} I_{DS}}$

$\Rightarrow r_o = \frac{1}{\lambda I_{DS}} = \cdots$



$\Rightarrow$



$V_{gs} = V_{in}$

$V_{out} = -g_m V_{gs} \cdot R_D // r_o = -g_m (R_D // r_o) V_{in}$

$A_v = \frac{V_{out}}{V_{in}}$

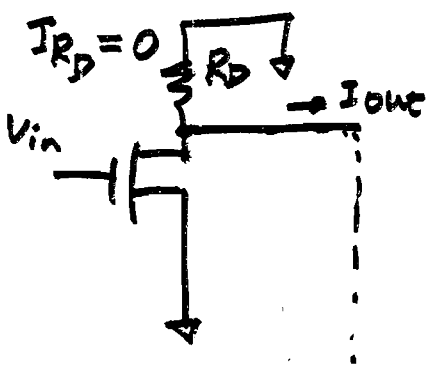
Lec# 3.

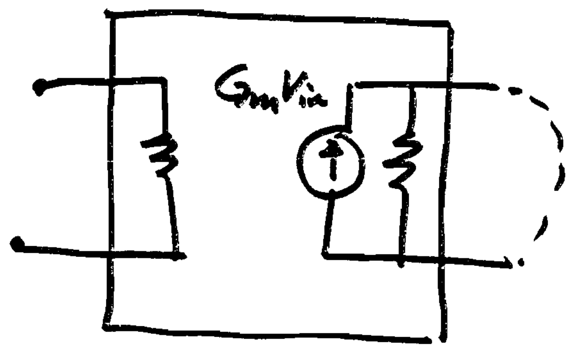
$r_o = 40K\Omega$, $R_D = 1K\Omega$

$R_D // r_o \doteq R_D$, $g_m \doteq 1.2 \times 10^{-3}$

$\Rightarrow A_v = 1.2$ too small Bad design

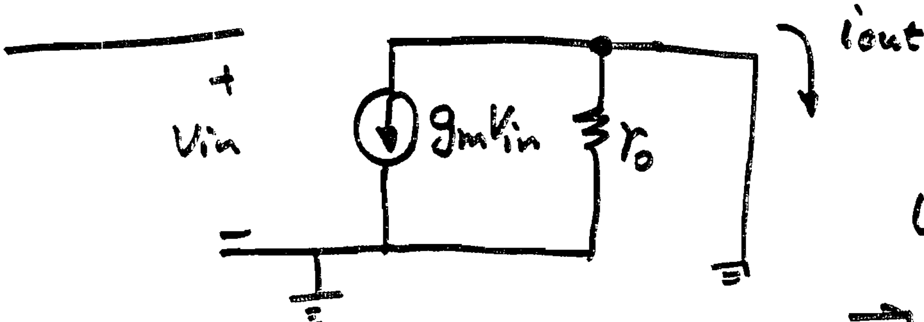
2-port and π-model
G_m vs. g_m





$I_{out} = G_m V_{in}$ short the output.

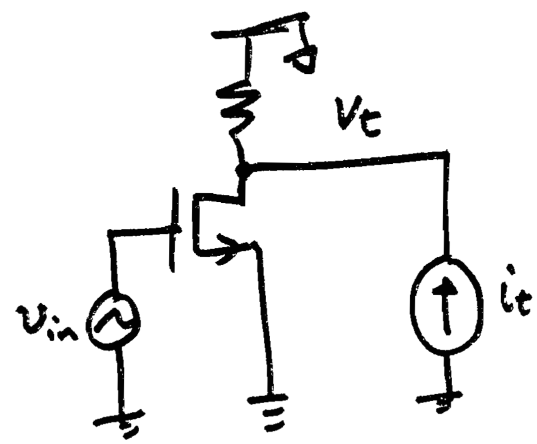
$$G_m = \frac{i_{out}}{v_{in}}\Big|_{v_{out}=0} = -g_m$$



$i_{out} = -g_m V_{in}$

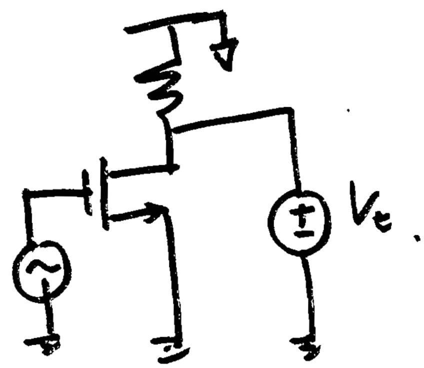
$\Rightarrow G_m = -g_m$

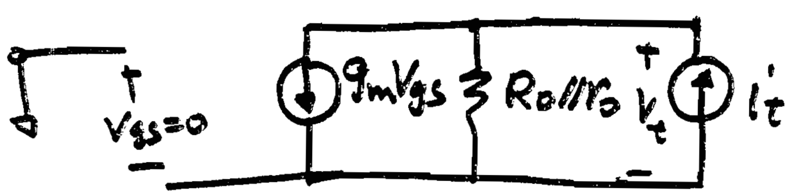
How to calculate R_{out}.



$$R_{out} = \frac{V_t}{i_t}\Bigg|_{\substack{\text{IND\_source}=0 \\ V_{in}=0}}$$

Ohm meter.

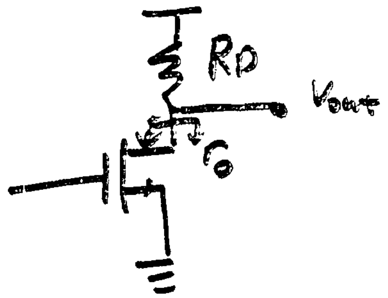




$$\Rightarrow R_{out} = \frac{V_t}{i_t} = R_D // r_o$$

You can do the same for R_{in}

$$\Rightarrow R_{in} = \infty$$



$$\boxed{\begin{aligned} G_m &= -g_m \\ R_{out} &= R_D \,/\!/\, r_o \\ R_{IN} &= \infty \\ A_v &= G_m R_{out} = -g_m (R_D \,/\!/\, r_o) \end{aligned}}$$

maximum Gain you can have

for CS: $A_v \overset{\text{if } R_D \gg r_o}{=} -g_m r_o \propto \frac{\sqrt{I_{DS}}}{I_{DS}} \sim \frac{1}{\sqrt{I_{DS}}}$

$I_{DS} \downarrow \Rightarrow A_v \uparrow$

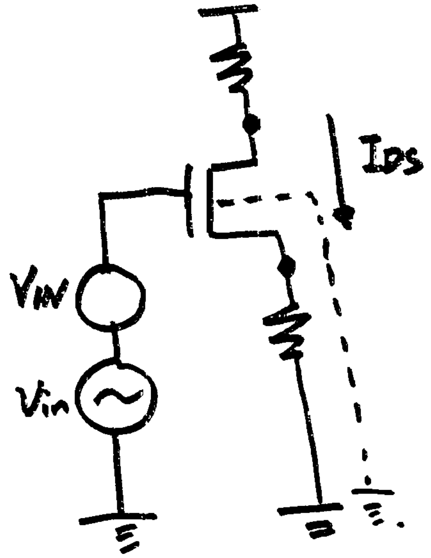
It causes r_o more dependant on I_{DS}

Not good!

bipolar is better! But CMOS cheap.

Lec # 3

DC analysis



$V_{DS} > V_{DSAT}$

boundary EOS (Edge of Saturation)

$\Rightarrow V_{DS} = V_{DSAT} \Rightarrow V_{DS} = V_{DD} - I_{DS}(R_D + R_S)$
$= V_{DSAT}$

$$\Rightarrow V_{DD} = V_{DSAT} + I_{DS}(R_D + R_S)$$

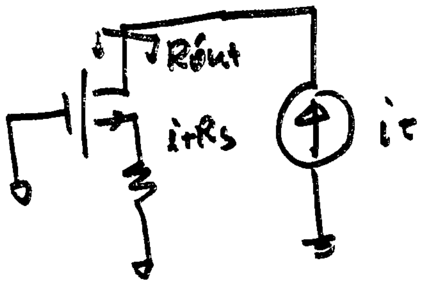
$\Rightarrow$ ~~V~~ EOS. $V_{IN,EOS}$

you want to set $V_{IN} = \frac{1}{2}(V_T + V_{IN,EOS})$

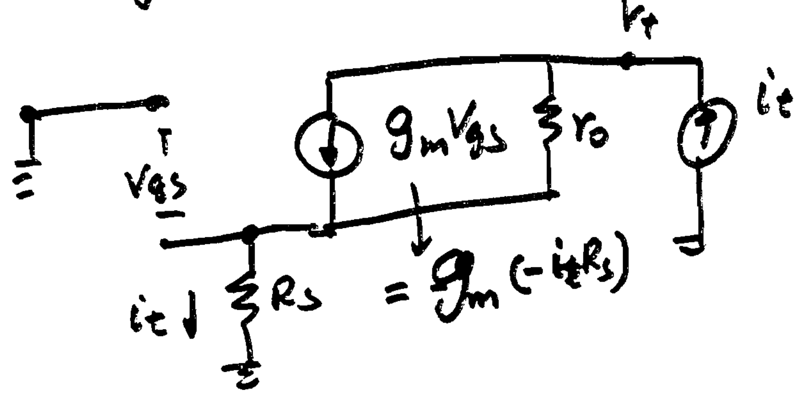
$$I_{DS} = \frac{1}{2} k' \frac{W}{L} (\underbrace{V_{GS}}_{V_{IN}} - V_T)^2 (\cdots)$$

$\Rightarrow I_{DS}$. at DC.

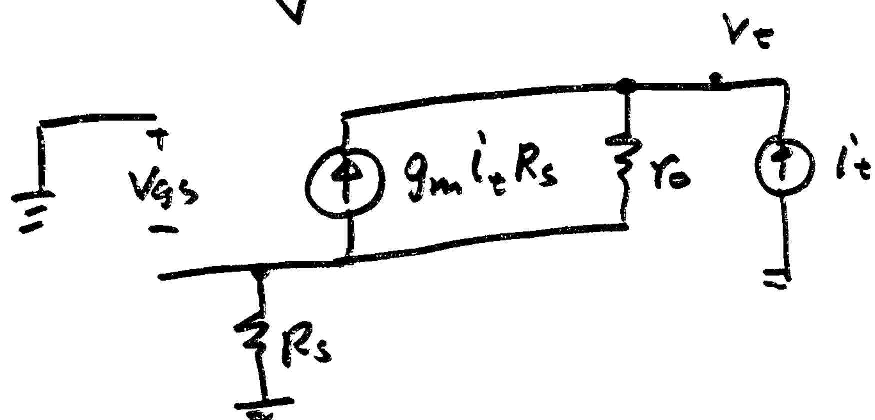
Now small signal analysis



$V_{gs} \neq 0 \Rightarrow V_g = 0$
$V_s \neq 0$



$\Downarrow$



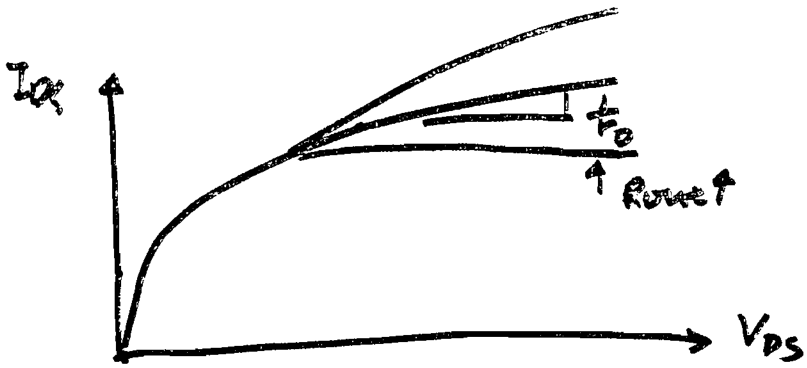
① This voltage at source pumps current to drain!

② $V_t = V_{R_s} + V_{r_o} = i_t R_s + i_t g_m R_s r_o = i_t(R_s + g_m R_s r_o)$

$\Rightarrow V_t = i_t(R_s + g_m R_s r_o)$

Effectively, because of ①, you see a jump increase in Rout! you improve Rout, why?

Lec# 3. SP.11

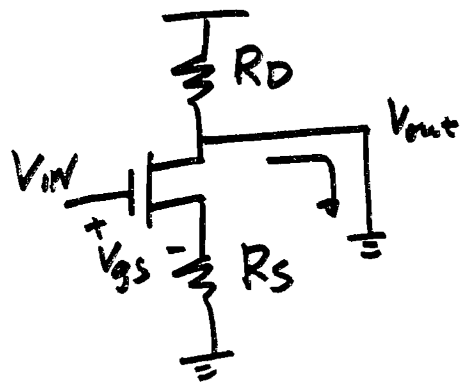


you can make it more like current source!

$$R_{out} = R_s + r_o[1+g_m(1+\chi)R_s] \,//\, R_D \;!!!$$

$$A_v = G_m R_{out}$$

$$G_m = ?$$



$$G_m = \frac{i_{out}}{V_{in}}$$

$$i_{ds} = g_m V_{gs} \quad = -i_{out}$$

$$V_{R_s} = g_m R_s V_{gs}$$

$$V_{gs} = V_{in} - g_m R_s V_{gs}$$

$$V_{gs}(1+g_m R_s) = V_{in}$$

$$\Rightarrow \quad V_{gs} = \frac{V_{in}}{1+g_m R_s}$$

$$\Rightarrow \boxed{G_m = \frac{-g_m}{1+g_m R_s}}$$

$r_o >> R_s$

$$R'_{out} \doteq r_o[1+\underbrace{g_m(1+\chi)R_s}_{>>1}] \doteq g_m(1+\chi)R_s r_o$$

$$A_v = G_m R_{out} = \frac{-g_m}{1+g_m R_s}\left(R_D \,//\, g_m(1+\chi)R_s r_o\right)$$

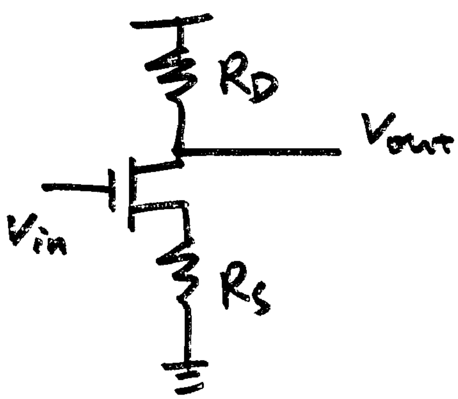
if $R_D << g_m R_s r_o$

(if R_D too big, you have big voltage drop)

$$A_v \doteq \frac{-g_m R_D}{1+g_m R_s} \doteq -\frac{R_D}{R_s}$$

$$\boxed{A_v \doteq -\frac{R_D}{R_s}}$$

very popular case

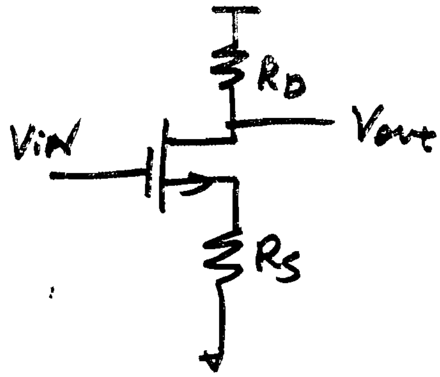


if well designed

$$A_v \doteq -\frac{R_D}{R_s}$$

① $g_m(1+\chi)R_s >> 1$ NO g_m

② $R_D << g_m R_s r_o$



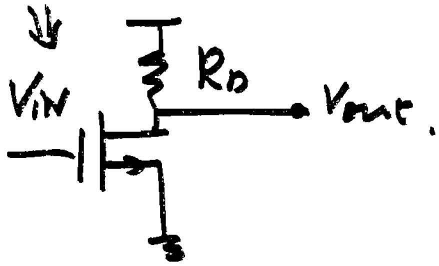
under

$g_m(1+\chi)R_s >> 1$

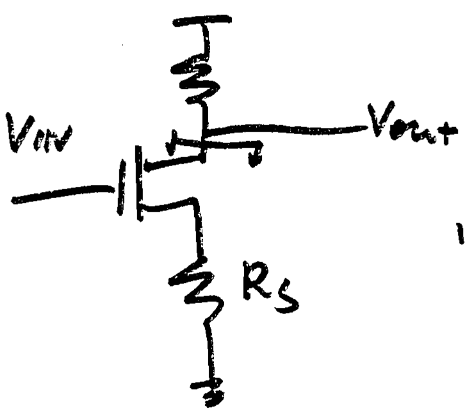
if $R_D << g_m R_s r_o$, $A_v \doteq \frac{R_D}{R_s}$

if $R_D >> g_m R_s r_o$ $A_v \doteq -g_m r_o$

⇓



☆ one Important Item

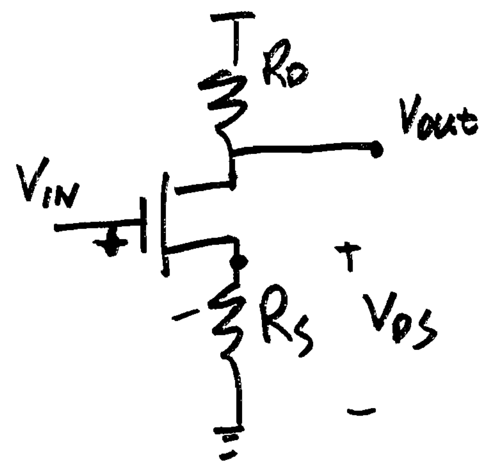


if you have R_s,

R'_{out} ↑ by $g_m(1+\chi)R_s$

$R'_{out} \doteq g_m(1+\chi)R_s r_o$.

Large signal



$$I_{DS} = \frac{V_{DD} - V_{out}}{R_D} \quad V_{out} = \frac{V_{DD}}{2}$$ ✓

✓ $V_S = V_{R_S} = I_{DS} R_S$

$I_{DS} \Rightarrow V_{DSAT}$.

$$V_{IN} - V_T = V_{DSAT} \Rightarrow V_{IN} = V_T + V_{DSAT}$$

$$V_{DS} = V_{out} - V_{R_S}$$

$$V_{DSAT} \Big| I_{DS} = \frac{V_{DD} - \overset{\frac{1}{2}V_{DD}}{V_{out}}}{R_D} = \frac{V_{DD} - (V_{DS} + V_{R_S})}{R_D}$$

$$\cancel{V_{out} \doteq A_V \cdot V_{IN} = \frac{R_D}{R_S} \cdot (V_{DSAT} + V_T)}$$

$$\cancel{\propto \frac{R_D}{R_S} \cdot \frac{V_{DD} - V_{out}}{R_D}}$$

$$\cancel{= \frac{1}{R_S} (V_{DD} - (V_{DS} + V_{R_S}))}$$

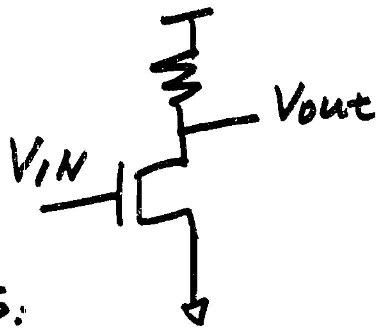
$$V_{out} \doteq \frac{V_{DD}}{2} \Rightarrow I_{DS} \Rightarrow V_{DSAT} \Rightarrow V_{IN}.$$

you put R_S there, It is easy (easier) to put transistor to sat region!

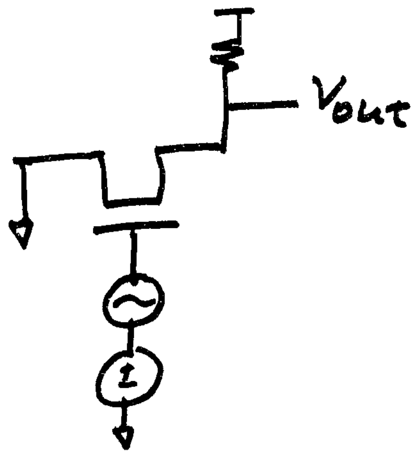
($I_{DS} \downarrow \Rightarrow V_{DSAT} \downarrow . \Rightarrow V_{IN} = V_T + V_{DSAT}$.

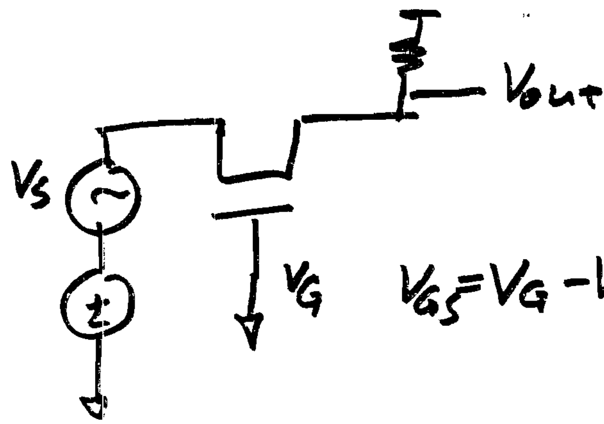
Common gate

CS:



$\Rightarrow$



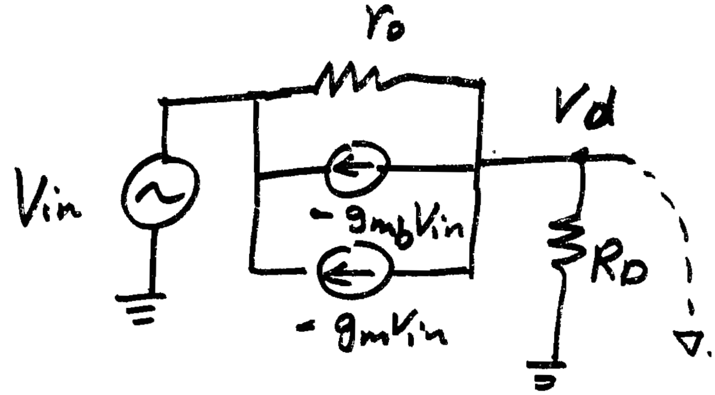


$V_{GS} = V_G - V_S = -V_{IN}$

non-inverting

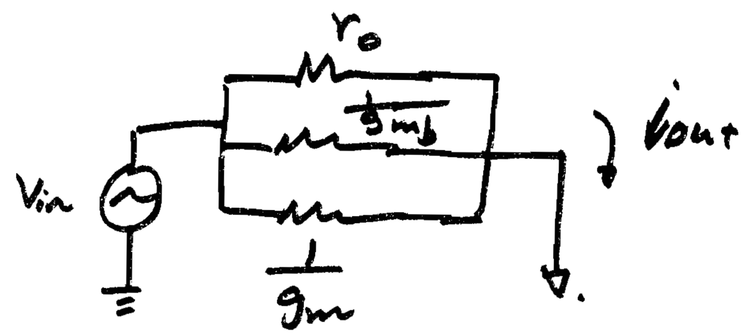
Your DC analysis the same!

Small signal analysis. $\longrightarrow$ body effect!



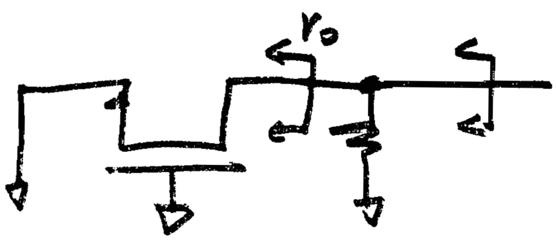
$V_{gs} = -V_{in}$

$G_m = ?$



$$G_m = \frac{i_{out}}{V_{in}} = r_o \parallel \frac{1}{g_{mb}} \parallel \frac{1}{g_m} = \cancel{\frac{1}{r_o}} + g_m(1+\chi)$$

Here is the Rare case where g_{mb} help G_m.



$R_{out} = r_o \parallel R_D$

$A_v = G_m R_{out}$

$= g_m(1+\chi)(r_o \parallel R_D)$

same as CS.

What is Rin ?

$$i_t + \frac{V_t - V_{OUT}}{r_o}\ g_m (1+\chi) V_t = 0$$

$$V_{OUT} = i_t R_D$$

$$\frac{v_t}{i_t} = R_{in} = \frac{r_o + R_D}{\cancel{1+}(1+\chi)\, g_m r_o}$$

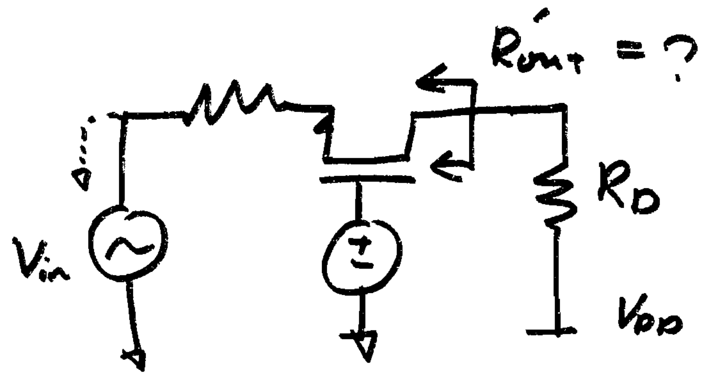
too small.

$$R_{in} = \frac{r_o + R_D}{(1+\chi)\, g_m r_o}$$

$$\begin{cases} R_D < r_o & R_{in} \doteq \dfrac{1}{g_m} \quad (100\,\Omega) \\ R_D = r_o & R_{in} \doteq \dfrac{2}{g_m} \end{cases}$$

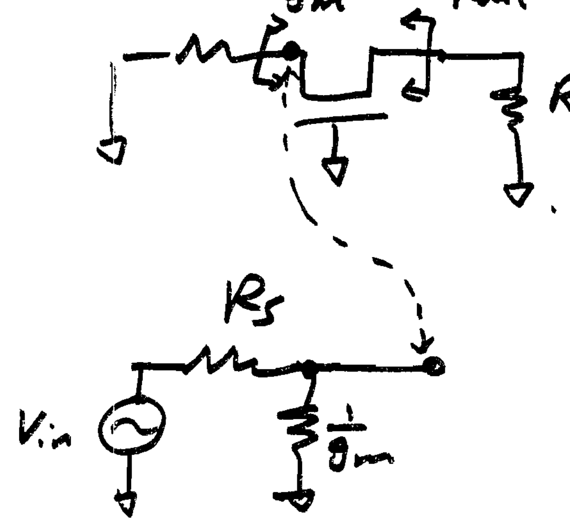
$$R_D > r_o \qquad R_{in} \doteq \frac{R_D}{(1+\chi)\, g_m r_o}$$

Common Gate with R_S



exactly as CS!

$R_{out}' \doteq g_m R_S r_o$



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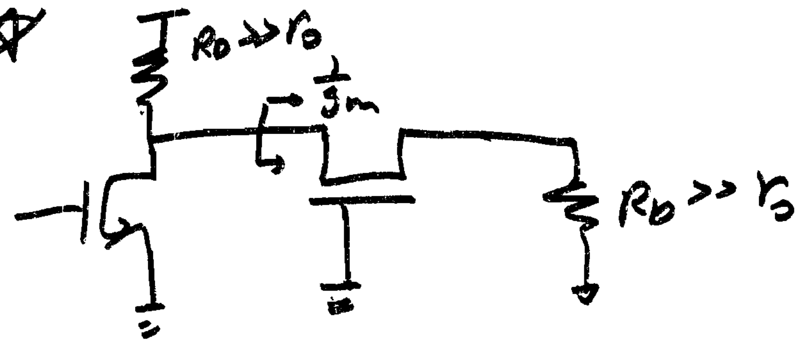

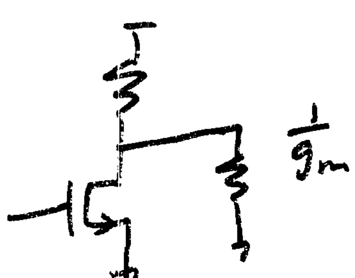

$R_{out} \doteq \frac{1}{g_m}$ $\quad G_m = -g_m$

$A_{v_1} = -g_m \cdot R_{out} = -1$

$A_{v_2} = g_m r_o$