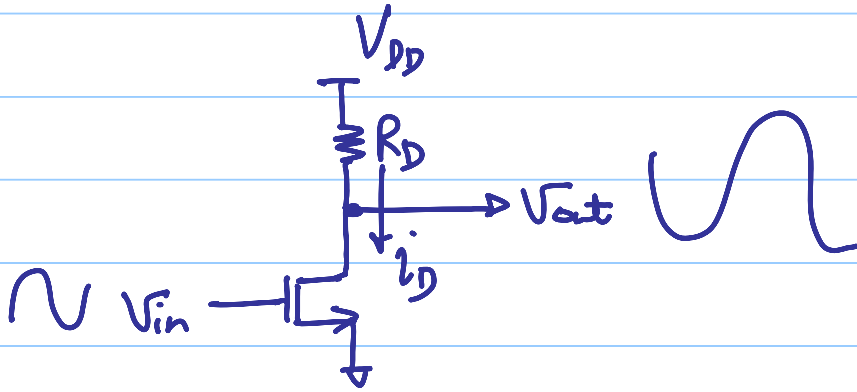
ECE 511 - Lecture 14

Note Title 3/6/2014

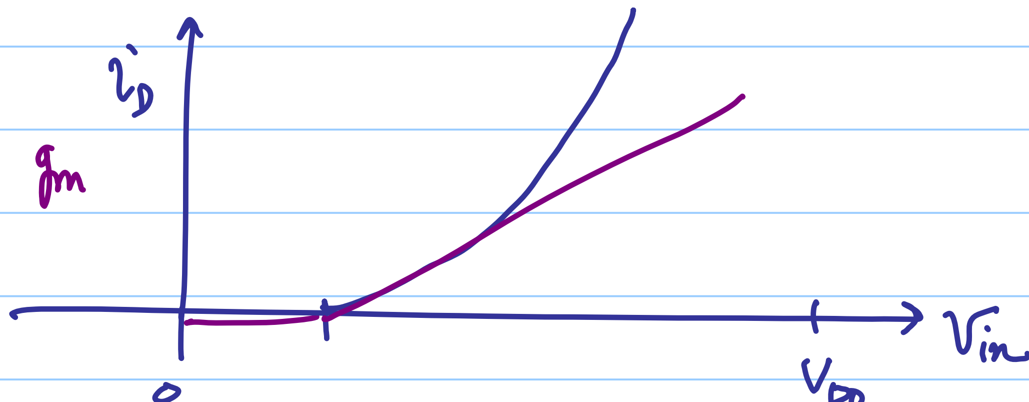


VCCS

$g_m R_D > 1$

small signal voltage gain

$P_{avg} = \langle V_{DD} \cdot I_D \rangle$



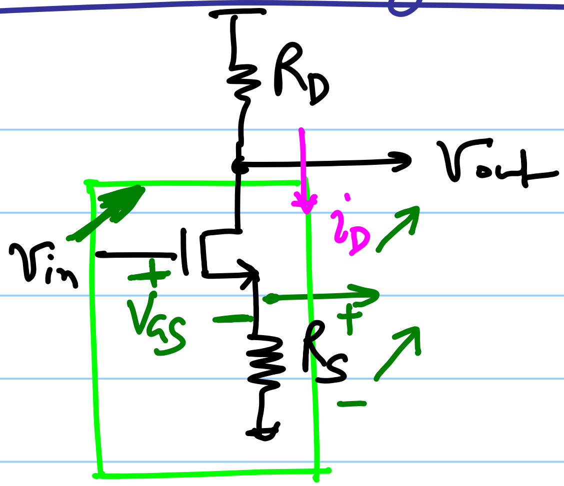
Large signal behavior

$g_m = f(V_{in})$

$\Rightarrow A_v = g_m R_D$

↳ non-linearity

CS : Source Degeneration



due to the −ve feedback V_{GS} is "almost" constant

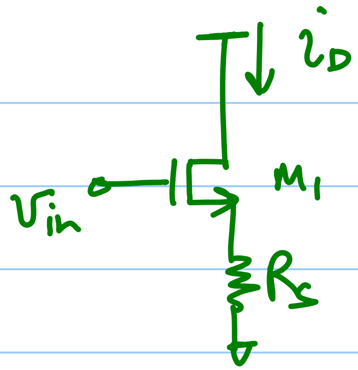
$$i_D \simeq \frac{V_{in} - V_{GS}}{R_S}$$

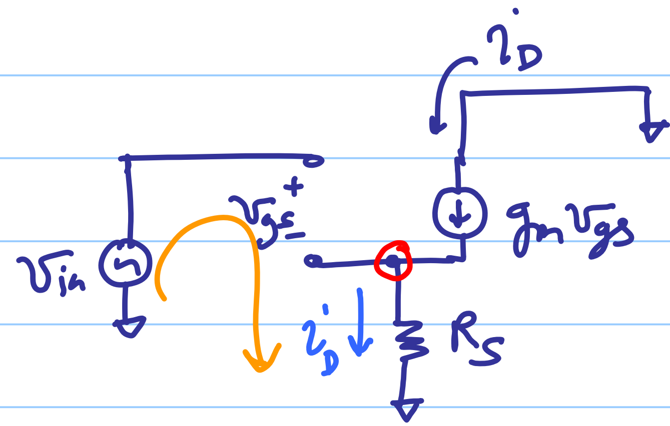
large portion of V_{in} is dropped across the resistor R_S

$\Rightarrow$ change in i_D is almost linear

$\lambda = 0, \gamma = 0$

Simplifying assumption





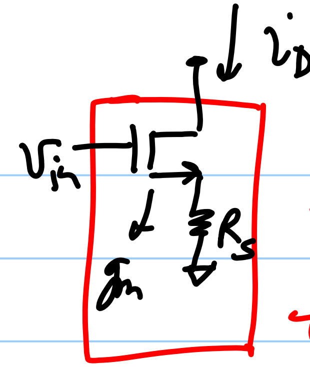
KVL: $v_{gs} = v_{in} - i_D R_s \longrightarrow (1)$

KCL: $i_D = g_m v_{gs} \longrightarrow (2)$

$$i_D = g_m (v_{in} - i_D R_s)$$

$$\Rightarrow i_D (1 + g_m R_s) = g_m v_{in}$$

$$\boxed{\frac{i_D}{v_{in}} = \frac{g_m}{1+g_mR_S}} = G_m$$



VCCS

G_m

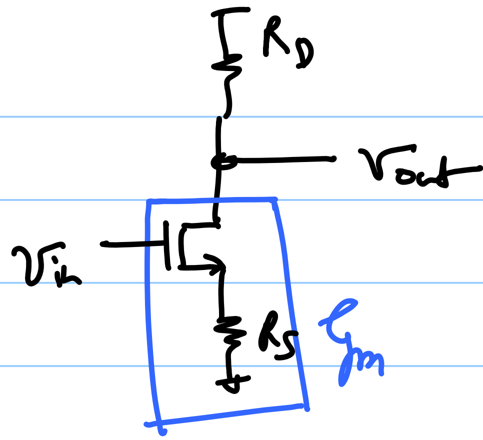
composite device

$$\boxed{G_m = \frac{g_m}{1+g_mR_S}} = \frac{1}{R_S + 1/g_m}.$$

for $\underbrace{R_S \gg 1/g_m}_{g_m \gg \frac{1}{R_S}} \Rightarrow G_m \simeq \frac{1}{R_S}$

G_m becomes a weak function of g_m

$\Rightarrow$ drain current is a "linearized" function of v_{in}.



$$A_v = -g_m R_D$$

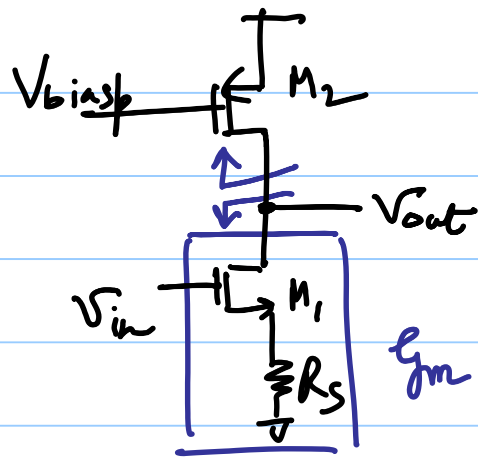
$$= -\frac{\boxed{g_m R_D}}{1 + g_m R_S} \simeq -\frac{R_D}{R_S}$$

for $g_m \gg \frac{1}{R_S}$

$\Rightarrow$ gain A_v is reduced by a factor of $(1 + g_m R_S)$

$\Rightarrow$ lower gain

Trading off linearity with gain.

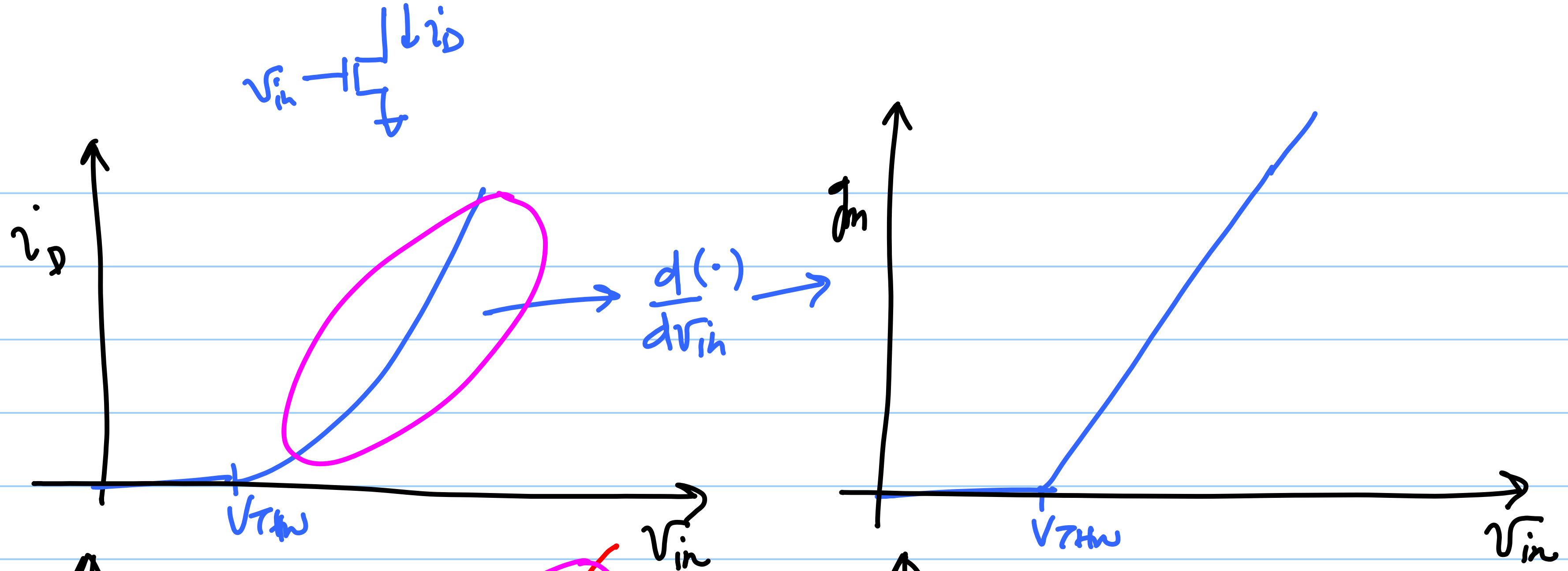


$$A_v = -g_m \cdot R_{out}$$

$$g_m = \frac{g_{m1}}{1+g_{m1}R_S}$$

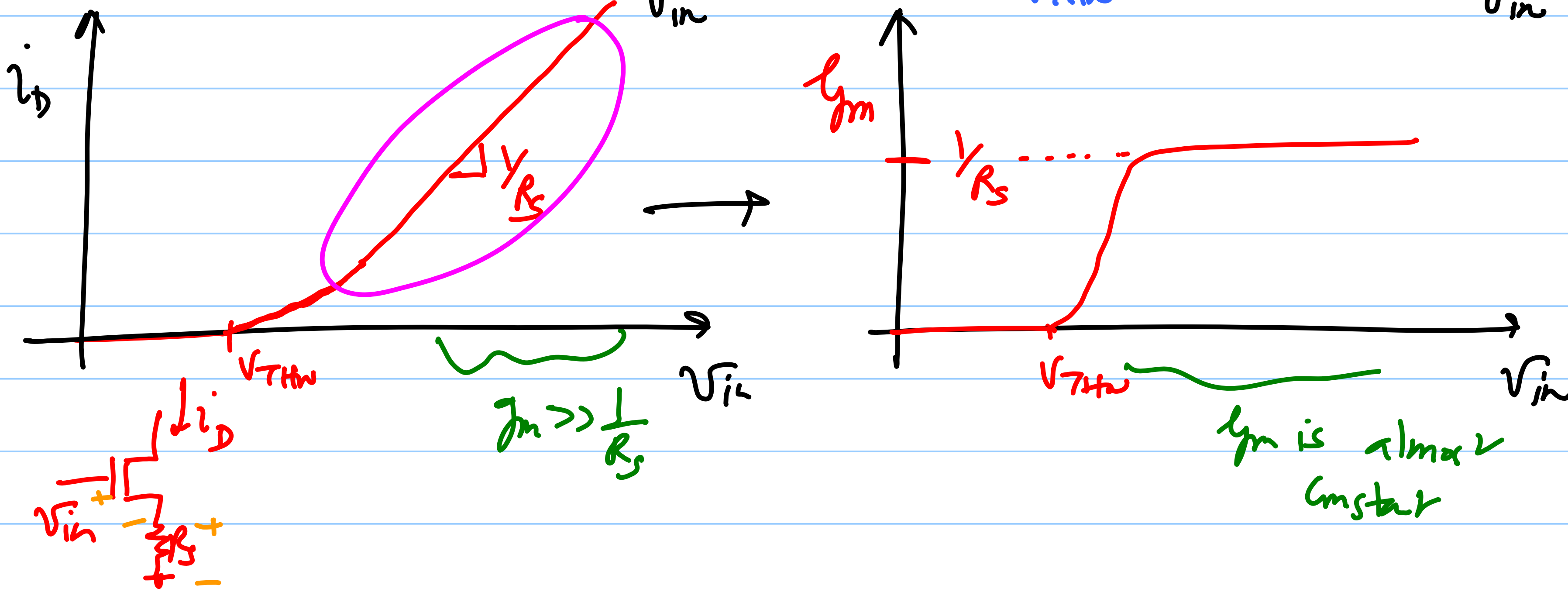
$$R_{out} = r_{o2} \,\|\, (\underbrace{g_{m1} r_{o1} R_S}_{\text{from cascading}})$$

$R_s \to 0$



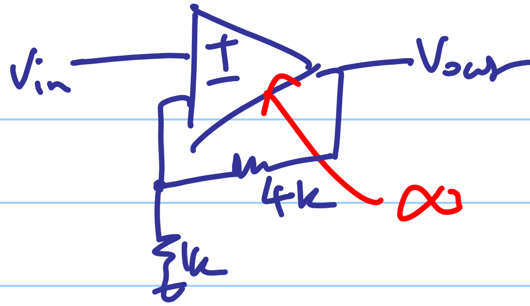
v_{in}
i_D
i_D
g_m
$\frac{d(\cdot)}{dv_{in}}$
V_{THN}
v_{in}
V_{THN}
v_{in}

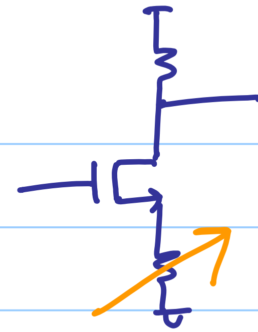
$R_s > 0$



i_D
$1/R_s$
g_m
$1/R_s$
V_{THN}
v_{in}
V_{THN}
v_{in}
$g_m \gg \frac{1}{R_s}$
g_m is almost constant
i_D
v_{in}
R_s

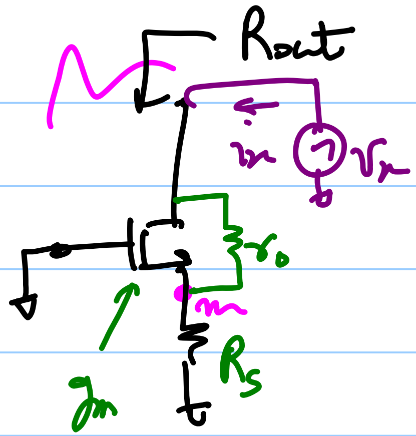
$A_v = 5$





PGA

open-loop gain

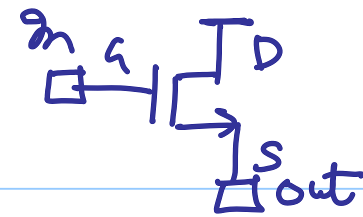


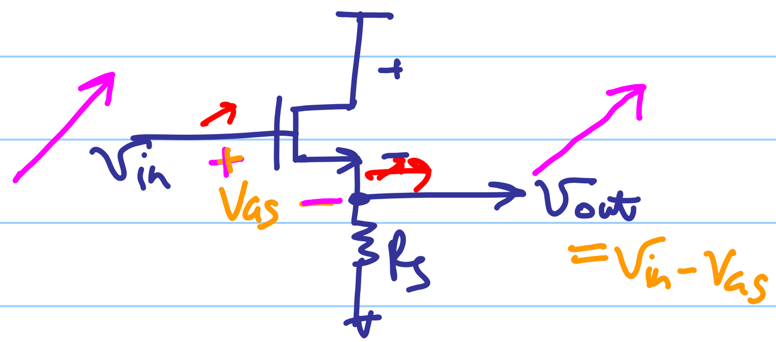
Razavi

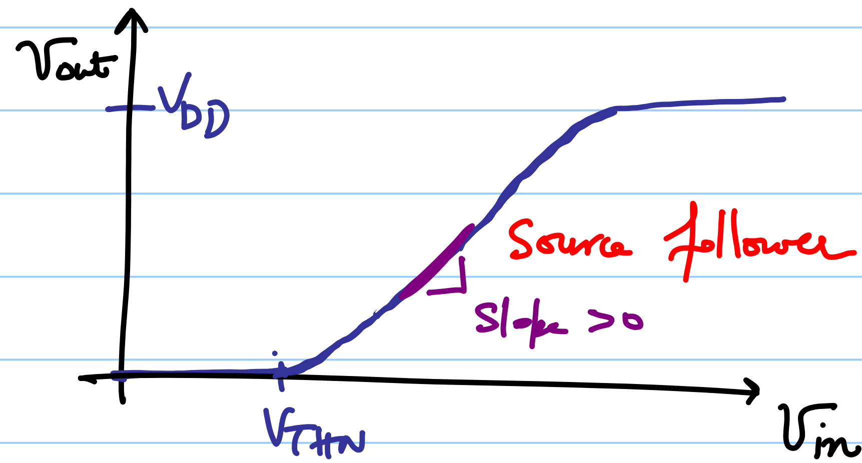
$$R_{out} = \left[1 + (g_m + g_{mb}) R_S\right] r_o$$

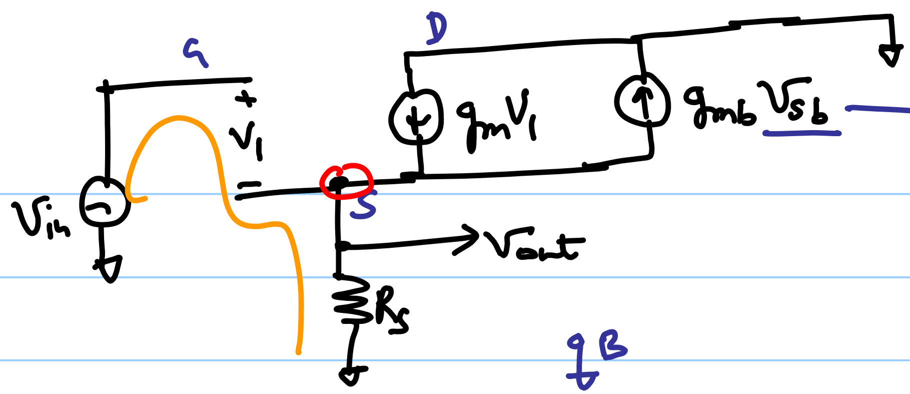
$$\simeq g_m R_S r_o$$

Source follower (CD)









$\longrightarrow V_{sb} = V_{out}$

KVL: $V_{out} = V_{in} - V_1 \longrightarrow (1)$

KCL: $g_m V_1 - g_{mb} V_{out} = \dfrac{V_{out}}{R_S} \longrightarrow (2)$

$$g_m (V_{in} - V_{out}) - g_{mb} V_{out} = \frac{V_{out}}{R_S}$$

$$\Rightarrow \quad V_{out}\left[g_m + g_{mb} + \frac{1}{R_S} \right] = g_m V_{in}$$

$$\Rightarrow \quad \boxed{A_v = \frac{V_{out}}{V_{in}} = \frac{g_m R_S}{1 + (g_m + g_{mb}) R_S}}$$

non-inverting "gain"

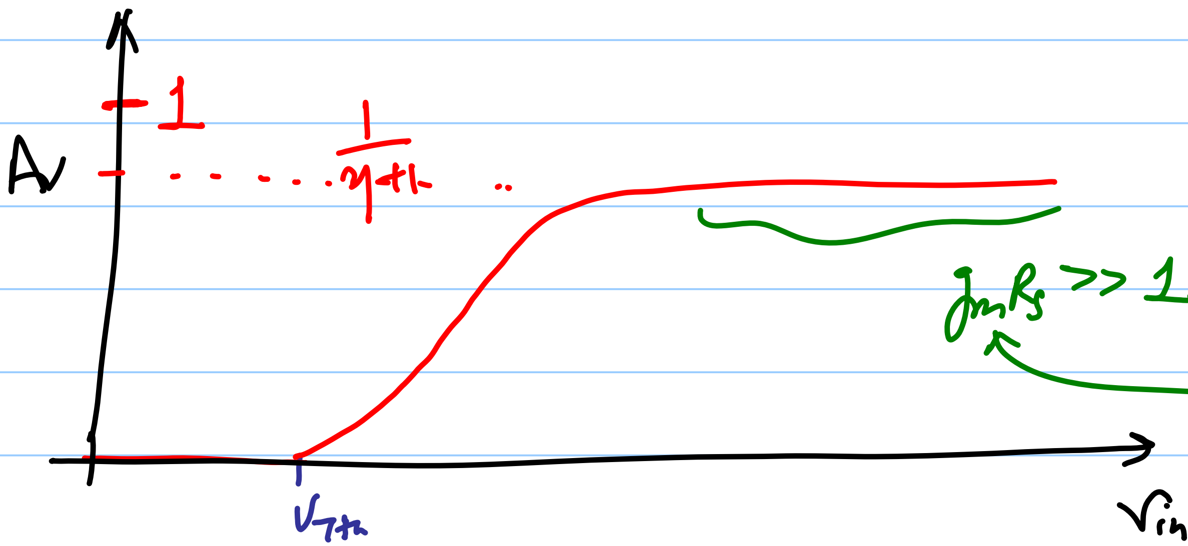
$g_{mb} = \eta g_m$ ($\eta \approx 0.7$)

$$\frac{g_m R_S}{1 + (\eta+1) g_m R_S}$$

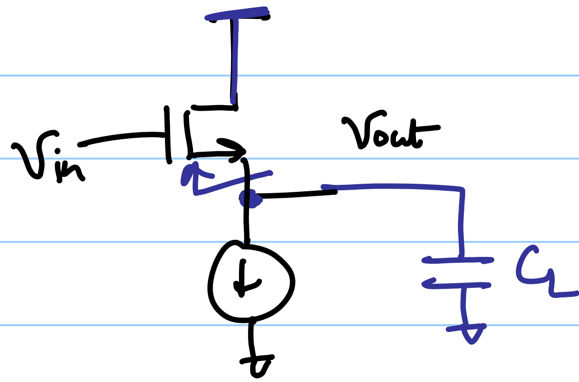
$$\simeq \frac{1}{(\eta+1) + \frac{1}{g_m R_S}}$$

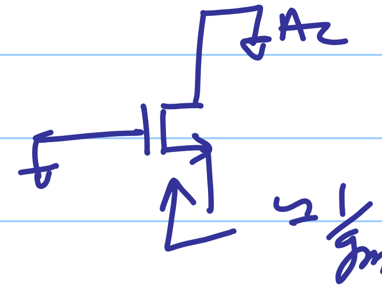
$$\simeq \boxed{\frac{1}{\eta+1}} \text{ for } g_m R_S \gg 1$$

$\boxed{A_v < 1}$

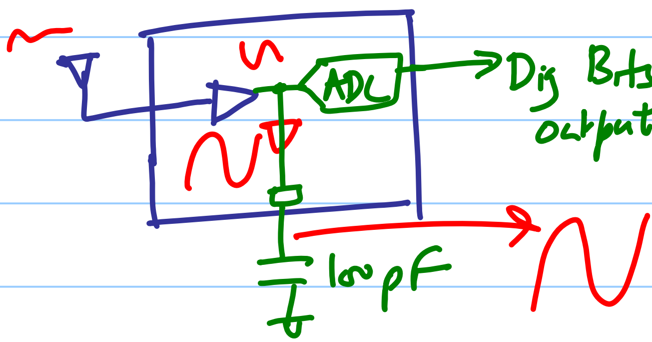


$g_m = f(V_{in})$





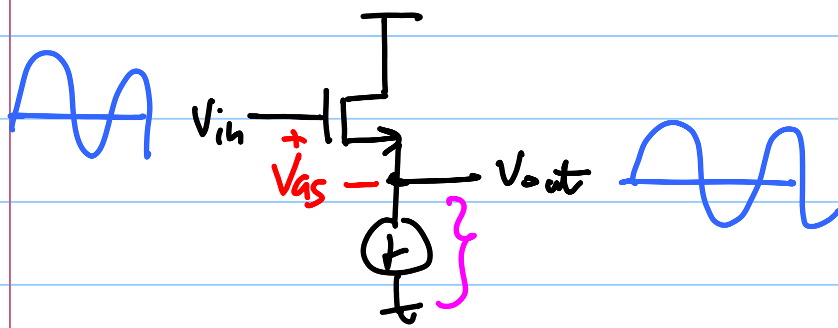
"Voltage Buffer"



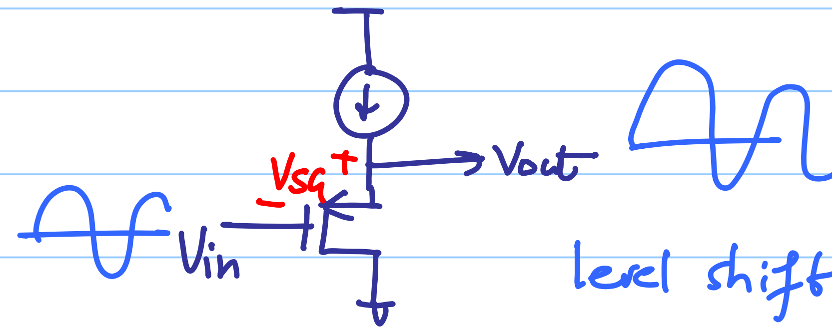
Analog Buffer

"Test Circuit"

"DC level shifting"

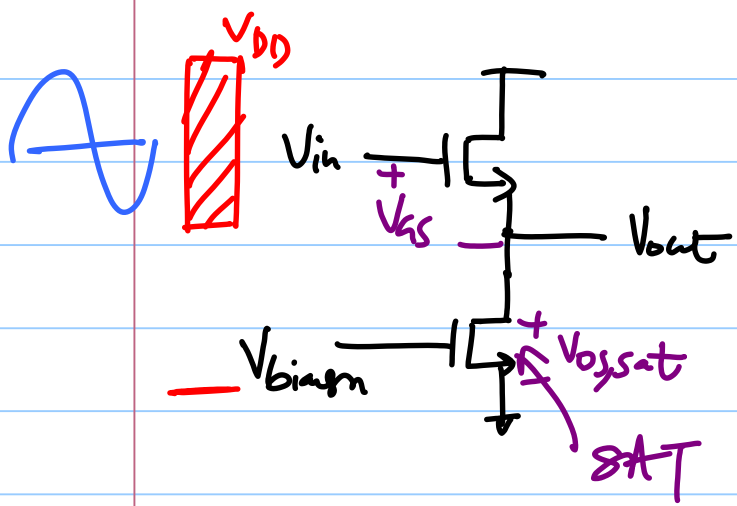


DC level-shifting

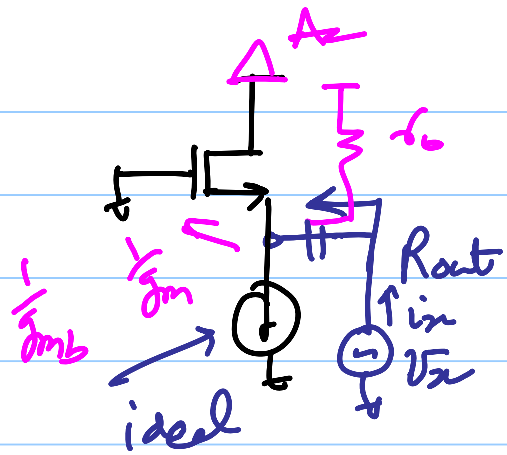


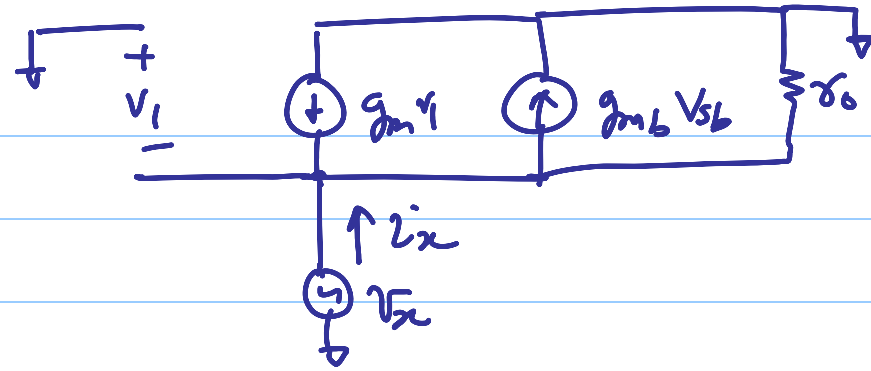
level shift-up

Voltage
limited headroom



$V_{in} \geq V_{GS} + V_{DS,sat}$





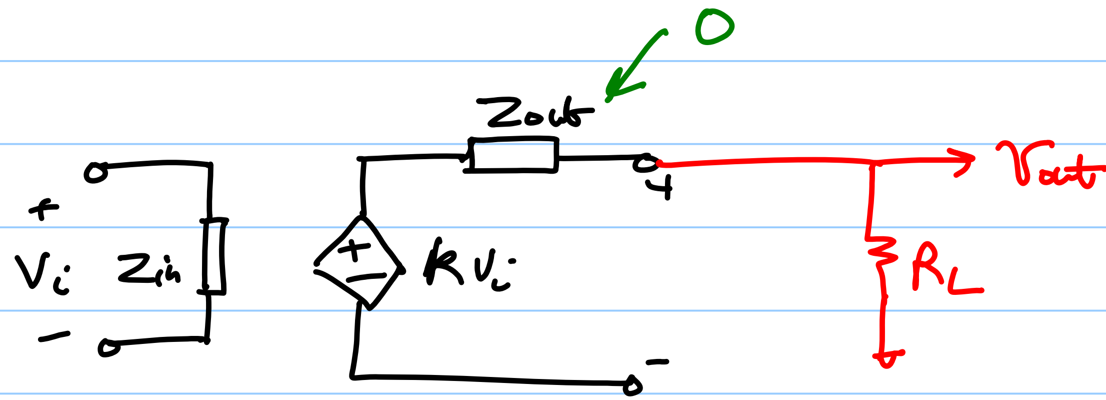
$$i_x - g_m v_x - g_{mb} v_x + \frac{v_x}{r_o} = 0$$

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

$$\boxed{R_{out} = \frac{1}{g_m} \parallel \frac{1}{g_{mb}} \parallel r_o} \simeq \frac{1}{g_m} \parallel \frac{1}{g_{mb}}$$

"Low output impedance"

Voltage Buffer   VCVS, Gain = 1



$$V_{out} = \left(\frac{R_L}{R_L + Z_{out}}\right) k V_i$$

$\Rightarrow$ ideally want $Z_{out} = 0$

$\Rightarrow$ SF $Z_{out} \simeq \frac{1}{g_m}$ $\Rightarrow$ Voltage Buffer