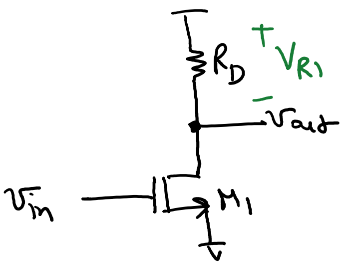
# ECE 515 - Lecture 10

Tuesday, September 25, 2018 10:58 AM




$$A_v = \frac{v_{out}}{v_{in}} = -g_{m1} R_D \quad \rightarrow \quad R_D$$

$$= -\sqrt{2KP_n \frac{W}{L} \cdot I_D} \cdot \left(\frac{V_{RD}}{I_D}\right)$$

$$= -\sqrt{2KP_n \frac{W}{L}} \cdot \frac{V_{RD}}{\sqrt{I_D}}$$

$|A_v| \uparrow \Rightarrow$

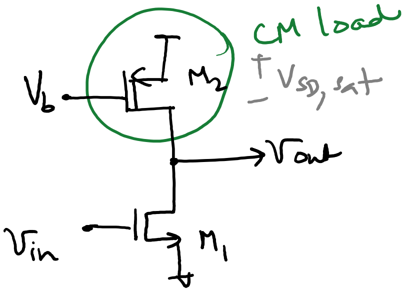
$\frac{W}{L} \uparrow \Rightarrow$ large device cap $\propto \sqrt{W/L}$

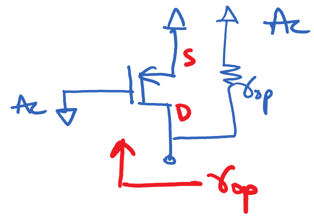
$V_{RD} \uparrow \Rightarrow R_D \uparrow \Rightarrow$ lower swings for $V_{DS}$

$I_D \downarrow \Rightarrow$ lower speed

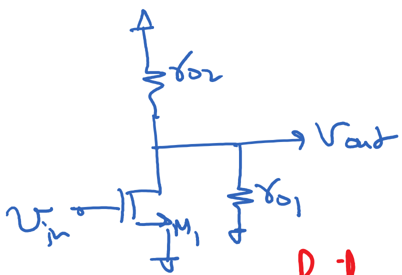
$V_{RD} = I_D \cdot R_D$

# Use current mirror loads




Output impedance value is no longer coupled with the voltage drop across the load!




$$\Rightarrow A_v = \frac{V_{out}}{V_{in}} = -g_{m1} \cdot (r_{o1} \| r_{o2}) \simeq -\frac{g_m r_o}{2}$$

Max gain

if $r_{o1} = r_{o2} = r_o$

higher gain!

# CS Stage with current-source load

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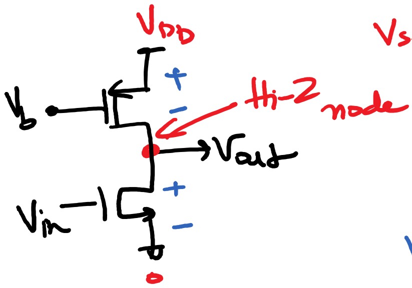
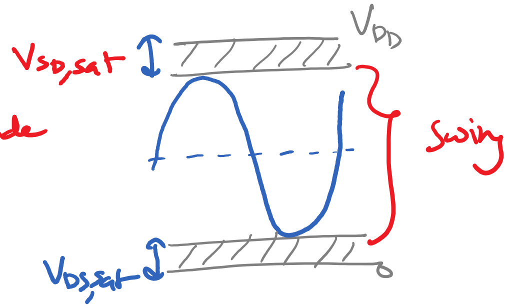
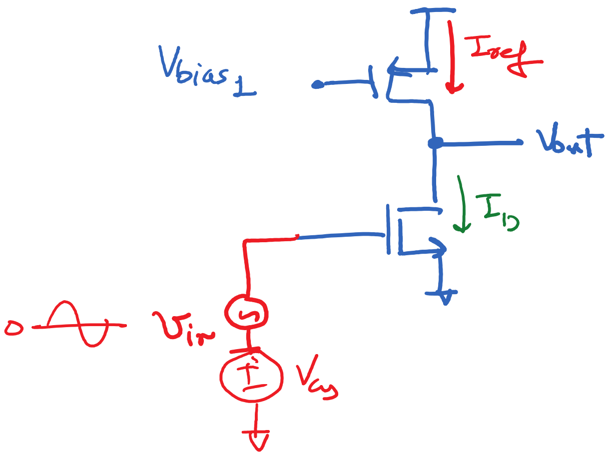


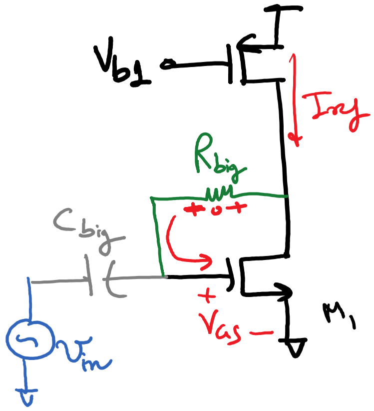




large output swing!

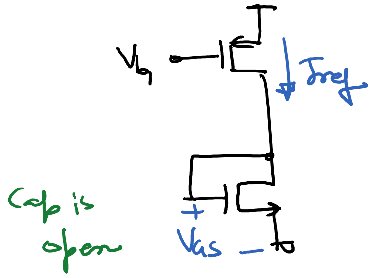



Two current sources trying to set drain bias level

Need to bias the CS stage properly.

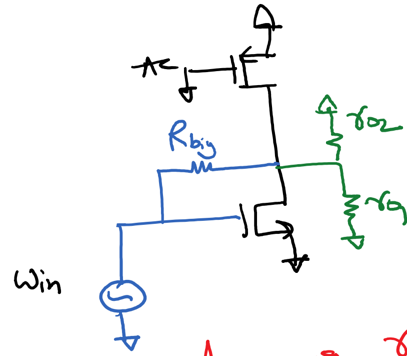



## DC picture




CS amplifier is biased

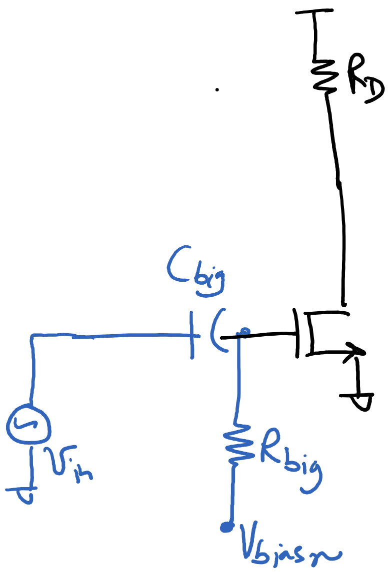
## AC picture



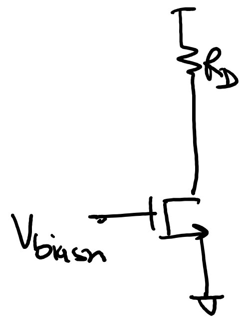

$$A_v = -g_{m1}\, r_{o1} \| r_{o2} \| R_{big}$$

$$\simeq -g_{m1}(r_{o1} \| r_{o2})$$

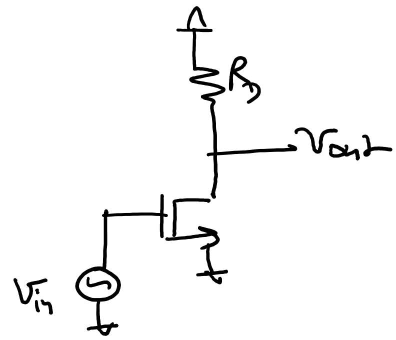
$$\omega_{in} >> \omega_x = \frac{1}{R_{big} C_{big}}$$




DC



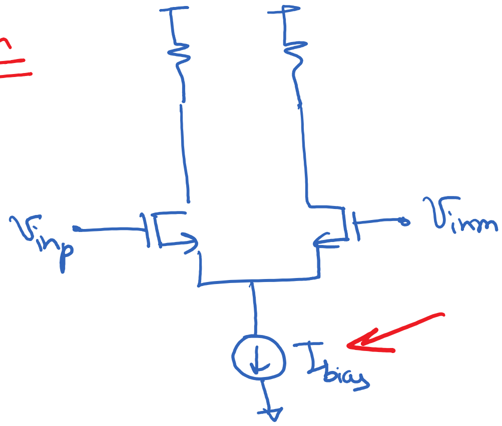

AC




$$\omega_{in} >> \omega_x$$

$$\omega_{in} > 10 \cdot \omega_x = \frac{10}{R_{big} C_{big}}$$

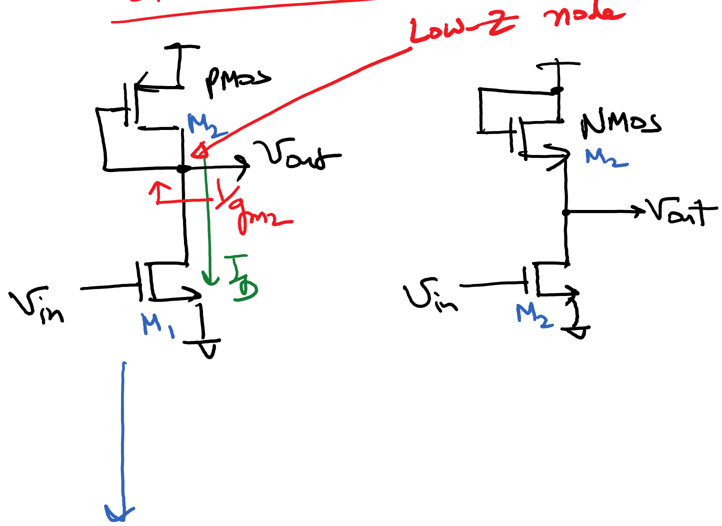
Solution




Diff pair input solves biasing problems

↳ we'll see later on!

# Diode Connected Load:




$$A_v = -g_{m1} \cdot \left( \frac{1}{g_{m2}} \| r_{o1} \right)$$

$$\simeq -\frac{g_{m1}}{g_{m2}}$$

$$= -\frac{\sqrt{2 k_{Pn} \cdot (W/L)_1 I_D}}{\sqrt{2 k_{Pp} (W/L)_2 I_D}} = \sqrt{\frac{k_{Pn} (W/L)_1}{k_{Pp} (W/L)_2}}$$

Can't get large gains :(

↳ linear gain

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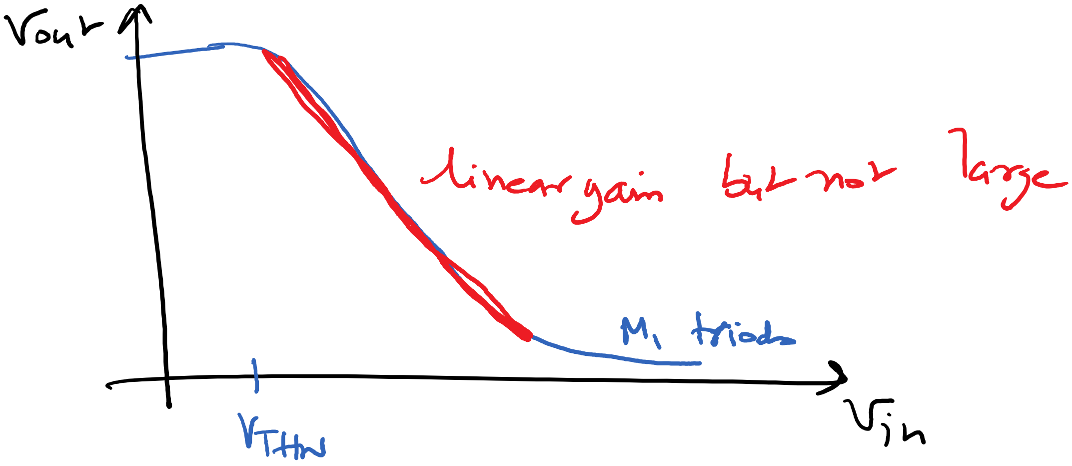
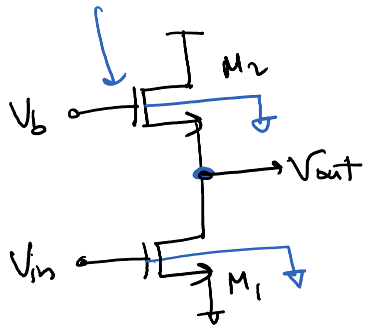
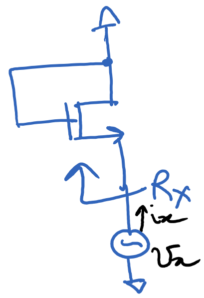
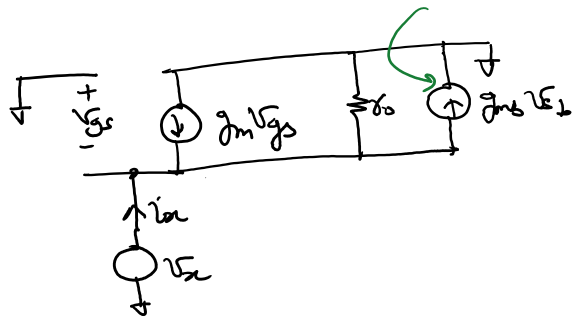


Body effect




Considering the body-effect




$$(g_m + g_{mb}) v_x + \frac{v_x}{r_o} = i_x$$

$$\Rightarrow R_x = \frac{v_x}{i_x} = \frac{1}{g_m + g_{mb} + r_o^{-1}}$$

lower impedance due to body effect → $\simeq \dfrac{1}{g_m + g_{mb}} = \dfrac{1}{g_m(1+\eta)}$

$g_{mb} = \eta g_m$

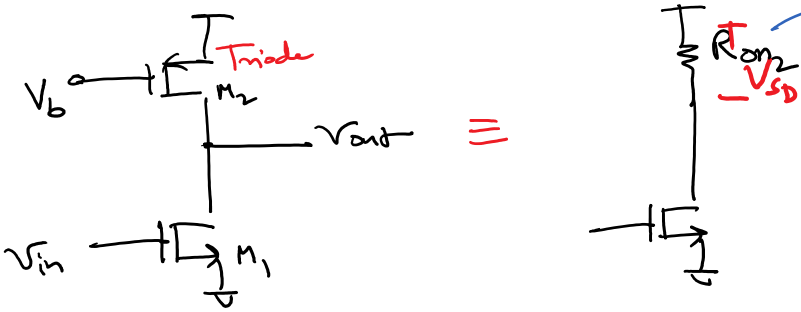
$\eta < 1$

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

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

$$= -\sqrt{\frac{(W/L)_1}{(W/L)_2}} \cdot \frac{1}{1+\eta}$$ ← lower gain due to body-effect

# Triode MOSFET as load




$$R_{on2} = \frac{1}{k'_p \left(\frac{W}{L}\right)_2 \left(V_{DD} - V_b - |V_{thp}| - V_{SD}\right)}$$

non linear resistor

↳ distortion

non linear term when not in deep Triode

# CS with Source Degeneration

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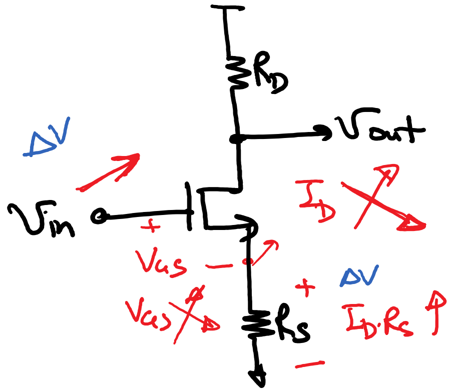
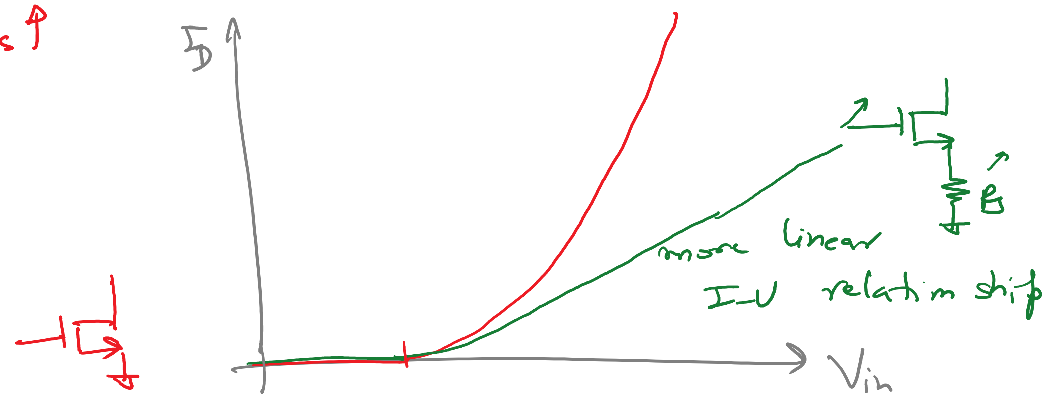



Negative feedback

more linear relationship between $I_D$ & $V_{in}$

↳ most of the change in $V_{in}$ is dropped across $R_S$.




Application: Linear amplifier stage.

VGA ⇒ variable gain amplifier is $R_s$ is programmable

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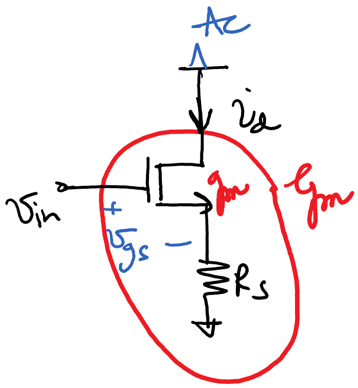
# Simplified Analysis ($\lambda = 0$, $g_{mb} = 0$)

channel length mod and body-effect are ignored




$$v_{gs} = v_{in} - i_d R_s \longrightarrow (1)$$

$$i_d = g_m v_{gs} \longrightarrow (2) \Leftarrow r_o \to \infty$$

(1) & (2) combined

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

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

$$\rightarrow \frac{i_d}{v_{in}} = \boxed{\frac{g_m}{1 + g_m R_s} = G_m}$$

effective transconductance of CS + SD

$$G_m = \frac{g_m}{1+g_m R_S} = \frac{1}{\frac{1}{g_m}+R_S} \longrightarrow \simeq \frac{1}{R_S} \text{ for } R_S >> \frac{1}{g_m}$$

$\Rightarrow g_m R_S >> 1$ ↑ can think of as loop gain

* as $R_S$ increases, $G_m$ becomes a weak function of $g_m$.

↳ drain current is a linearized function of input voltage

(+) higher linearity

(−) lower gain

(−) higher noise

with $\lambda \neq 0, \gamma \neq 0$

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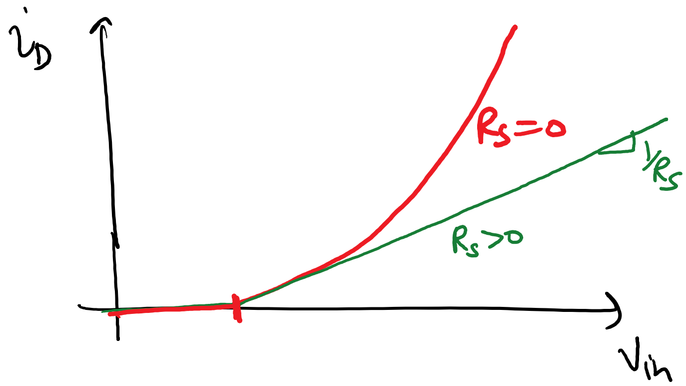
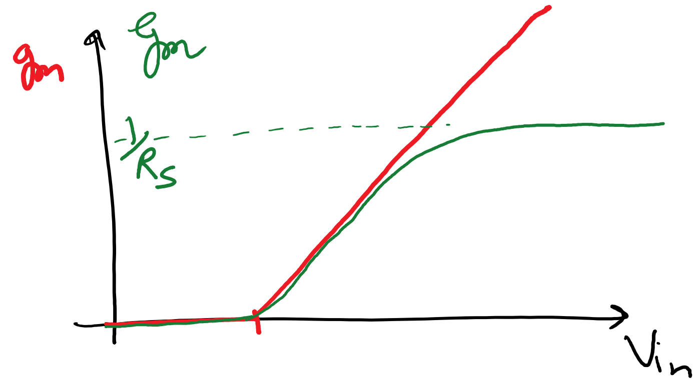
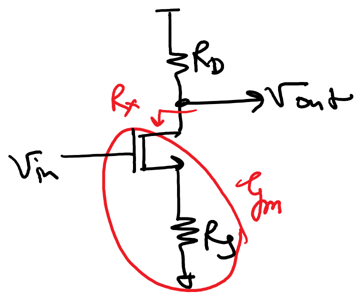
$$G_m = \frac{g_m r_o}{R_S + [1 + (g_m + g_{mb}) R_S] r_o}$$ ← Razavi



Example:

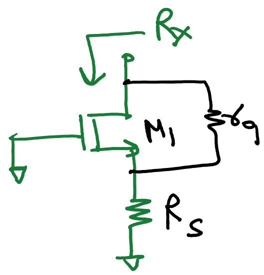



$$A_v = -G_m \cdot R_D \| R_X$$

$$= -\frac{g_m}{1+g_m R_S} \cdot (R_D \| R_X) \qquad \because R_X >> R_D$$

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

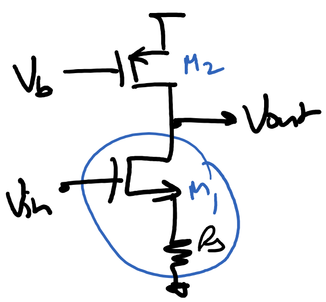
for $g_m R_S >> 1$




$$R_X = g_{m1} r_{o1} R_S + r_{o1} + R_S$$

$$\simeq g_{m1} r_{o1} R_S \Leftarrow R_X$$

See cascode output resistance derivation




$$A_v = -G_m \cdot r_{o2} \| (g_{m1} r_{o1} R_S) \simeq -G_m r_{o2}$$

$$= -\frac{g_m r_{o2}}{1+g_m R_S}$$