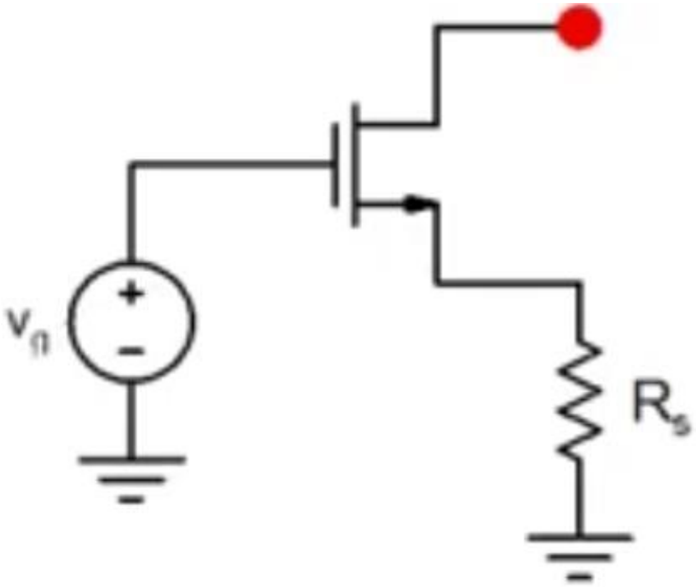
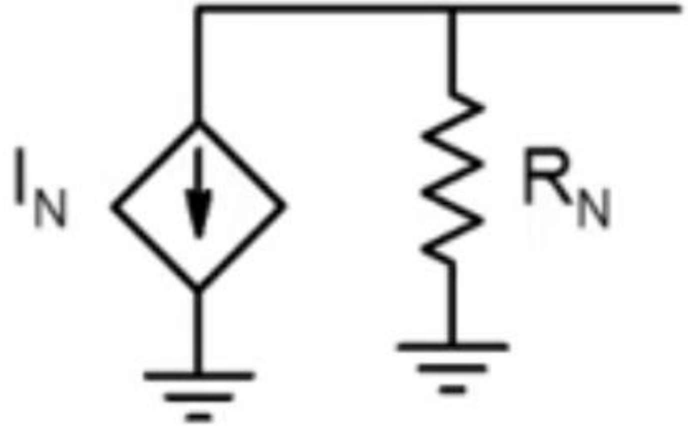
Useful Results

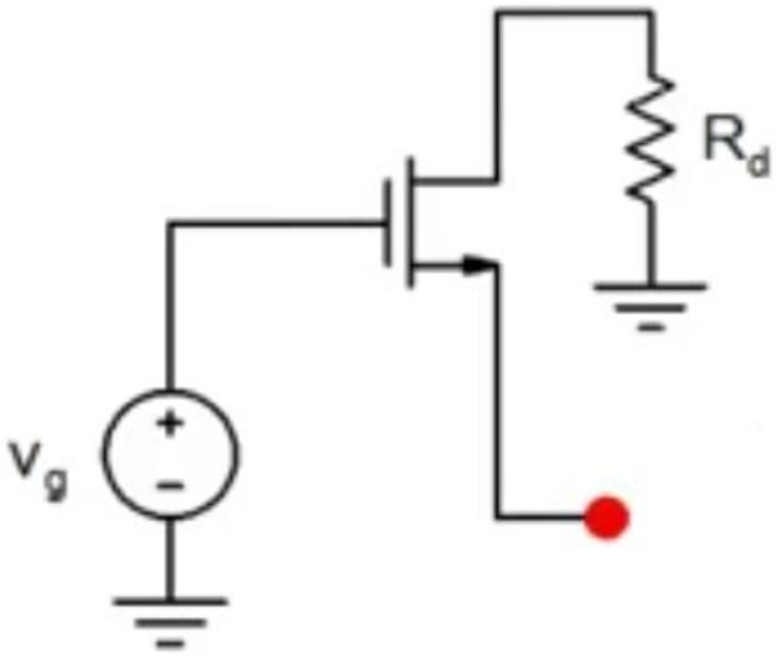


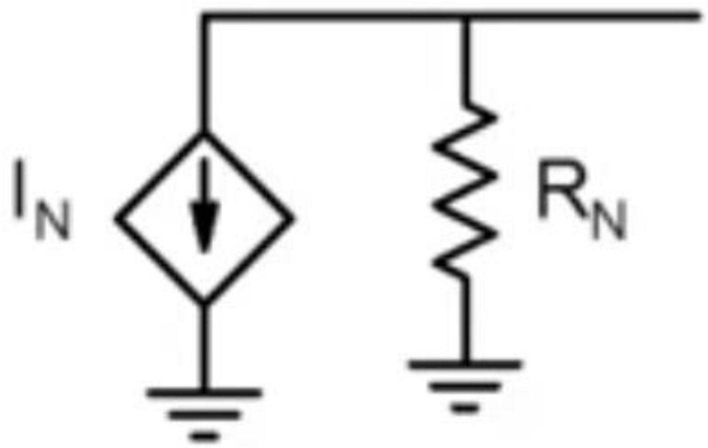


$$i_n \cong \frac{g_m v_g}{1+(g_m+g_{mb})R_S}$$

$$R_n \cong r_o \times \{1+(g_m+g_{mb})R_S\}$$

Useful Results





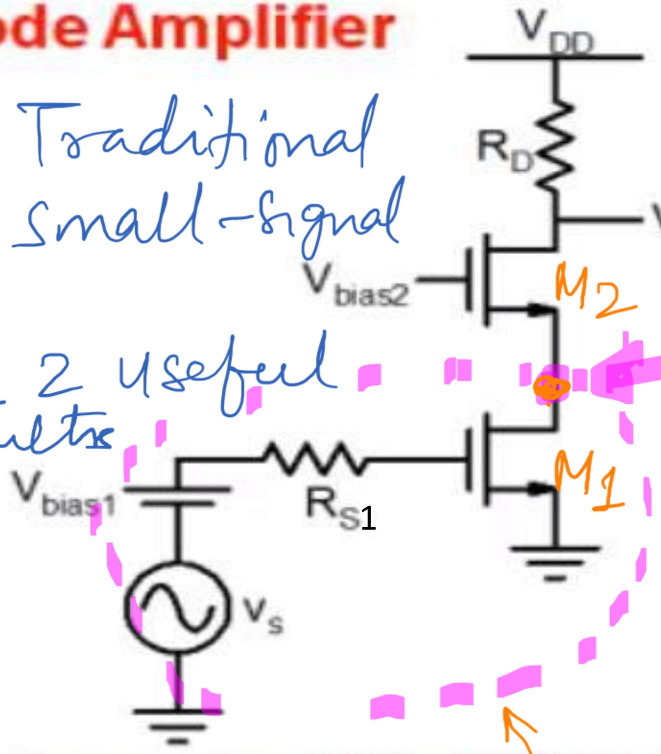
$$i_n = -\frac{g_m v_g}{1 + R_d / r_o}$$

$$R_n \cong \frac{1 + R_d / r_o}{g_m + g_{mb}}$$

Cascode Amplifier

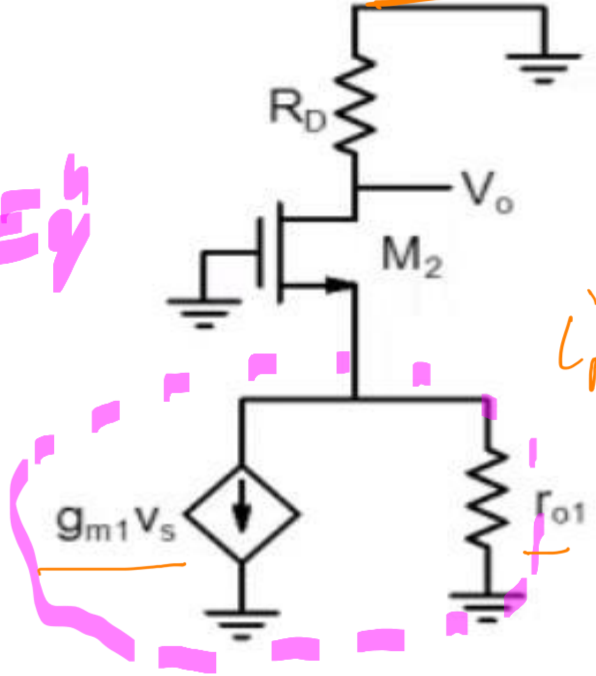
Method-1: Traditional way → small-signal

Method-2: Use 2 useful Results



• Let's calculate the Gain of This Amplifier

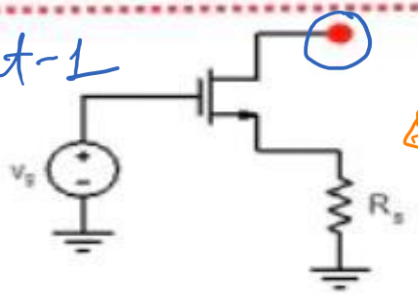
norton Eq



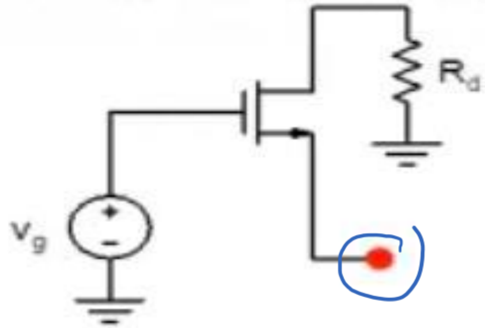
$i_N \simeq g_{m1} v_s$

$R_N \simeq r_{o1}$

useful Result-1



useful Result-2



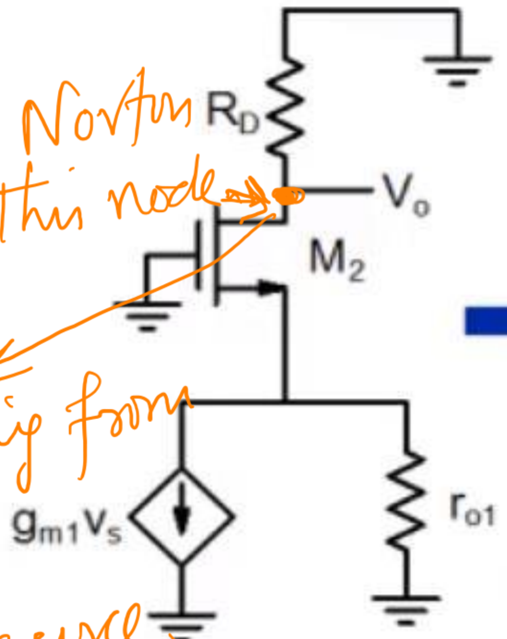
✓ $i_n \cong \dfrac{g_m v_g}{1+(g_m+g_{mb})R_S}$

✓ $R_n \cong r_o \times \{1+(g_m+g_{mb})R_S\}$

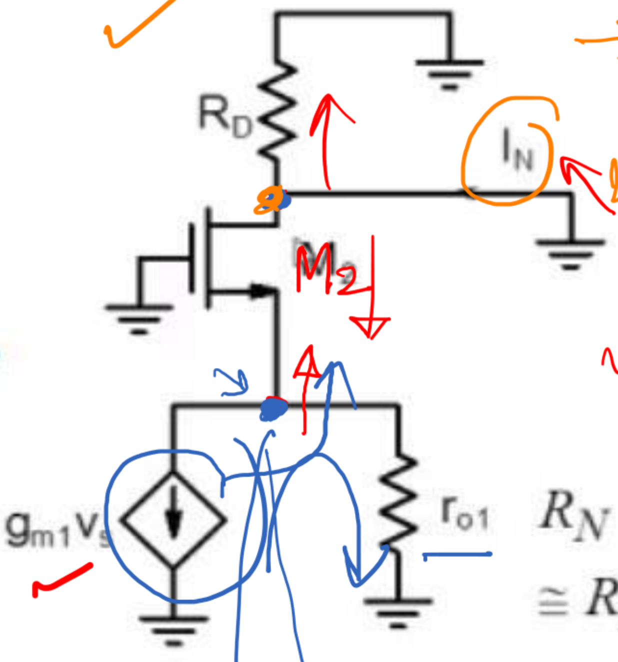
$i_n = -\dfrac{g_m v_g}{1+R_d/r_o}$ $\quad R_n \cong \dfrac{1+R_d/r_o}{g_m+g_{mb}}$

Cascode Amplifier

Built Norton eqn at this node



The whole ckt looking from this node is a current source in parallel with R_N.



Now, Built Norton eqn at V_o

→ Find the Norton current (I_N) → gnd

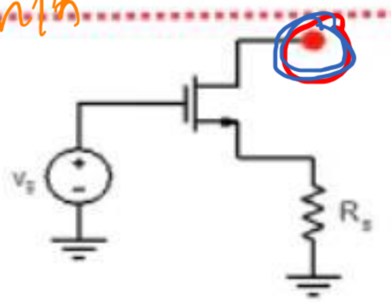
→ Source of I_N is $g_{m1}V_s$

$$i_N \cong g_{m1} v_s$$

→ This current ($g_{m1}V_s$) has two choices → r_{o1} → M_2

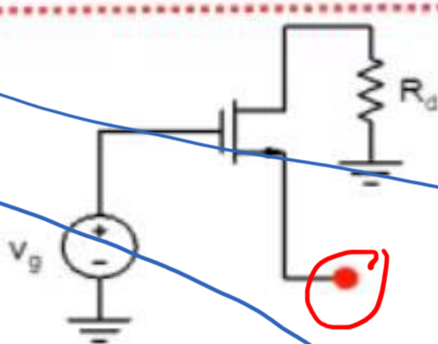
$$R_N = R_D \| r_{o2}(1+(g_{m2}+g_{mb2}))r_{o1}$$
$$\cong R_D$$

→ flow into M_2 and come out as I_N



$$i_n \cong \frac{g_m v_g}{1+(g_m+g_{mb})R_S}$$

$$\boxed{R_n \cong r_o \times \{1+(g_m+g_{mb})R_S\}}$$



what is Resistance when we look into M_2

$$i_n = -\frac{g_m v_g}{1+R_d/r_o} \qquad R_n \cong \frac{1+R_d/r_o}{g_m+g_{mb}}$$

$$R_n \cong \frac{1}{g_{m2}+g_{mb2}}$$

→ Remember: The order of r_o and resistance looking into source

$r_o \downarrow \sim M\Omega$; source $\downarrow \sim k\Omega$

→ Therefore, the current will flow into M_2

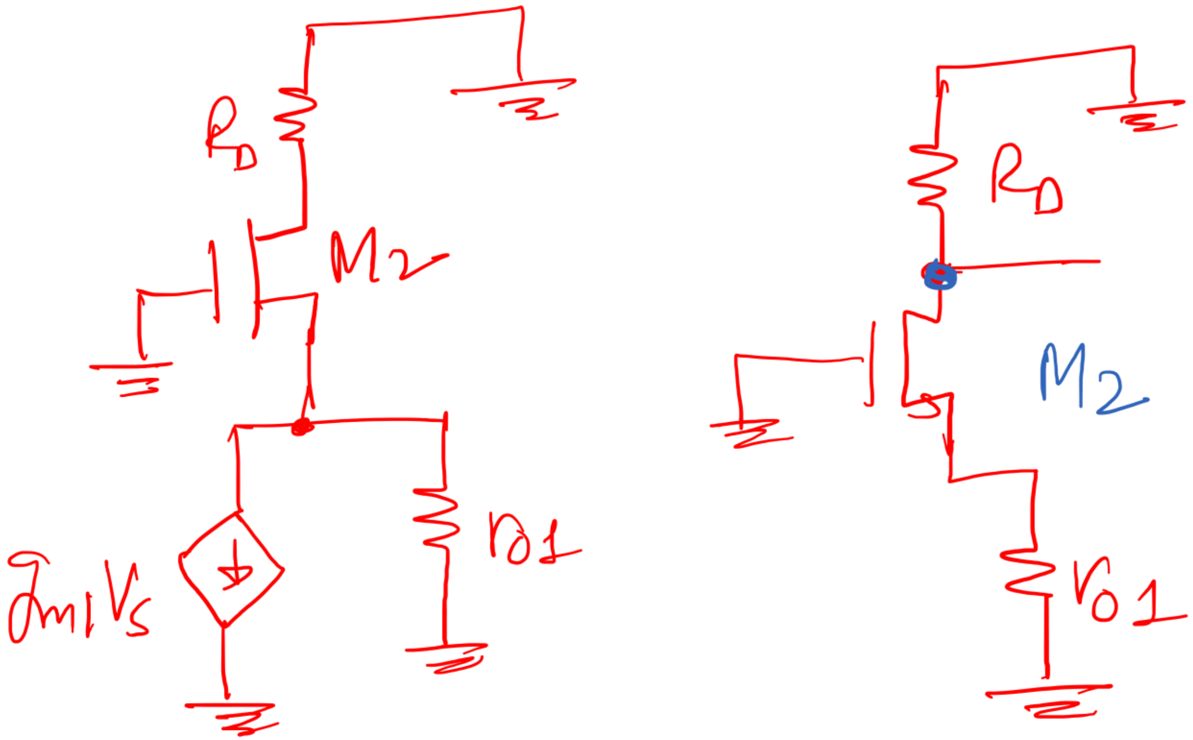
$$\boxed{i_N \simeq g_{m1} V_s}$$

→ Now, let's find the Norton resistance at that node

- Forget the ground

→ Resistance looking up → R_D

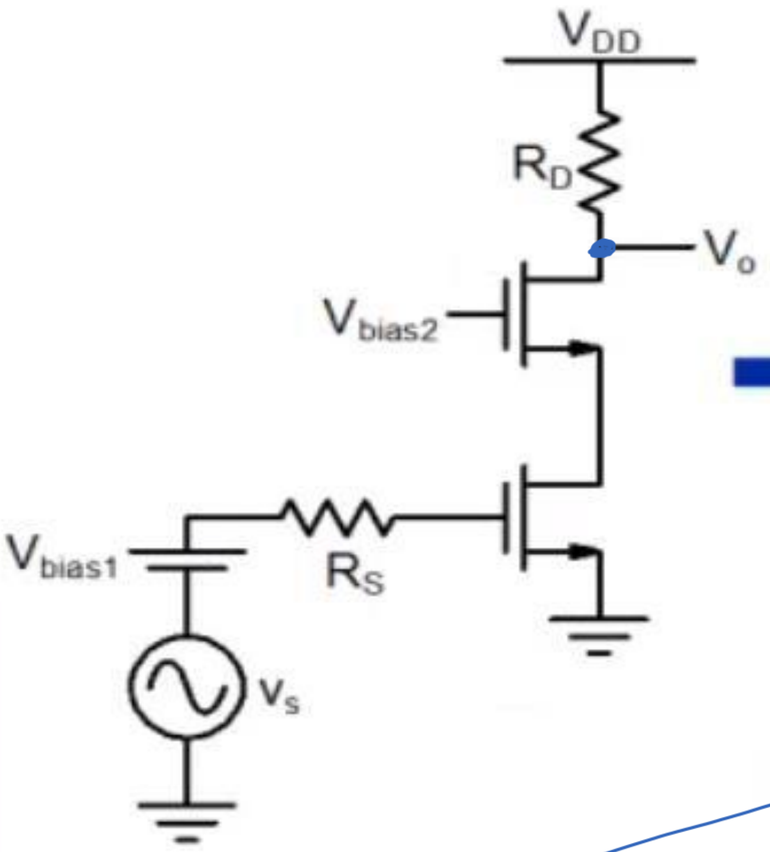
→ Resistance looking down → short all sources

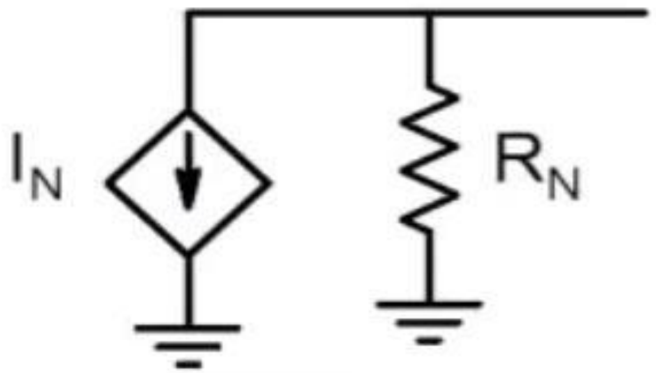


$$R_N \simeq R_D \,\|\, r_{o2}\left(1 + (g_{m2} + g_{mb2})\, r_{o1}\right)$$

$$R_N \simeq R_D$$

Cascode Amplifier





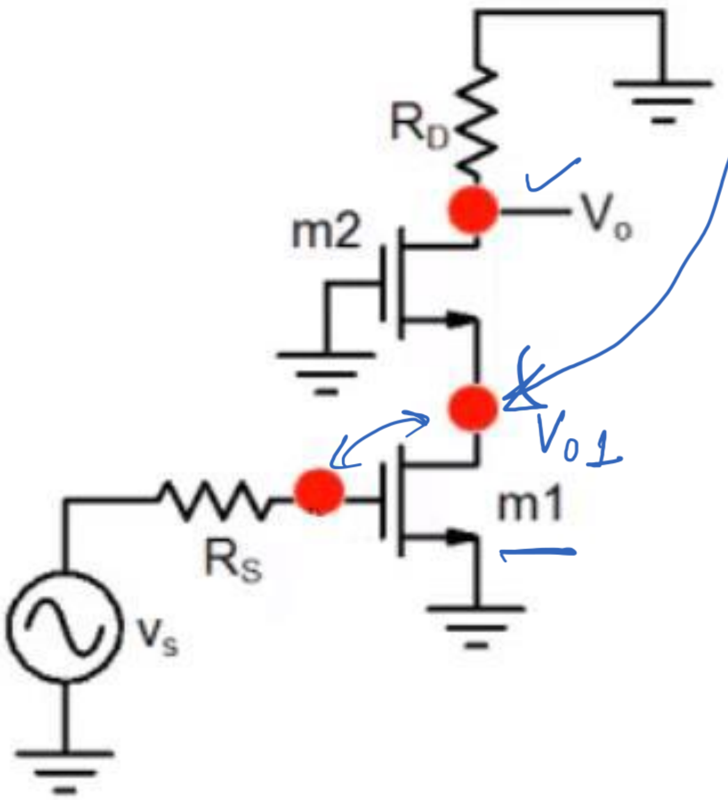
$$i_N \cong g_{m1} v_s \qquad R_N \cong R_D$$

$$\frac{v_o}{v_s} = -g_{m1} R_D$$

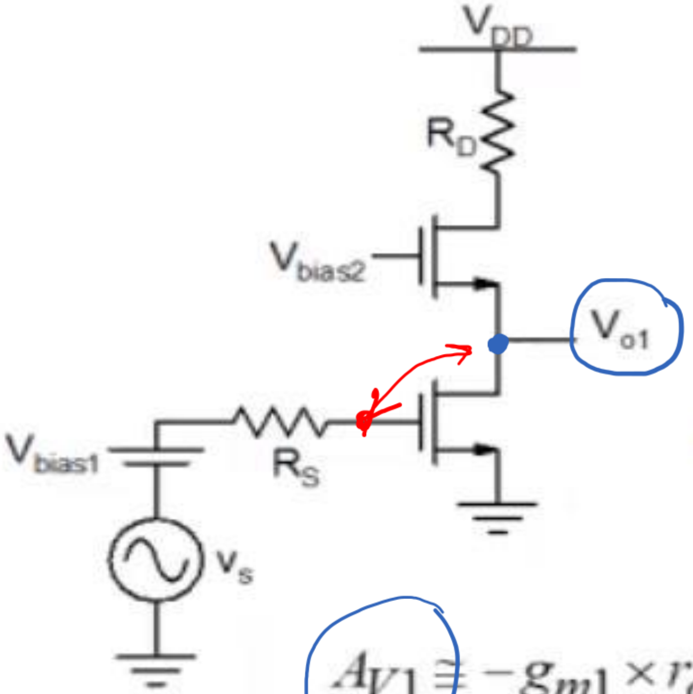
$A_V \cong -g_{m1} R_D$ just like a CS amplifier

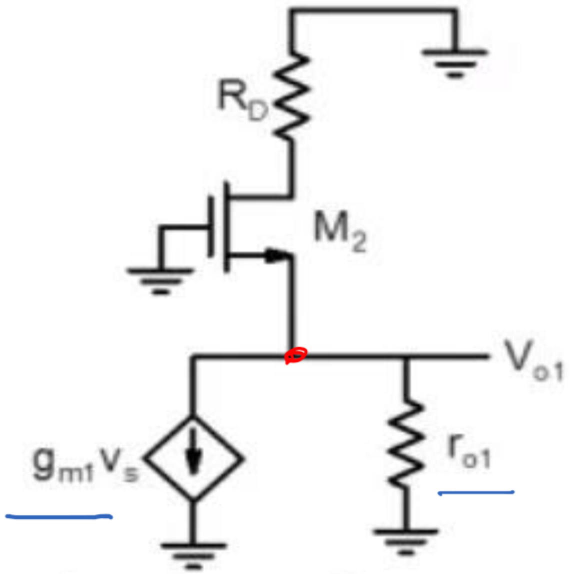
$$R_O \cong R_D$$

Cascode Amplifier: Frequency Response



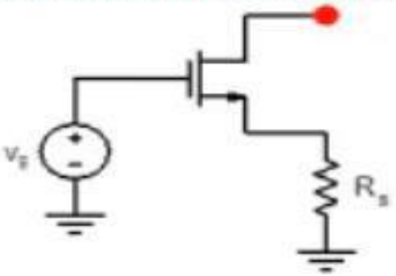
- Gain(M_1) will suffer from Miller effect
- Let's built a gain at V_{o1}
- Built Norton eq^n.





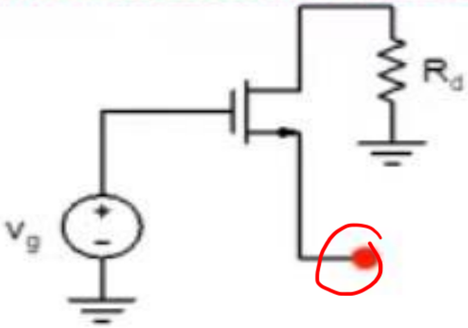
Let's solve this

$$A_{V1} \cong -g_{m1} \times r_{o1} \,\|\, \left\{ \frac{1}{g_{m2}+g_{mb2}} \left(1+\frac{R_D}{r_{o2}}\right) \right\} \cong -\frac{g_{m1}}{g_{m2}+g_{mb2}}$$



$$i_n \cong \frac{g_m v_g}{1+(g_m+g_{mb})R_S}$$

$$R_n \cong r_o \times \{1+(g_m+g_{mb})R_S\}$$



$$i_n = -\frac{g_m v_g}{1+R_d/r_o} \qquad R_n \cong \frac{1+R_d/r_o}{g_m+g_{mb}}$$

Use useful Result -2

$$= \frac{1 + R_d / r_o}{g_{m2} + g_{mb2}}$$

$$R_N \simeq r_{o1} \,||\, \left\{ \frac{1}{g_{m1} + g_{mb2}} (1 + R_D / r_{o2}) \right.$$

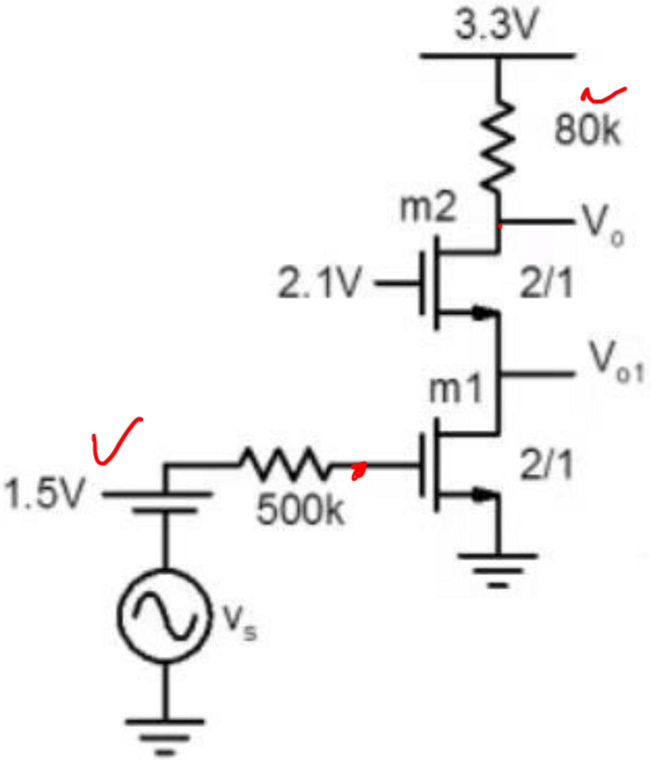
So, Net voltage develop at $V_{o1} = I_N \cdot R_N$

$$V_{o1} = g_{m1} \cdot V_s * \frac{r_{o2} \,||\, \left\{ \frac{1}{g_{m2} + g_{mb2}} (1 + R_D / r_{o2}) \right\}}{}$$

$$\boxed{\frac{V_{o1}}{V_s} = \frac{g_{m1}}{g_{m2} + g_{mb2}}}$$

if both the MOS are identical, and if we ignore g_{mb2}, then $A_V \leq 1$

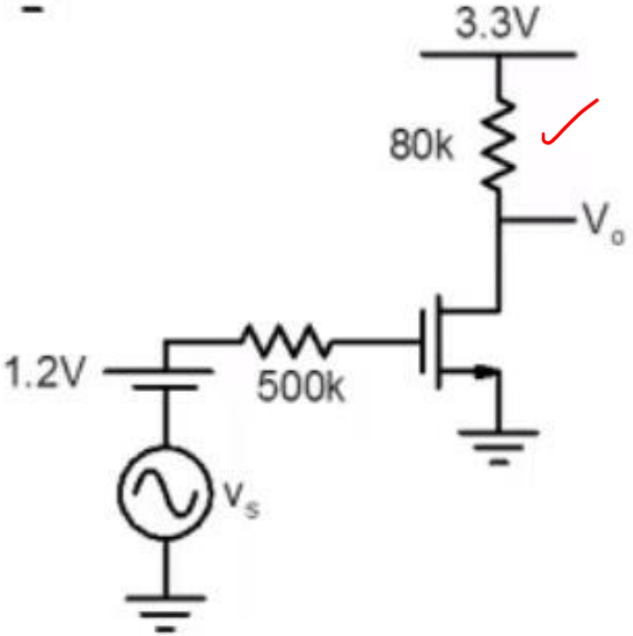
Example



$$I_{DSQ} = 25\mu A \qquad V_{sat1} = 0.5V$$

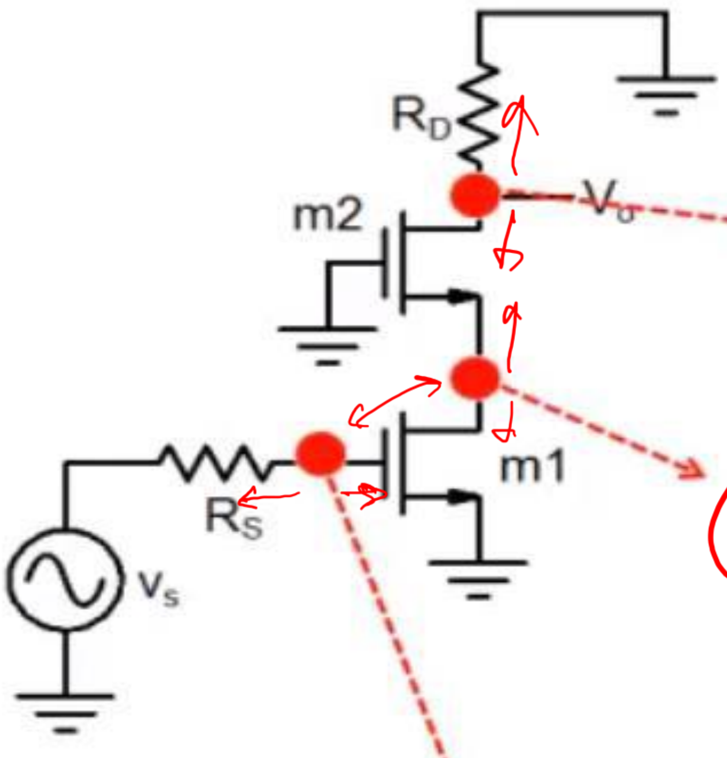
$$V_{o1}(dc) = 0.6V \qquad V_o(dc) = 1.3V$$

$$A_V = \frac{v_o}{v_s} = -8 \qquad A_{V1} = \frac{v_{o1}}{v_s} = -0.77$$



$$A_V = \frac{v_o}{v_s} = -8$$

Cascode Amplifier: Frequency Response



$$R_3 = R_D$$

$$C_3 = C_{gd} + C_{db}$$

$$R_2 = r_{o1} \| \{\frac{1}{g_{m2} + g_{mb2}}(1 + \frac{R_D}{r_{o2}})\}$$

$$C_2 = C_{gd1}(1 - \frac{1}{A_{v1}}) + C_{gs2} + C_{db1} + C_{sb2}$$

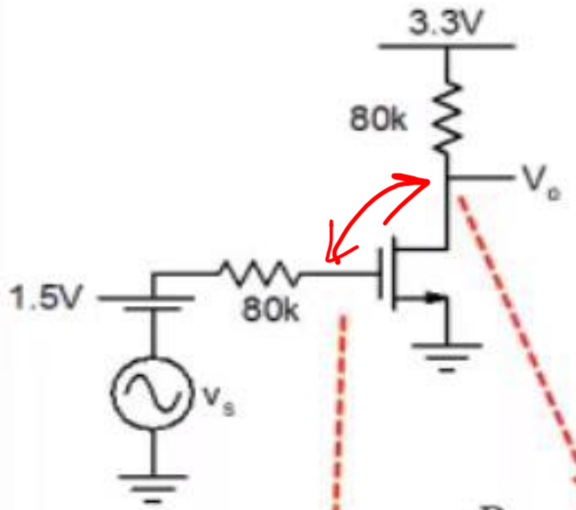
$$R_1 = R_S$$

$$C_1 = C_{gs1} + C_{gd1}(1 - A_{v1})$$

$$f_{3dB} \cong \frac{1}{2\pi \sum R_j C_j}$$

$R_3 \; C_3$

Comparison-1



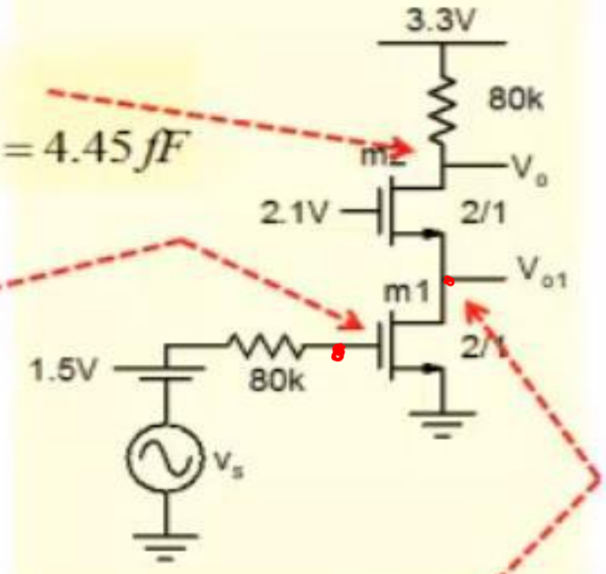
$$R_3 = R_D = 80k$$
$$C_3 = C_{gd} + C_{db} = 4.45fF$$

$$R_1 = R_S$$
$$C_1 = C_{gs1} + C_{gd1}(1 - A_v)$$
$$= 4 + 3.6 = 7.6fF$$

$$f_{3dB} \cong \frac{1}{2\pi\sum R_j C_j} = 166MHz$$

$$R_3 = R_D = 80k$$
$$C_3 = C_{gd} + C_{db} = 4.45fF$$

$$R_1 = R_S$$
$$C_1 = C_{gs1} + C_{gd1}(1 - A_{v1})$$
$$= 4 + 0.8 = 4.8fF$$



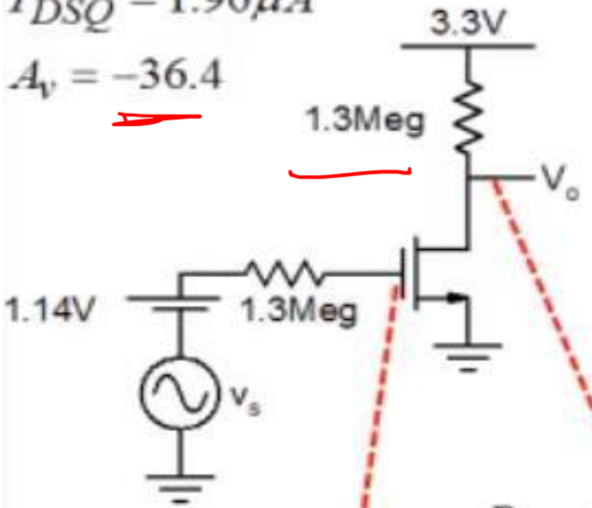
$$R_2 = r_{o1} \| \{\frac{1}{g_{m2} + g_{mb2}}(1 + \frac{R_D}{r_{o2}})\} = 10k$$
$$C_2 = C_{gd1}(1 - \frac{1}{A_{v1}}) + C_{gs2} + C_{db1} = 12.8fF$$

$$f_{3dB} \cong \frac{1}{2\pi\sum R_j C_j} = 183MHz$$

Comparison-2

$I_{DSQ} = 1.96\mu A$

$A_v = -36.4$



$R_1 = R_S$

$C_1 = C_{gs1} + C_{gd1}(1 - A_v)$

$= 4 + 15 = 19\,fF$

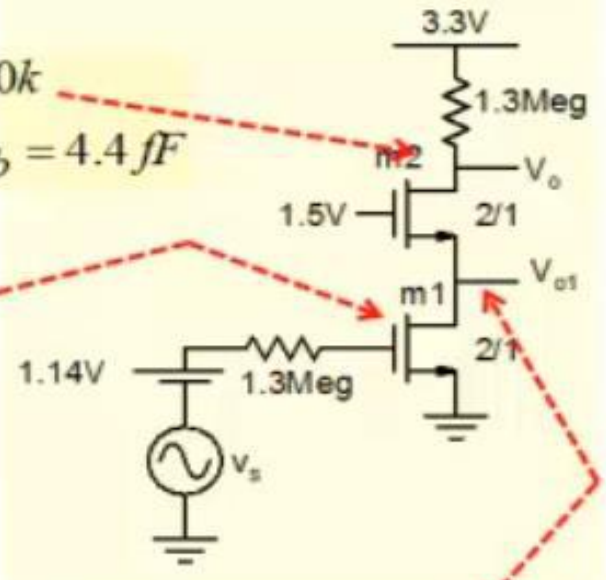
$R_3 = R_D = 1300k$

$C_3 = C_{gd} + C_{db} = 4.4\,fF$

$$f_{3dB} \cong \frac{1}{2\pi \sum R_j C_j} = 5.24MHz$$

$R_3 = R_D = 1300k$

$C_3 = C_{gd} + C_{db} = 4.4\,fF$



$R_1 = R_S$

$C_1 = C_{gs1} + C_{gd1}(1 - A_{v1})$

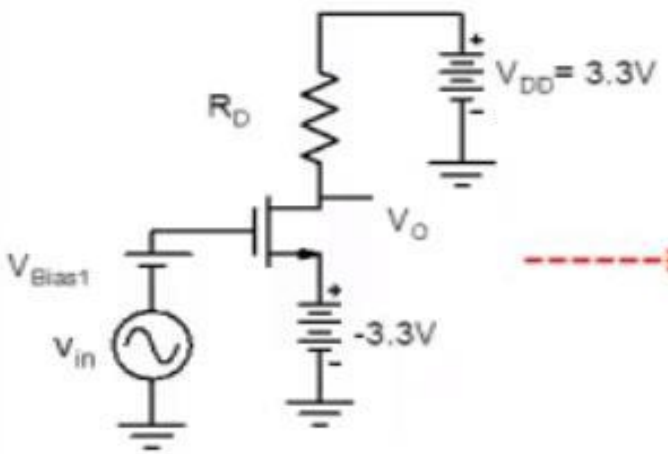
$= 4 + 0.8 = 4.8\,fF$

$R_2 = r_{o1} \| \{\frac{1}{g_{m2} + g_{mb2}}(1 + \frac{R_D}{r_{o2}})\} = 35.7k$

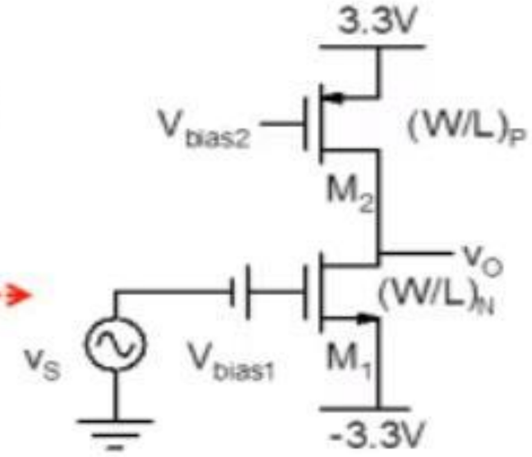
$C_2 = C_{gd1}(1 - \frac{1}{A_{v1}}) + C_{gs2} + C_{db1} + C_{sb2} = 12.8\,fF$

$$f_{3dB} \cong \frac{1}{2\pi \sum R_j C_j} = 12.8MHz$$

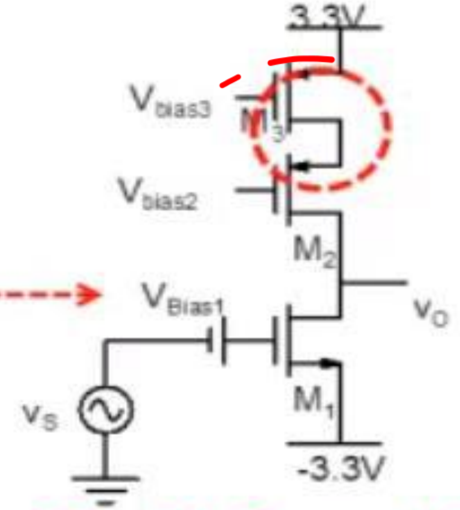
Body effect is ignored



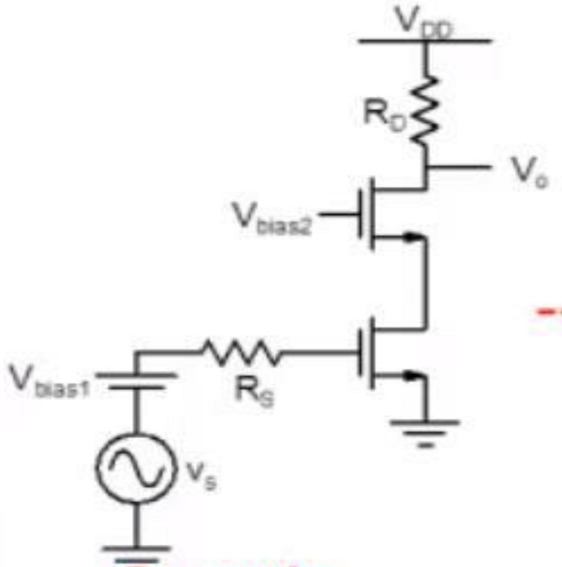
CS amplifier



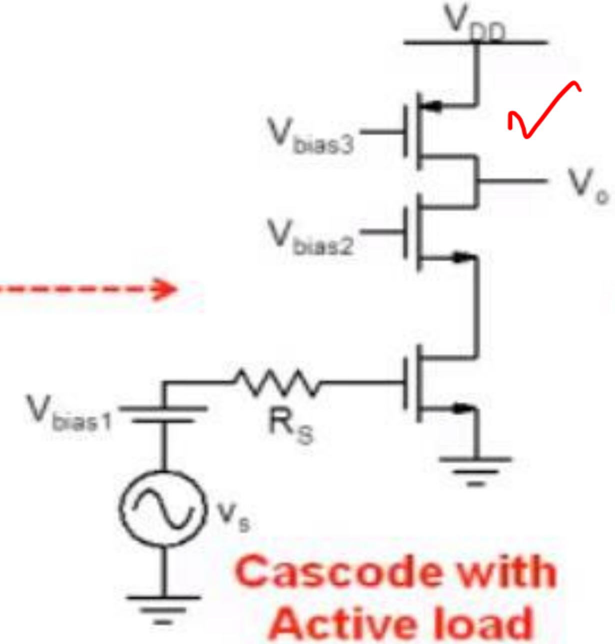
CS with Active Load



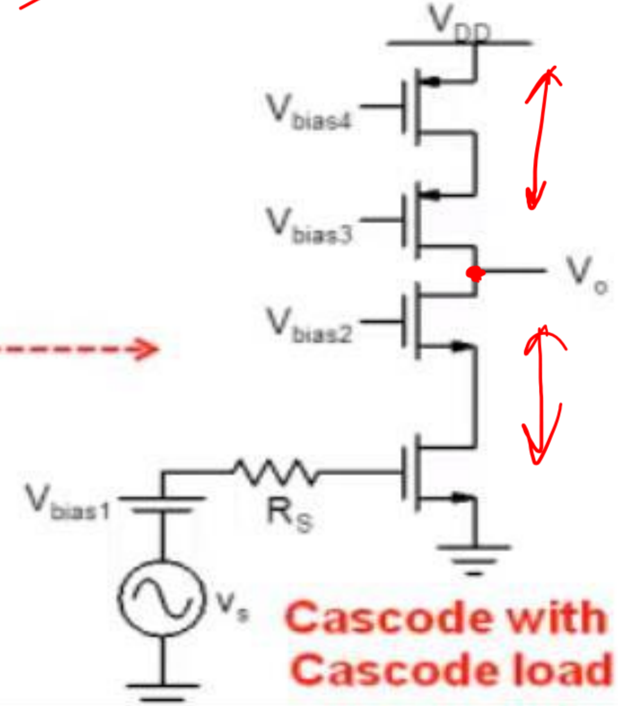
CS with Cascode Load



Cascode with Resistive load



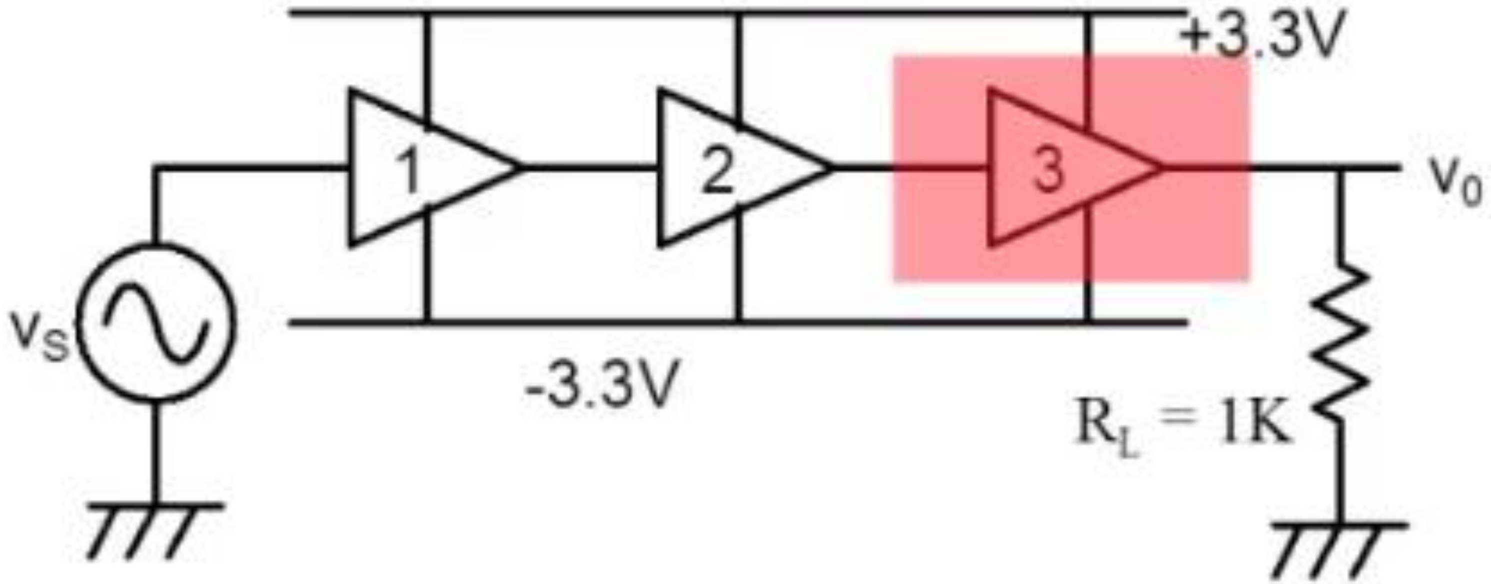
Cascode with Active load



Cascode with Cascode load

Common Drain Amplifier

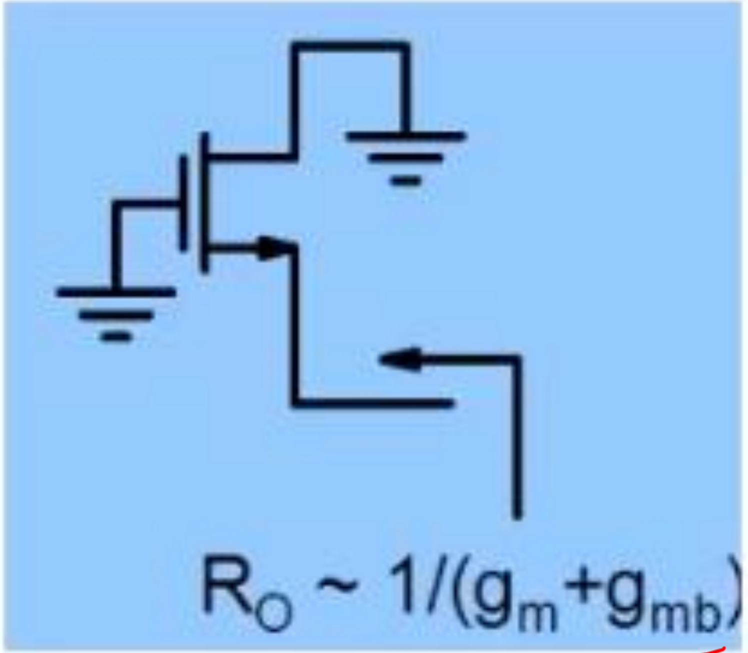
Why do we want one more amplifier configuration?

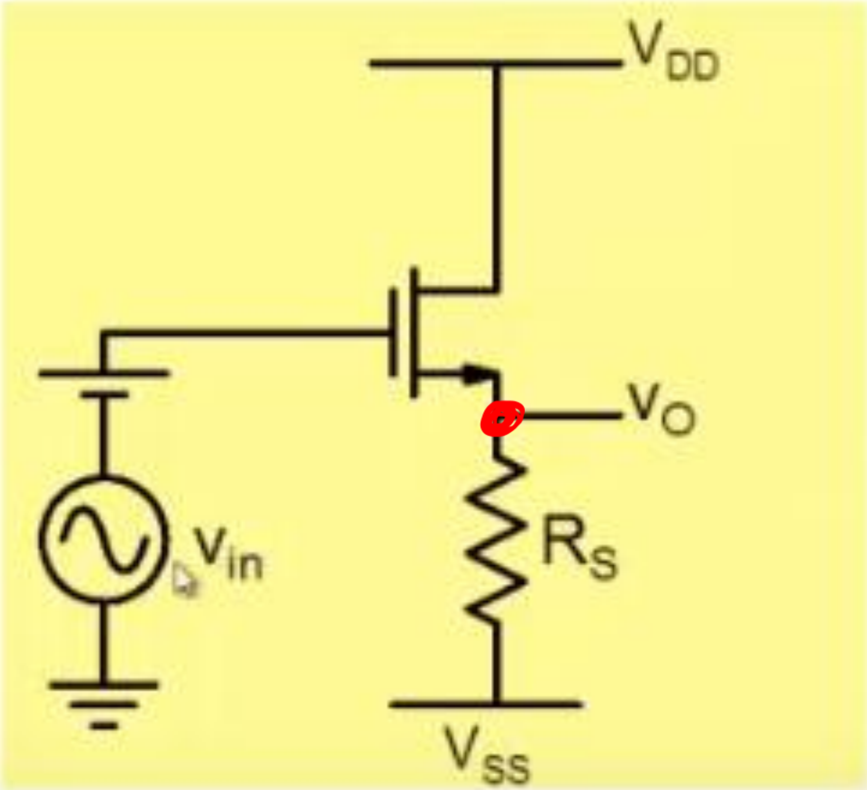


Low output Resistance;
Rail-to-Rail voltage swing; Low distortion
High efficiency

Strategy for obtaining Low output resistance

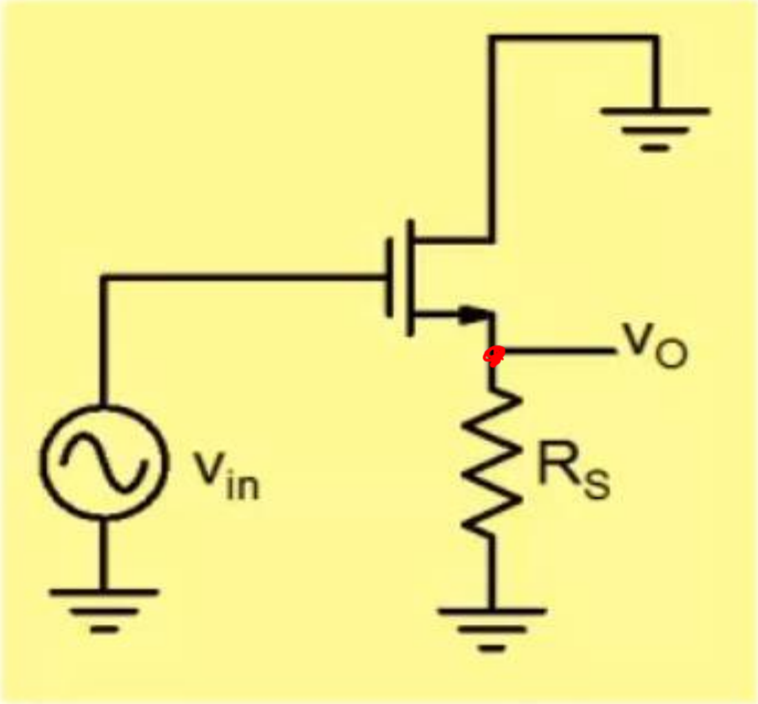
Resistance looking into source is small !

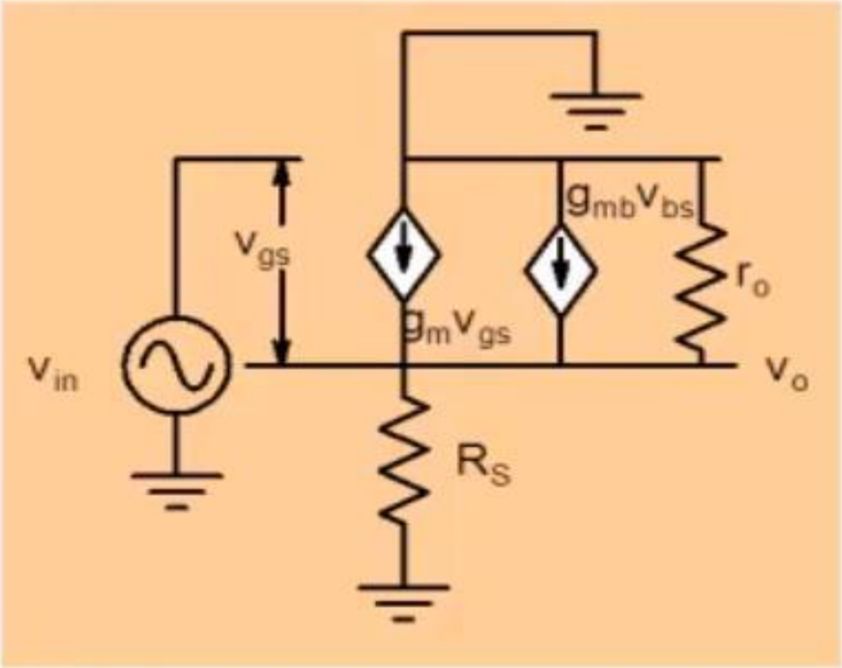




Apply input at gate, take output at Source

Small Signal Analysis



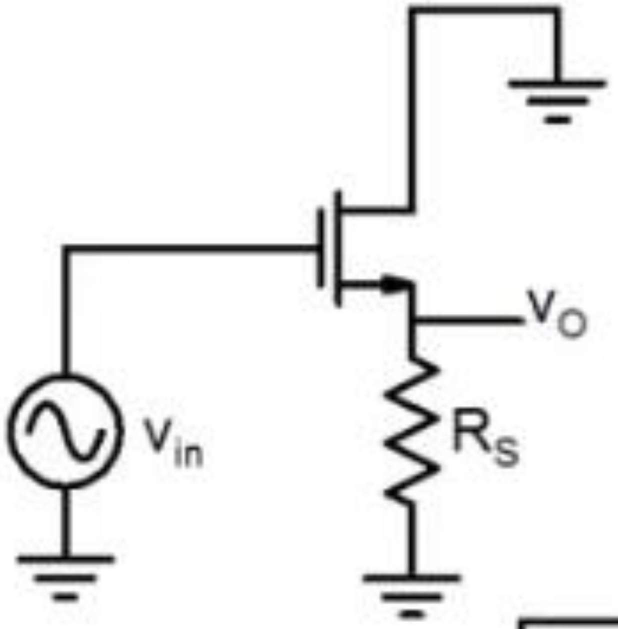


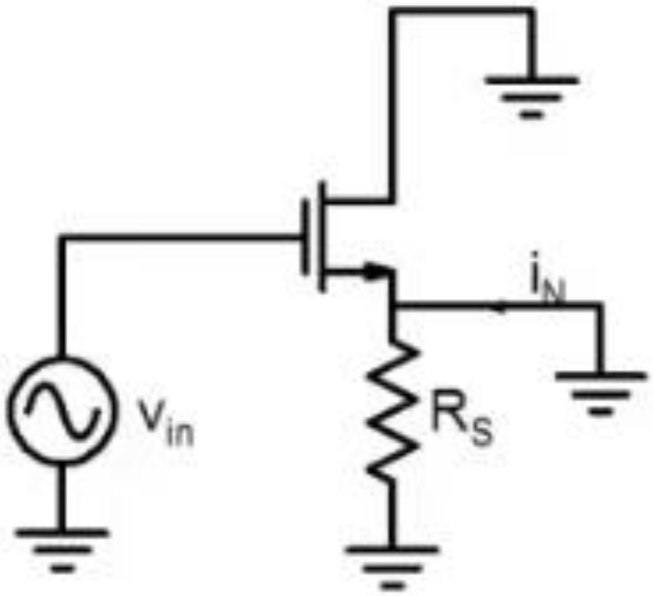
$$A_v = \frac{g_m R_S \| r_o}{1 + (g_m + g_{mb}) R_S \| r_o}$$

$$R_o = R_S \left\| \frac{1}{g_m + g_{mb}} \right. \cong \frac{1}{g_m + g_{mb}}$$

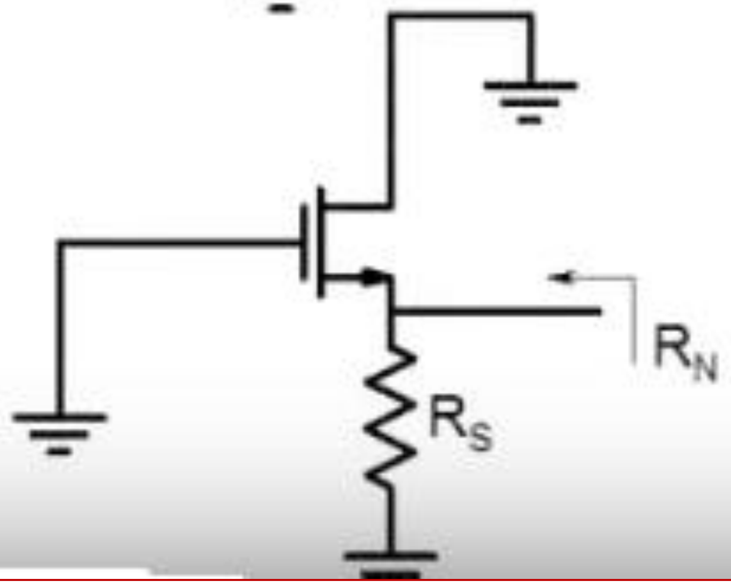
Gain is less than unity !

Output resistance is low !





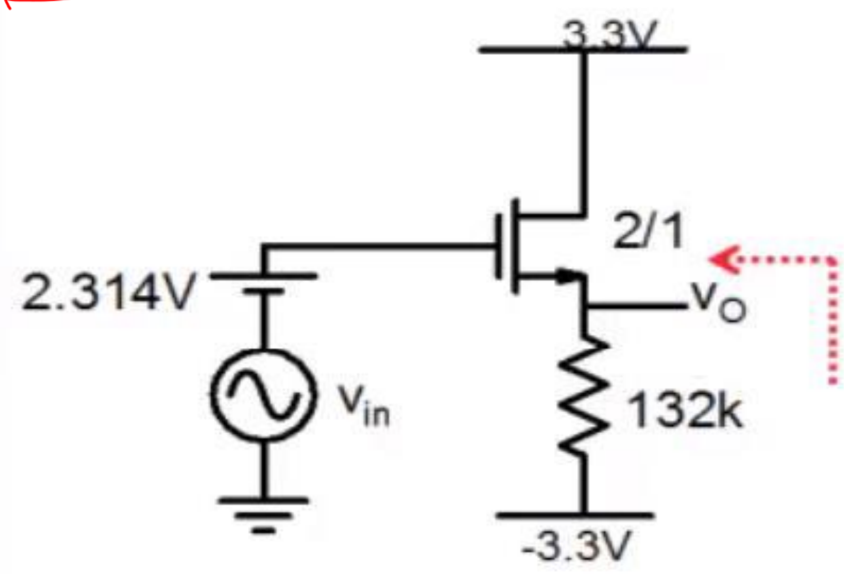
$$i_N = -g_m v_{gs}$$



$$R_N = R_s \,\Big\|\, \frac{1}{g_m + g_{mb}}$$

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

Example:



$$V_{Bias} = V_{GSQ} + I_{DSQ}R_S + V_{SS}$$

$$I_{DSQ} = \frac{\beta_N}{2}(V_{GSQ} - V_{THN})^2[1 + \lambda_n V_{DSQ}]$$

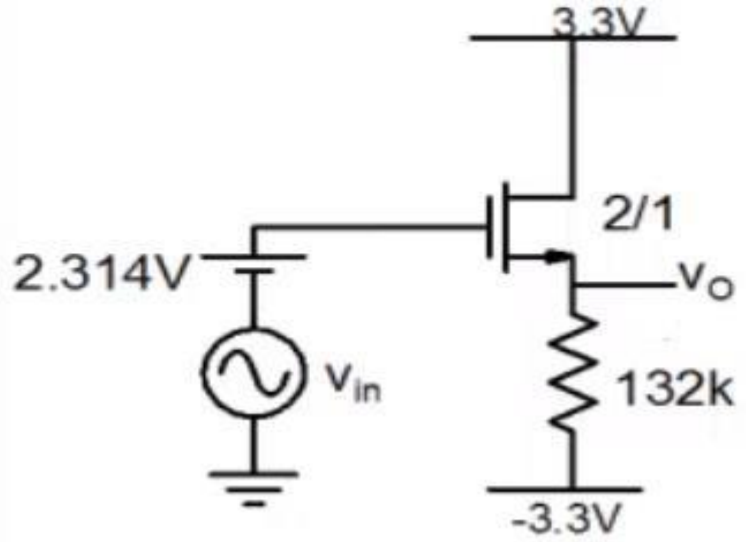
$$V_{THN} = V_{THN0} + \gamma(\sqrt{2\phi_F + V_{SBQ}} - \sqrt{2\phi_F})$$

$$V_{SBQ} = I_{DSQ}R_S \; ; \; V_{DSQ} = V_{DD} - I_{DSQ}R_S - V_{SS}$$

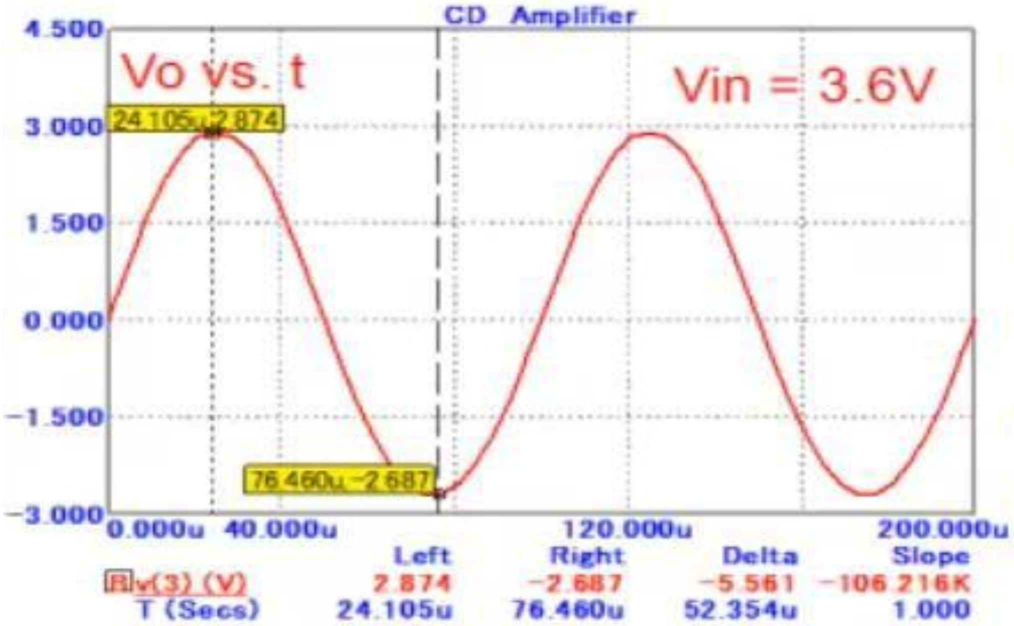
$$I_{DSQ} = 25\mu A \qquad V_{SBQ} = 3.3V \Rightarrow V_{THN} = 1.8V ; V_{GSQ} = 2.314V \quad V_{DSQ} = 3.3V$$

$$g_m = 100\mu A/V \; ; \; g_{mb} = 17.5\mu A/V ; \; r_o = 4M\Omega$$

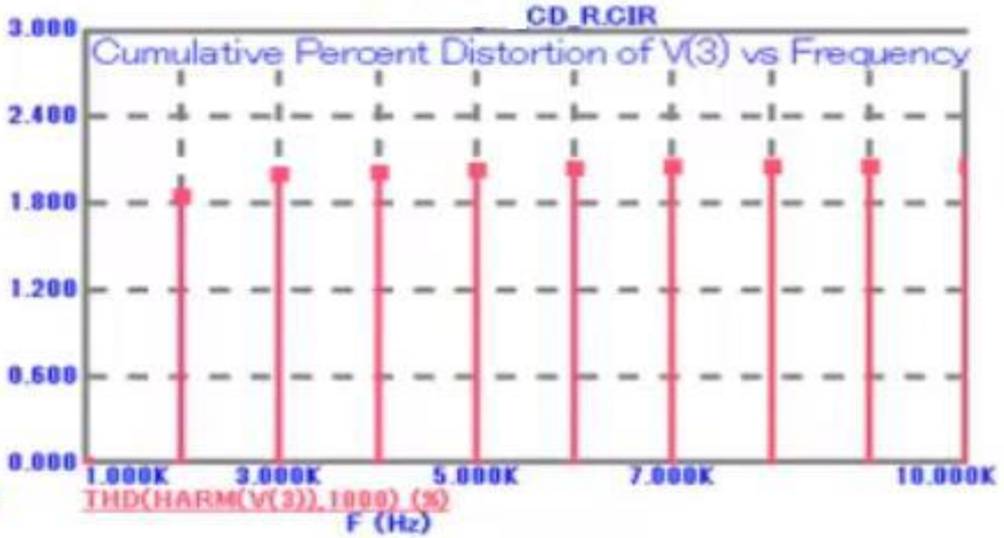
$$A_v = \frac{g_m R_S}{1 + (g_m + g_{mb})R_S} = 0.8 \qquad R_o = R_S \left\| \frac{1}{g_m + g_{mb}} \right. \sim 8k$$

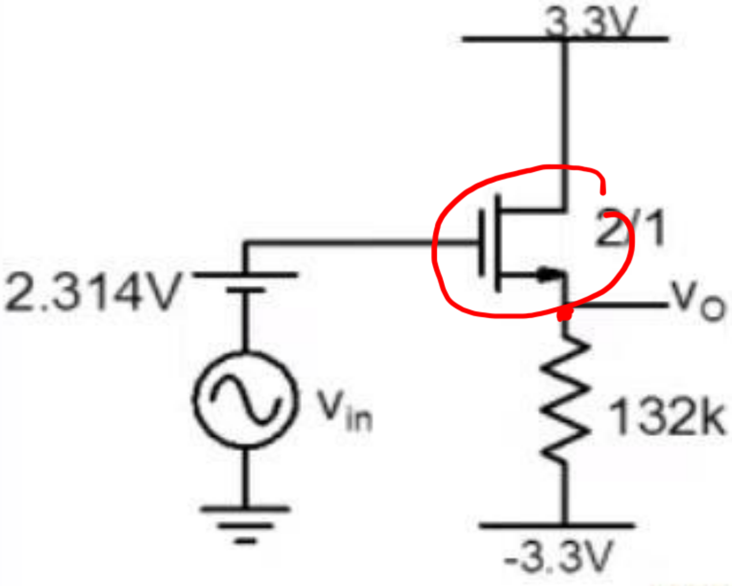


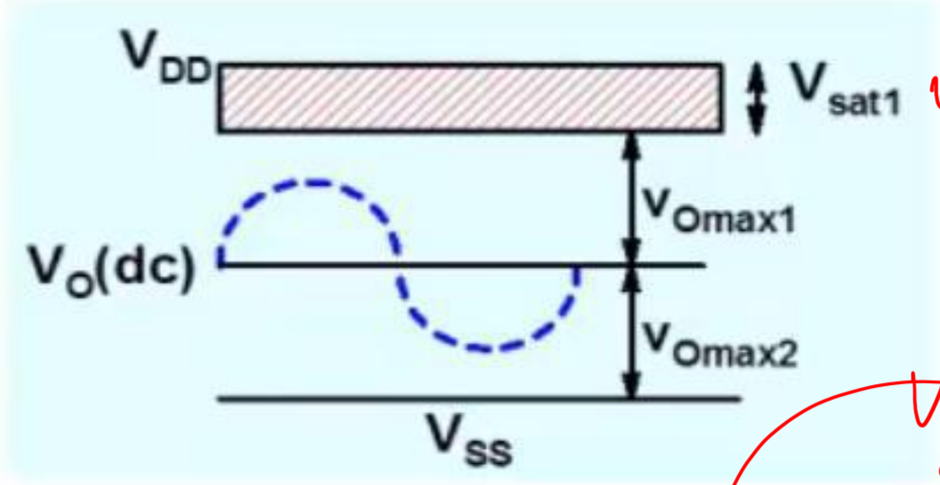
CD amplifier has good linearity and thus less prone to harmonic distortion



Vin = 3.6V

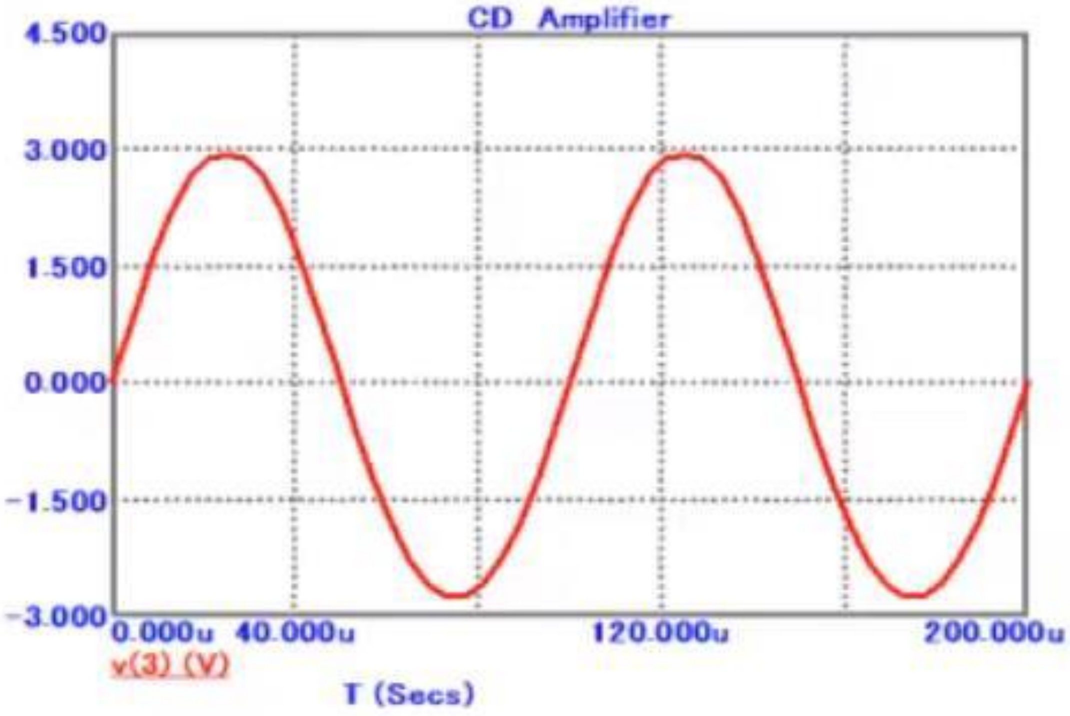






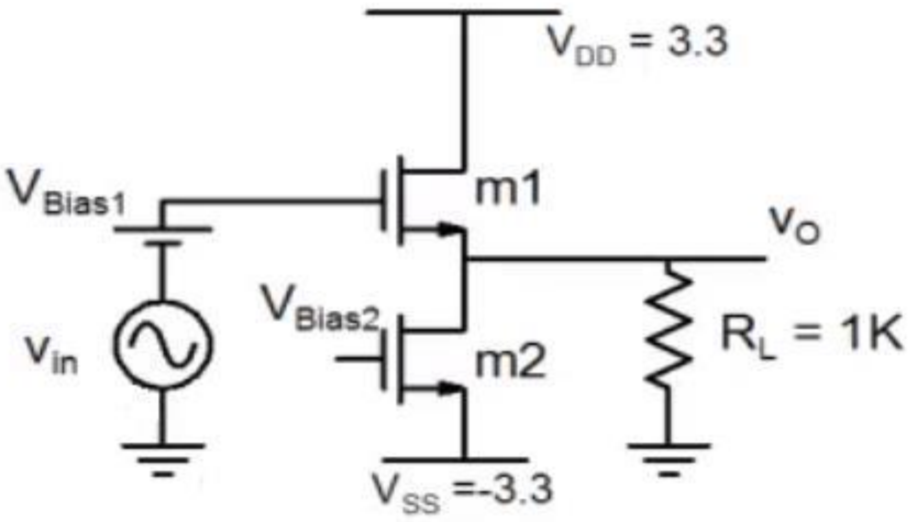
✓

voltage swing
• limited by current



Example

$$I_{DSQ} = 3.3mA$$



$$\frac{W_1}{L_1} = \frac{200}{1}\ ;\ V_{GS1} = 2.389V ; V_O = 0V$$

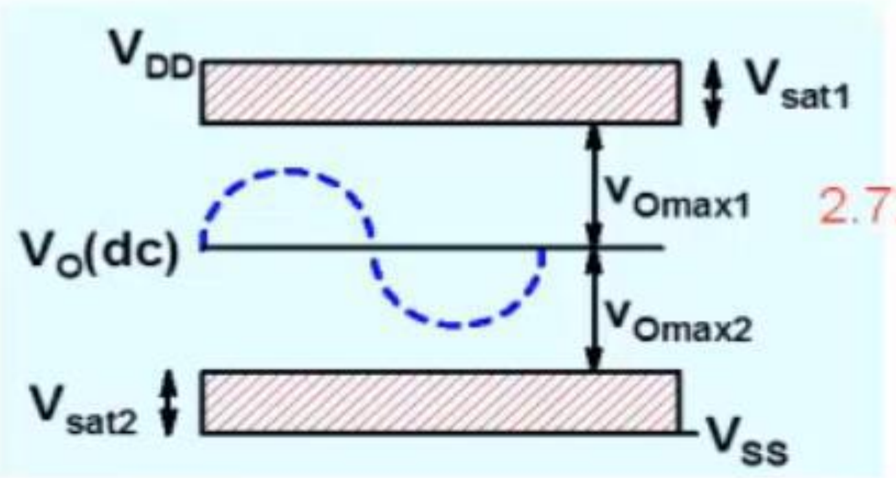
$$\frac{W_2}{L_2} = \frac{200}{1}\ ;\ V_{GS2} = 1.575V$$

$$\Rightarrow V_{bias2} = -1.725V$$

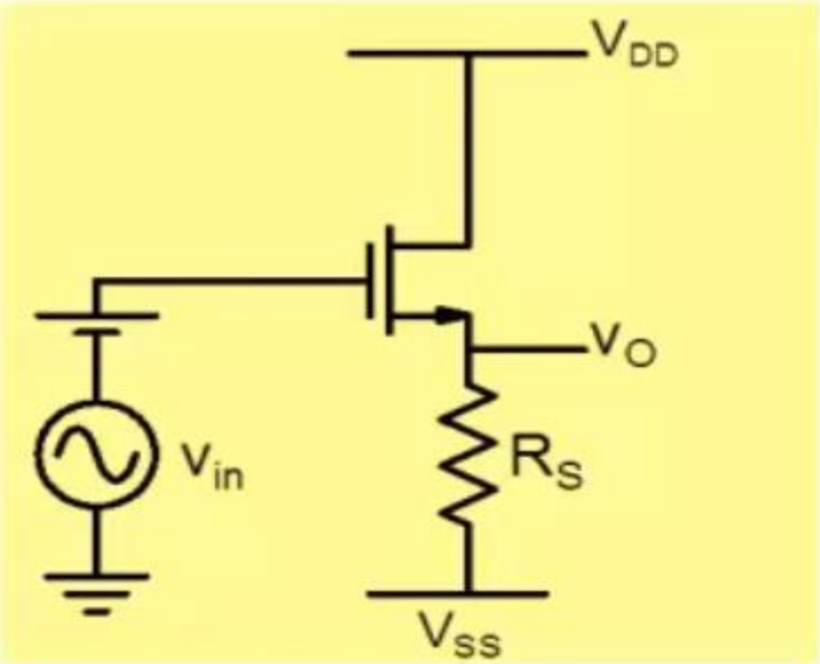
$$V_{sat} = 0.575V$$

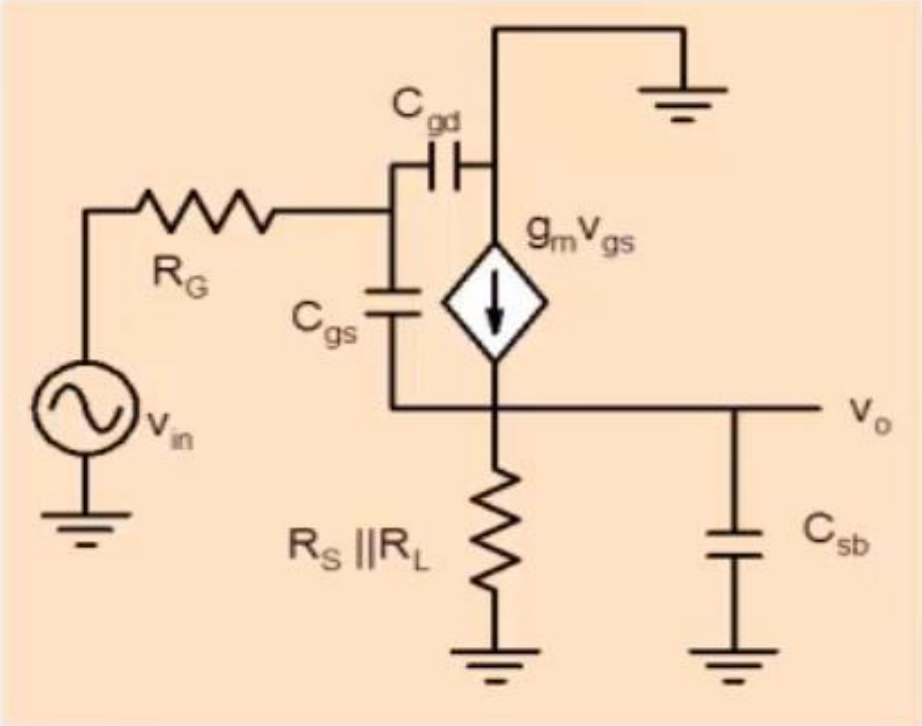
$$A_v = \frac{g_m R_L}{1+(g_m + g_{mb})R_L} = 0.79$$

$$R_o = \frac{1}{g_m + g_{mb}} \sim 74\Omega$$



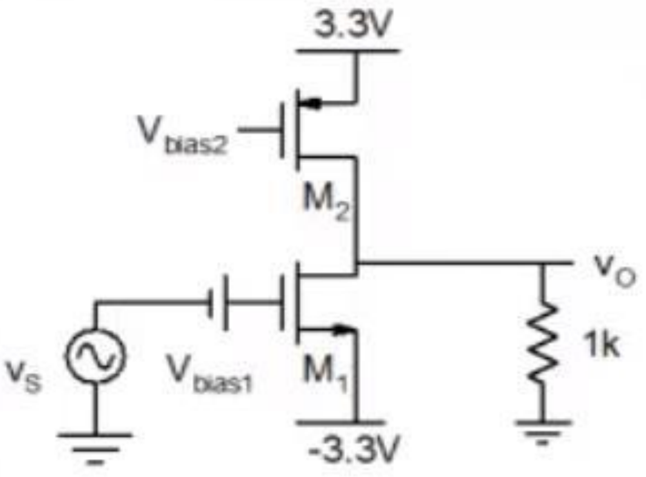
Frequency Response





$$f_{3dB} = \frac{1}{2\pi \sum \tau_j} \qquad \tau_j = R_j C_j$$

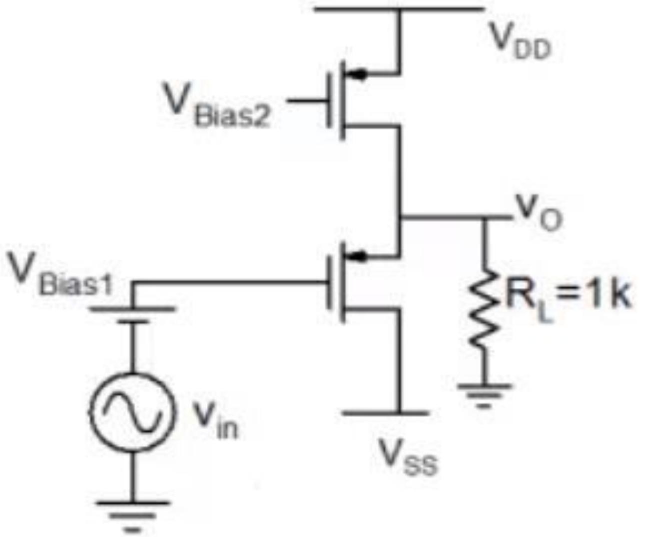
Summary



CS

1. Low Output resistance requires large bias current
2. Rail-to-rail output swing
3. Frequency response suffers from Miller's effect and is inferior.

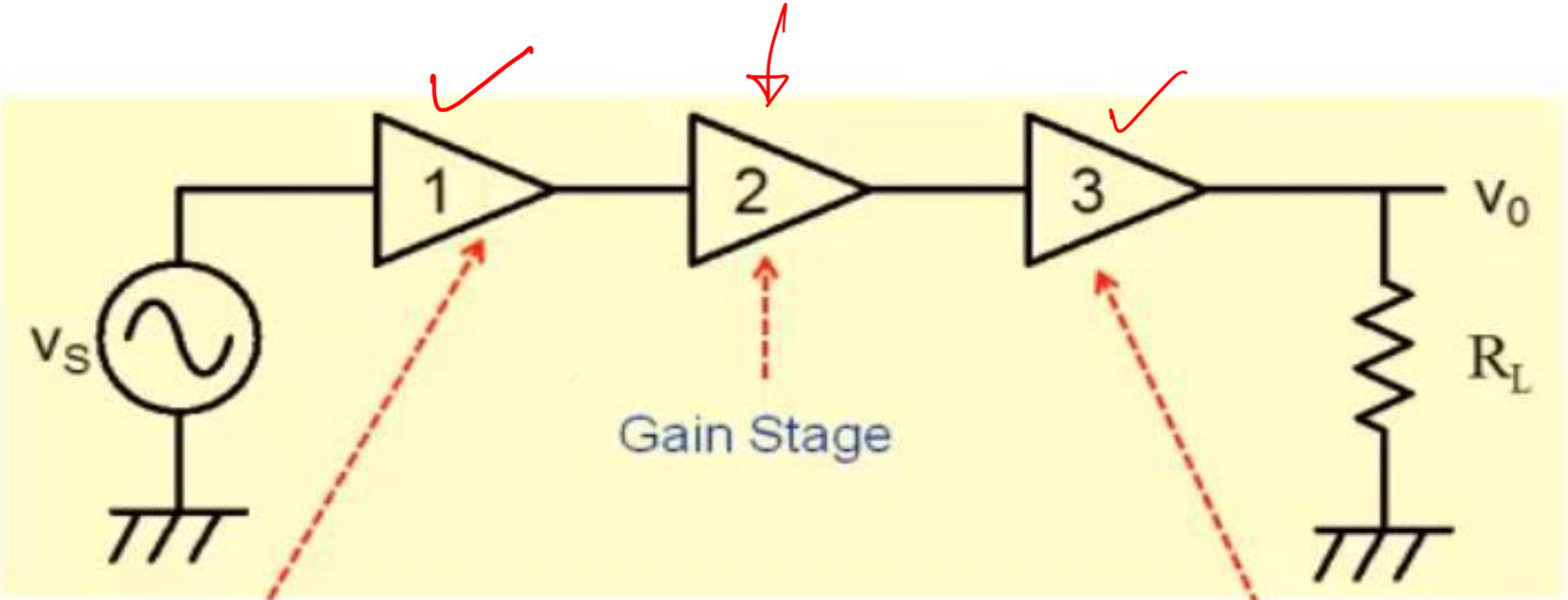
CD



1. Significantly Lower Output resistance can be obtained at same value of bias current
2. Swing lower by about a V_T drop
3. Good frequency response

Efficiency limited to < 25% for both the stages

Principle of Division of labor !



Specialize in input resistance

Specialize in output resistance
and power delivery