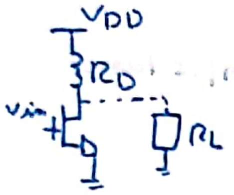
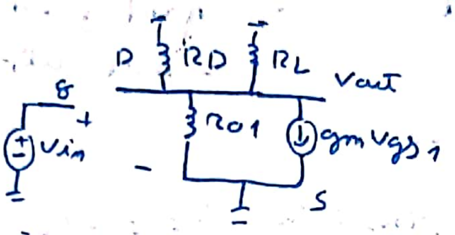
8. Basic CS stages

Out Put Impedance

$$\frac{V_x}{I_x} = \frac{1}{\frac{1}{R_D} + \frac{1}{r_{o1}}}$$ -> Too high -> cont drain loads

CS stage with Resistance (and Load) (assum The gain when M1 is In saturation)





$$-\frac{V_{out}}{R_D // R_L // R_1} - g_m V_{in} = 0$$

$$\frac{V_{out}}{V_{in}} = \frac{-g_m}{1} \times (R_D // R_L // R_1)$$

$$\frac{V_{out}}{V_{in}} = \frac{-g_m}{\frac{1}{R_D} + \frac{1}{R_L} + \frac{1}{R_1}} = A_V$$

In large signal

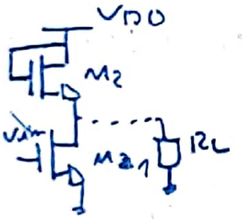
$$A_V = \frac{\partial V_{out}}{\partial V_{in}}$$

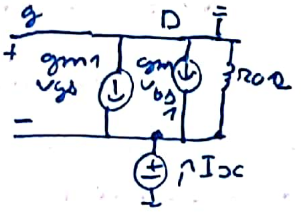
↑RD -> gain
↑$\frac{W}{L}_1$ -> gain

CS stage with Diode connected Load

M2 always in saturation

M2 equivalent Impedance

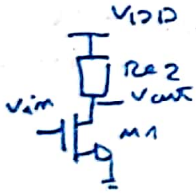


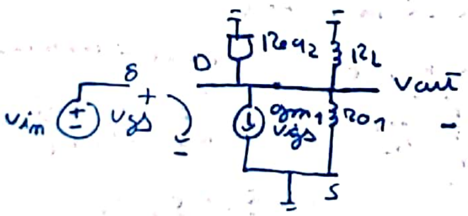


$$\frac{V_x}{r_{o2}} - g_{mb2}(v_{bs}) - g_{m2}(v_{gs}) = I_x$$

$$V_x\left(\frac{1}{r_{o2}} + g_{mb2} + g_{m2}\right) = I_x$$

$$\frac{V_x}{I_x} = \frac{1}{\frac{1}{r_{o2}} + g_{mb2} + g_{m2}} = r_{eq2}$$





$$-\frac{V_x}{R_{eq} // R_L // r_{o1}} - g_{m1}(v_{in}) = 0$$

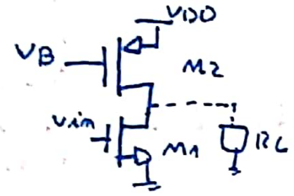
$$\frac{V_x}{V_{in}} = -g_{m1}(R_{eq2} // R_L // r_{o1})$$

$$A_V = \frac{-g_{m1}}{\frac{1}{r_{eq2}} + \frac{1}{R_L} + \frac{1}{r_{o1}}}$$

$$A_V = \frac{-g_{m1}}{\frac{1}{r_{o2}} + g_{mb2} + g_m + \frac{1}{R_L} + \frac{1}{r_{o1}}}$$

↓$\frac{W}{L}_2$ -> Increases gain
↑r_{o2} -> ↓$\frac{W}{L}_2$ -> Increases gain
↑g_{m1} -> $\frac{W}{L}_1$↑ -> Increases gain

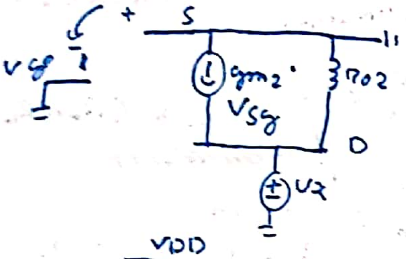
CS stage with a current source



M2 is assumed in saturation
→ works like a current source

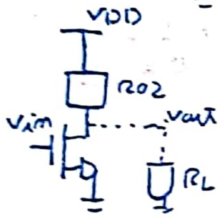
→ good gain
→ Bad output Impedance

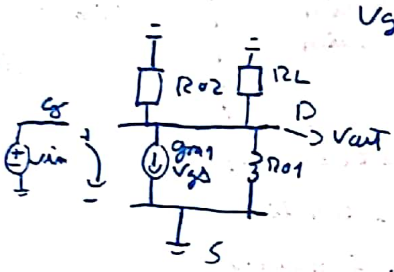
M2 Impedance



$V_{SG}=0$

$I_x(r_{o2}) = V_x \qquad \frac{V_x}{I_x} = r_{o2}$





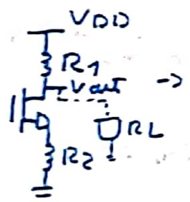
$V_{GS}=V_{in}$

$$\frac{-V_{out}}{r_{o2}\|R_L\|r_{o1}} - g_{m1}V_{in}=0$$

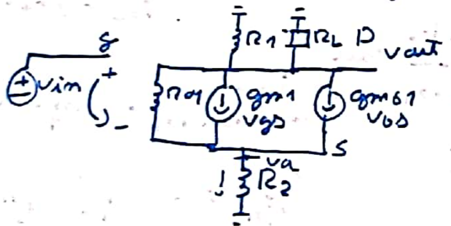
$$\frac{V_{out}}{V_{in}} = -g_{m1}(r_{o2}\|R_L\|r_{o1})$$

$$A_V = \frac{-g_{m1}}{\frac{1}{r_{o2}}+\frac{1}{R_L}+\frac{1}{r_{o1}}}$$

CS stage with source degeneration



equivalent small signal model



$V_{BS}=-V_A$

$V_{GS}=V_{in}-V_a$

$R_{eq}=R_1\|R_L$

$$\frac{V_a}{R_2} = -\frac{V_{out}}{R_{eq}}$$

$$\cancel{\frac{-V_{out}}{R_{eq}} - \frac{V_{out}}{r_{o1}}} + \frac{V_a}{r_{o1}}$$

$$\frac{-V_{out}}{R_{eq}} - \frac{(V_{out}-V_a)}{r_{o1}} - g_{m1}(V_{GS}) - g_{m1}(V_{BS})$$

$$\frac{-V_{out}}{R_{eq}} - \frac{V_{out}}{r_{o1}} - \frac{R_2V_{out}}{R_{eq}r_{o1}} - g_{m1}V_{in} - \frac{g_{m1}R_2V_{out}}{R_{eq}} - \frac{g_{m1b}R_2V_{out}}{R_{eq}}$$

$$+g_{m1}V_{in} = -V_{out}\left(\frac{1}{R_{eq}}+\frac{1}{r_{o1}}+\frac{R_2}{R_{eq}}\left(\frac{1}{r_{o1}}+g_{m1}+g_{m1b}\right)\right)$$

$$\frac{V_{out}}{V_{in}} = A_V = \frac{-g_{m1}}{\frac{1}{r_{eq}}+\frac{1}{r_{o1}}+\frac{R_2}{r_{o1}R_{eq}}+\frac{R_2}{R_{eq}}(g_{m1}+g_{m1b})}$$

$$\boxed{= \frac{-g_{m1}\, r_{eq}\, r_{o1}}{r_{o1}+R_{eq}+R_2+R_2r_{o1}(g_{m1}+g_{m1b})}}$$

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