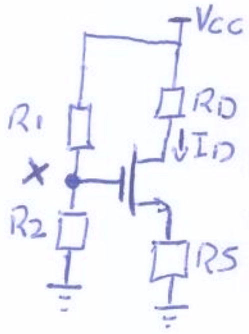
AULA 10A Amplificadores CMOS

1- Polarização

→ Existem ~~vários~~ várias técnicas de polarização, vamos estudar 2.

1.1 Polarização por divisor resistivo



$$V_X = \frac{V_{CC}}{R_1+R_2} \cdot R_2$$

$$V_{GS} = V_X - I_D R_S$$

$$\begin{cases} \boxed{V_{GS} = \frac{V_{CC}}{R_1+R_2} \cdot R_2 - I_D R_S} \; (1) \\ I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} \cdot (V_{GS} - V_{TH})^2 \end{cases}$$

→ desprezando a modulação da largura do canal

$$\Rightarrow V_{GS} = \frac{V_{CC}}{R_1+R_2} \cdot R_2 - R_S \cdot \frac{1}{2} \mu_n C_{ox} \frac{W}{L} \cdot (V_{GS}^2 - 2V_{GS}V_{TH} + V_{TH}^2)$$

$$* \frac{1}{V_1} = R_S \mu_n C_{ox} \frac{W}{L}$$

$$\Rightarrow V_{GS} = \frac{V_{CC}}{R_1+R_2} R_2 - \frac{1}{2} \cdot \frac{1}{V_1} \cdot (V_{GS}^2 - 2V_{GS}V_{TH} + V_{TH}^2)$$

$$V_{GS} = \frac{V_{CC}}{R_1+R_2} \cdot R_2 - \frac{1}{2V_1} \cdot V_{GS}^2 + \frac{1}{\cancel{2}V_1} \cancel{2} V_{GS} V_{TH} - \frac{1}{2V_1} \cdot V_{TH}^2$$

$$\frac{V_{GS}^2}{2V_1} + V_{GS} - \frac{V_{GS}V_{TH}}{V_1} + \frac{V_{TH}^2}{2V_1} - \frac{V_{CC}R_2}{R_1+R_2} = 0$$

$$\boxed{\frac{V_{GS}^2}{2V_1} + V_{GS}\left(1 - \frac{V_{TH}}{V_1}\right) + \frac{V_{TH}^2}{2V_1} - \frac{V_{CC}R_2}{R_1+R_2} = 0}$$

Resolver e substituir em (1)

$$V_{GS} = \frac{-\left(1 - \frac{V_{TH}}{V_1}\right) \pm \sqrt{\left(1 - \frac{V_{TH}}{V_1}\right)^2 - \frac{\cancel{4}^{2}}{\cancel{2}V_1} \cdot \left(\frac{V_{TH}^2}{2V_1} - \frac{V_{CC}R_2}{R_1+R_2}\right)}}{\frac{\cancel{2}}{\cancel{2}V_1}}$$

$$V_{GS} = V_1 \left[-\left(\frac{V_1 - V_{TH}}{V_1} \right) \pm \sqrt{\left(\frac{V_1 - V_{TH}}{V_1} \right)^2 - \frac{\cancel{2}}{V_1} \left(\frac{V_{TH}^2 (R_1+R_2) - 2V_1 V_{cc} R_2}{\cancel{2} V_1 (R_1+R_2)} \right)} \right]$$

$$V_{GS} = \cancel{V_1} \left[- \frac{V_1 - V_{TH}}{\cancel{V_1}} \pm \sqrt{\frac{(V_1 - V_{TH})^2}{\cancel{V_1}^2} - \frac{V_{TH}^2 (R_1+R_2) - 2V_1 V_{cc} R_2}{\cancel{V_1}^2 (R_1+R_2)}} \right]$$

$$V_{GS} = -(V_1 - V_{TH}) \pm \left[\sqrt{(V_1 - V_{TH})^2 - V_{TH}^2 - \frac{2V_1 V_{cc} R_2}{R_1+R_2}} \right]$$

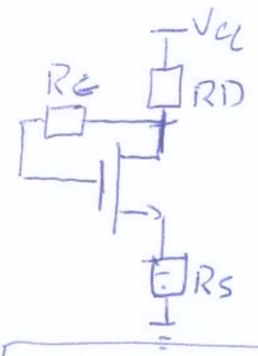
$$V_{GS} = -(V_1 - V_{TH}) \pm \sqrt{V_1^2 - 2V_1 V_{TH} + \cancel{V_{TH}^2} - \cancel{V_{TH}^2} - 2V_1 \frac{V_{cc} R_2}{R_1+R_2}}$$

$$\boxed{V_{GS} = -(V_1 - V_{TH}) \pm \sqrt{V_1^2 - 2V_1 \cdot \left(V_{TH} - \frac{V_{cc} R_2}{R_1+R_2} \right)}} \Rightarrow V_{GS} > 0$$

$$\boxed{V_1 = \frac{1}{R_S \mu_n C_{ox} \frac{W}{L}}}$$

$$\stackrel{1}{=}\!> \boxed{I_D = \left(V_{cc} \frac{R_2}{R_1+R_2} - V_{GS} \right) / R_S}$$

1.2 Autopolarização



- $I_G = \emptyset \Rightarrow V_D = V_G \Rightarrow \boxed{V_{DS} = V_{GS}}$

- $V_{CC} = R_D I_D + \underbrace{V_{DS}}_{V_{GS}} + R_S I_D$

- $\boxed{V_{CC} = V_{GS} + I_D(R_D+R_S)} \Rightarrow \boxed{V_{GS} = V_{CC} - I_D(R_D+R_S)}$

- $\boxed{I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\cdot(V_{GS}-V_{TH})^2}$ desprezando o efeito da modulação de largura do canal

(1), $\cancel{V_{CC} = V_{GS} + \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2 (R_D+R_S)}$

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(V_{CC} - I_D(R_D+R_S) - V_{TH}\right)^2$$

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\cdot\left((V_{CC}-V_{TH}) - I_D(R_D+R_S)\right)^2$$

$$I_D = \underbrace{\frac{1}{2}\mu_n C_{ox}\frac{W}{L}}_{A}\cdot\left[(V_{CC}-V_{TH})^2 - 2(V_{CC}-V_{TH})\cdot I_D(R_D+R_S) + I_D^2(R_D+R_S)^2\right]$$

$$I_D = A(V_{CC}-V_{TH})^2 - 2A(V_{CC}-V_{TH})I_D(R_D+R_S) + \underline{A I_D^2(R_D+R_S)^2}$$

$$A.\ I_D^2(R_D+R_S)^2 - 2I_D\left[\frac{1}{2} + A(V_{CC}-V_{TH})(R_D+R_S)\right] + A(V_{CC}-V_{TH})^2 = \emptyset$$

$\div A$

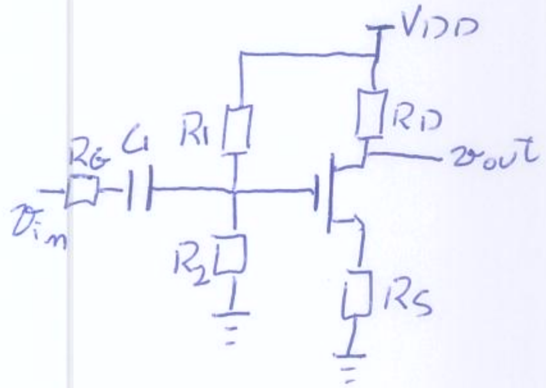
$$I_D^2(R_D+R_S)^2 - \frac{2I_D}{A}\left[\frac{1}{2} + A(V_{CC}-V_{TH})(R_D+R_S)\right] + (V_{CC}-V_{TH}^2) = \emptyset$$

$$I_D^2(R_D+R_S)^2 - 2I_D\left[\frac{1}{2.A} + (V_{CC}-V_{TH})(R_D+R_S)\right] + (V_{CC}-V_{TH})^2 = \emptyset$$

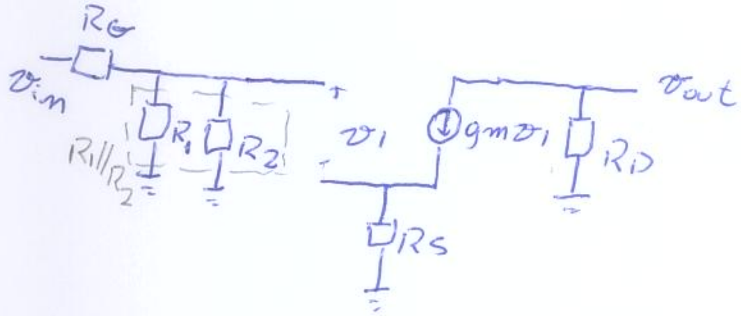
$$\boxed{I_D^2(R_D+R_S)^2 - 2I_D\left[\frac{1}{\mu_n C_{ox}\frac{W}{L}} + (V_{CC}-V_{TH})\cdot(R_D+R_S)\right] + (V_{CC}-V_{TH})^2 = \emptyset}$$

Resolver e substituir em 1

※ Estágio F.C. com polarização I



$\Rightarrow$



$$v_{in} = v_{RG} + v_1 + v_{RS} = R_G i_G + v_1 + R_S g_m v_1 = R_G \cdot \frac{v_{in}}{R_G + R_1 /\!/ R_2} + v_1 + R_S g_m v_1$$

$$v_{in} - v_{in} \frac{R_G}{R_G + R_1/\!/R_2} = v_1 (1 + R_S g_m)$$

$$v_{in} \left(1 - \frac{R_G}{R_G + R_1/\!/R_2} \right) = v_1 (1 + R_S g_m)$$

$$v_{in} \left(\frac{\cancel{R_G} + R_1/\!/R_2 - \cancel{R_G}}{R_G + R_1/\!/R_2} \right) = v_1 (1 + R_S g_m)$$

$$v_{in} = v_1 \cdot (1 + R_S g_m) \cdot \frac{R_G + R_1/\!/R_2}{R_1/\!/R_2}$$

$$v_{out} = -g_m v_1 R_D$$

$$A_v = \frac{v_{out}}{v_{in}} = \frac{-g_m R_D}{\frac{(1 + R_S g_m) \cdot (R_G + R_1/\!/R_2)}{R_1/\!/R_2}} = \frac{-g_m R_D \cdot R_1/\!/R_2}{(1 + R_S g_m) \cdot (R_G + R_1/\!/R_2)} \begin{matrix} \div g_m \\ \div g_m \end{matrix}$$

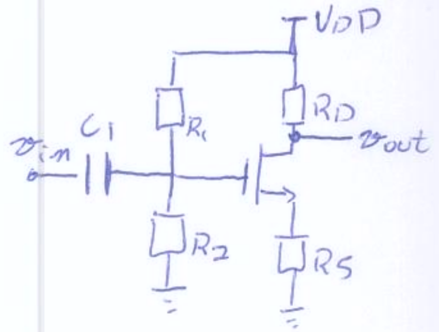
$$\boxed{A_v = \frac{R_1/\!/R_2}{R_G + R_1/\!/R_2} \cdot \frac{-R_D}{\frac{1}{g_m} + R_S}}$$

$$\boxed{R_{in} = R_G + R_1/\!/R_2}$$

$$\boxed{R_{out} = R_D}$$

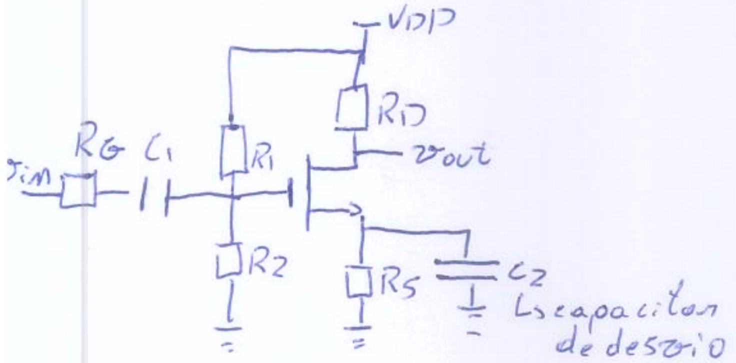
$\hookrightarrow v_{in} = \phi \Rightarrow v_1 = \phi$

* Estágio F.C. com polarização II



$\Rightarrow R_G = \emptyset \Rightarrow$ $\boxed{A_v = \frac{-R_D}{\frac{1}{g_m} + R_S} \quad R_{in} = R_1 // R_2 \quad R_{out} = R_D}$

* Estágio F.C. com polarização III



$\Rightarrow C_2$ = curto circuito $\Rightarrow R_S = \emptyset$ no modelo de pequenos sinais

$\Rightarrow$ $\boxed{A_v = \frac{R_1 // R_2}{R_G + R_1 // R_2} \cdot -R_D \cdot g_m \quad R_{in} = R_G + R_1 // R_2 \quad R_{out} = R_D}$